Third Edition

AUTOMOTIVE TECHNOLOGY

Principles, Diagnosis, and Service



James D. Halderman

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PRENTICE HALL AUTOMOTIVE

Automotive Technology

Principles, Diagnosis, and Service

THIRD EDITION



James D. Halderman

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Preface

Updates to the third edition include:

1. The number of chapters has increased from 50 to 103.
2. Whereas many large chapters were split into smaller, more manageable ones to teach or learn from, most of the new chapters represent new content.
3. Greatly expanded content on both hand and power tools.
4. Hundreds of new and updated topics, including:
   - Electronic suspension systems and electronic stability control (ESC)
   - Electronic throttle control (ETC)
   - Satellite radio and On-Star
   - Navigation systems, backup cameras, and sensors
   - New chapters on alternative fuel, including biodiesel and E85
   - Three new chapters on hybrid electric vehicles (HEVs), including first responder safety procedures
   - New chapter on light diesel operation and fuel systems, plus emission controls
   - Expanded coverage on automotive electrical accessories, including Bluetooth, memory seats, heated and cooled seats, and automatic dimming mirrors
   - Expanded coverage on airbag circuits, now including side and curtain airbags and data recorder information
   - New chapter on computer network communication
   - Expanded coverage on fuel delivery systems
   - Expanded coverage on scan tools and engine performance diagnosis
   - Greatly expanded coverage on automotive and light truck/van braking systems, including antilock brake systems (ABSs) and traction control systems (TCSs)
   - Tires and wheels area expanded to two chapters which include nitrogen inflation and tire pressure monitoring system (TPMS) operation, diagnosis, and service procedures
   - Automatic and dual climate control systems added to the coverage on HVAC systems
   - Updated chapters on manual and automatic transmissions
5. Over 20 new photo sequences are included, which help students visualize actually doing the procedure.
6. All topics include theory and servicing either in one chapter or in the very next chapter, which makes studying, learning, and teaching a particular topic easy.
7. Hundreds of new color photographs and line drawings make the subject come alive.

CHAPTER COMPONENTS

Hundreds of Tech Tips, Real World Fixes, and Frequently Asked Questions make the book easy to read and help illustrate complex technical information by giving examples from actual real-world experiences by master technicians.

The third edition of *Automotive Technology: Principles, Diagnosis, and Service* is organized around the eight ASE automobile test areas and is correlated to the NATEF Task List. Terminology throughout the text reflects the SAE J1930 standard.

ASE AND NATEF CORRELATED

This comprehensive textbook is divided into sections that correspond to the eight areas of certification as specified by the National Institute for Automotive Service Excellence (ASE) and the National Automotive Technicians Education Foundation (NATEF). The areas of the ASE material certification test are listed in the objectives at the beginning of each chapter, and all laboratory worksheets are correlated to the NATEF Task List.

DIAGNOSTIC APPROACH

The primary focus of this textbook is to satisfy the need for problem diagnosis. Time and time again, the author has heard that technicians need more training in diagnostic procedures and skill development. To meet this need and to help illustrate how real problems are solved, diagnostic stories are included throughout. Each new topic covers the parts involved plus their purpose, function, and operation, as well as how to test and diagnose each system.

MULTIMEDIA

The multimedia DVD that accompanies and supplements the textbook is informative and also makes learning more fun for the student. The DVD includes:

1. Live action videos and animation to help students understand complex systems.
2. PowerPoint slides.
3. Chapter quiz and chapter review questions.
4. ImageLibrary.
5. ASE content list for each of the eight ASE areas.
6. A glossary of automotive terms.
7. Spanish translation of the text and Spanish glossary.

WORKTEXT

A worktext is also available for purchase and each worksheet correlates to the NATEF task list. The worksheets in it apply the text materials to everyday-type activities and typical service and testing procedures. Further, the worksheets show likely results and a listing of what could be defective if the test results are not within the acceptable range. These sheets help build diagnostic and testing skills.

TEXT ORGANIZATION

- Each chapter opens with a list of learning *objectives*, including the ASE content area covered by the chapter. These objectives identify the topics covered and goals to be achieved in the chapter.
- Most chapters contain *Tech Tips, Real World Fixes, Frequently Asked Questions, High-Performance Tips,* and *Safety Tips.*
- All chapters contain a *summary* at the end that highlights the material covered in the chapter.

- *Review questions* (discussion-type questions) are offered at the end of each chapter.
- Each chapter contains a *chapter quiz* with multiple-choice questions.

INSTRUCTOR PACKAGE

A comprehensive *instructor package* is available free when the text is adopted for classroom use from Prentice Hall Publishing Company (1-800-526-0485 or visit Prentice Hall online at *www.pearsoned.com*). This instructor package includes the following:

- Instructor's Resource Manual.
- Instructor DVD to accompany the Instrustor's Resource Manual with suggested student activities, a test bank, image library with hundreds of digital color photos, as well as many other useful elements for the classroom.
- PowerPoint presentation on all topics covered in the text.
- Answers to all questions in the textbook.

The following list contains the instructor resources also included online: PowerPoint presentation, image bank, instructor's manual, and test generator. To access supplementary materials online, instructors need to request an instructor access code. Go to *www.pearsonhighered.com/irc* where you can register for an instructor access code. Within 48 hours after registering you will receive a confirming e-mail including an instructor access code. Once you have received your code, go to the site and log on for full instructions on downloading the materials you wish to use.

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TECHNICAL AND CONTENT REVIEWERS

The following people reviewed the manuscript before production and checked it for technical accuracy and clarity of presentation. Their suggestions and recommendations were included in the final draft of the manuscript. Their input helped make this textbook clear and technically accurate while maintaining the easy-to-read style that has made other books from the same author so popular.

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Jim Halderman brings a world of experience to his writing. He has been a professional flat-rate service technician, business owner, and a professor at a nationally known college for over 20 years. Jim has a bachelor's degree from Ohio Northern University and a master's in Education from Miami University (Ohio) and is an ASE Certified Master Technician plus L1 and Alternative Fuel. Jim has written many automotive textbooks published by Prentice Hall Publishing Company and is the Chek-Chart automotive textbook series editor. Jim also writes a weekly newspaper column titled "Straight Talk" for the *Dayton Daily News* in Dayton, Ohio, and is the holder of a U.S. patent (5,505,284) for an electronic transmission control device. He was named outstanding alumnus from Ohio Northern University and outstanding regional instructor by General Motors Corporation.

Jim is also a member (member grade) of the Society of Automotive Engineers (SAE) as well as the North American Council of Automotive Teachers (NACAT) and has given technical presentations for many years at California Automotive Teachers (CAT), Illinois College Automotive Instructor Association (ICAIA), and NACAT national conferences. Jim is married, has two children, and lives in Dayton, Ohio.

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FEATURES OF THIS TEXT

To enhance readability and understanding, as well as making study more enjoyable, this text is packed with many special features.



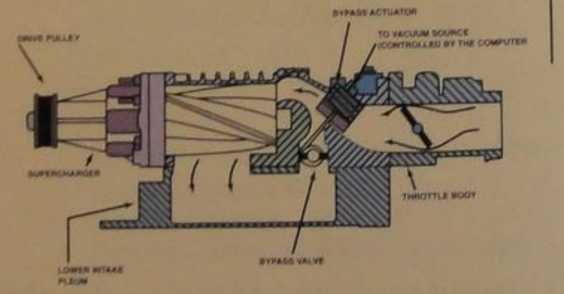
Automotive Technology: Principles, Diagnosis, and Service, 3E, is arranged into 14 major sections. These sections cover the eight Automotive Service Excellence (ASE) areas as well as several new areas such as *Careers in the Automotive Service Area* and *Principles, Math, and Calculations.*

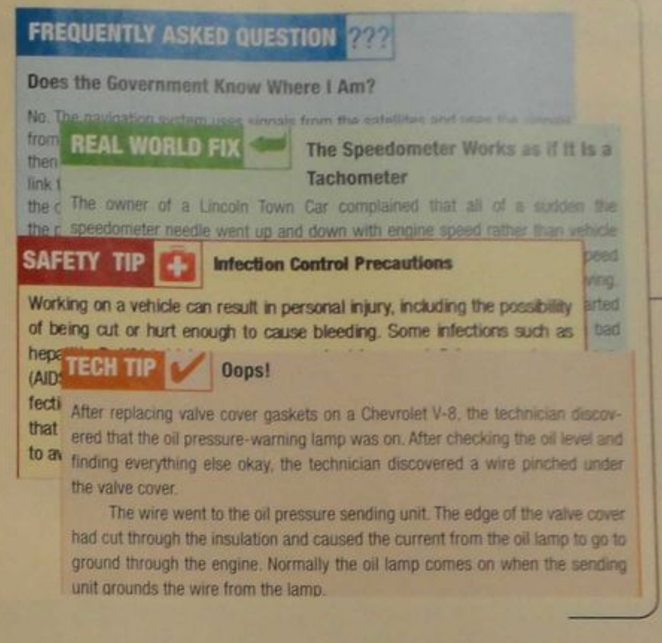
PHOTO SEQUENCES show in details the steps involved in performing a test or service procedure. The Photo Sequences reinforce classroom instruction by allowing students to view the important elements in automotive procedures as they learn specific topics.



More than 3700 **PHOTOS** and **ILLUSTRATIONS,** most in full color, graphically depict critical components and procedures students need to understand to be successful automotive service technicians.







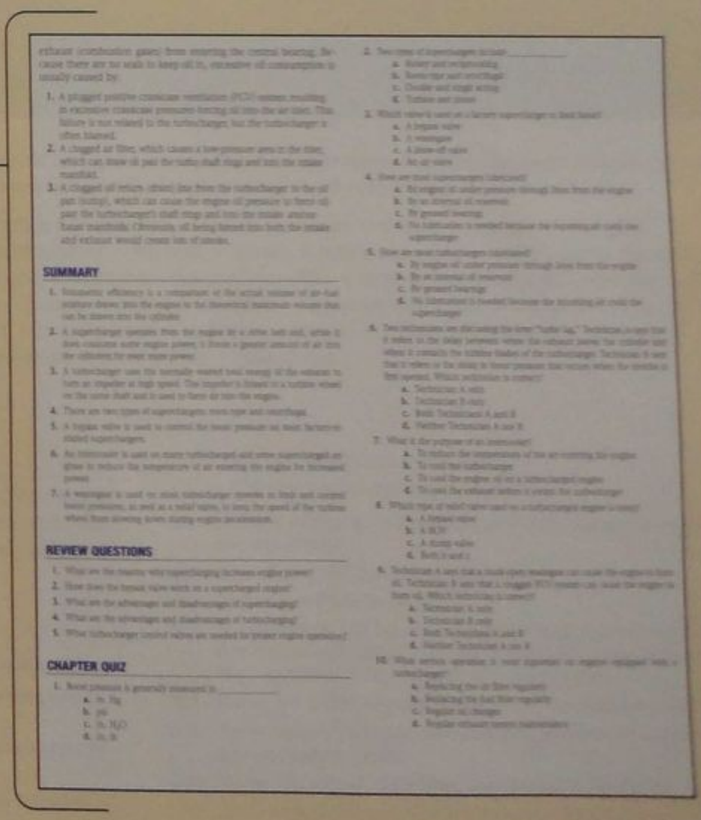
The **FREQUENTLY ASKED QUESTION** feature addresses student and faculty needs to questions that many students and beginning service technicians have when studying technical automotive topics.

Each **REAL WORLD FIX** presents a problem or situation that the service technician might face. These stories explain the steps taken to arrive at a solution to a technical problem.

The **SAFETY TIP** feature warns students about possible hazards on the job and how to avoid harm.

TECH TIPS These real-world examples help students gain insight into specific situations they may encounter on the job.

REVIEW QUESTIONS and a **CHAPTER QUIZ** at the end of each chapter will help students prepare for the ASE certification exam.



SECTION 1

Careers in the Automotive Service Area

1 Automotive Background and Overview
2 Careers in the Automotive Service Industry
3 Starting a Career in the Automotive Industry
4 Working as a Professional Service Technician
5 Technician Certification



CHAPTER 1

Automotive Background and Overview

OBJECTIVES: After studying Chapter 1, the reader will be able to: Explain the evolution of the automobile. • Discuss the major components of a vehicle. • Describe the evolution of engines. • List the common components of most vehicles. • List eight areas of automotive service.

KEY TERMS: air filter • body • body-on-frame (BOF) • carbon monoxide (CO) • catalytic converter • chassis • coolant • drive shaft • evaporative emission system (EVAP) • exhaust gas recirculation (EGR) • flat head • frames • hydrocarbon (HC) • ignition control module (ICM) • inline engine • intake manifold • internal combustion engine • malfunction indicator lamp (MIL) • manufacturer's suggested retail price (MSRP) • OBD-II • oil filter • oil galleries • oil pan • oil pump • oil sump • overhead cam (OHC) • overhead valve (OHV) • oxides of nitrogen (NOX) • PCV valve • pillars • positive crankcase ventilation (PCV) • propeller shaft • radiator • scan tool • self-propelled vehicle • thermostat • transaxle • transfer case • unibody • universal joints (U-joints) • water jackets • water pump

HISTORICAL BACKGROUND

For centuries, man either walked or used animals to provide power for transportation. After the invention of electric, steam, and gasoline propulsion systems, people used **self-propelled vehicles,** which are vehicles that moved under their own power.

Major milestones in vehicle development include:

1876 The OTTO four-stroke cycle engine was developed by a German engineer, Mikolaus Otto.

1885 The first automobile was powered by an OTTO cycle gasoline engine designed by Karl Friedrick Beary (1844–1929).

1892 Rudolf Diesel (1858–1913) received a patent for a compression ignition engine. The first diesel engine was built in 1897.

1896 Henry Ford (1863–1947) built his first car, called the Quadricycle. See Figure 1–1.

1900 About 4,200 automobiles were sold, including:

- 40% were steam powered
- 38% were battery/electric powered
- 22% were gasoline engine powered

1902 Oldsmobile, founded by Ransom E. Olds (1864–1950), produced the first large-scale, affordable vehicle.

1908 William Durant (1861–1947) formed General Motors.

1908 The Ford Model T was introduced.

1912 The electric starter was invented by Charles F. Kettering (1876–1958) of Dayton, Ohio, first used on a Cadillac. The starter was produced by a new company called Delco, which stood for Dayton Electric Laboratories Company.

1914 First car with a 100% steel body was made by the Budd Corporation for Dodge.

1922 The first vehicle to have four-wheel hydraulically operated brakes was a Duesenberg built in Indianapolis, Indiana.

1940 The first fully automatic transmission was introduced by Oldsmobile.

1973 Airbags were offered as an option on some General Motors vehicles.

1985 Lincoln offers the first four-wheel antilock braking system.

1997 The first vehicle with electronic stability control was offered by Cadillac.

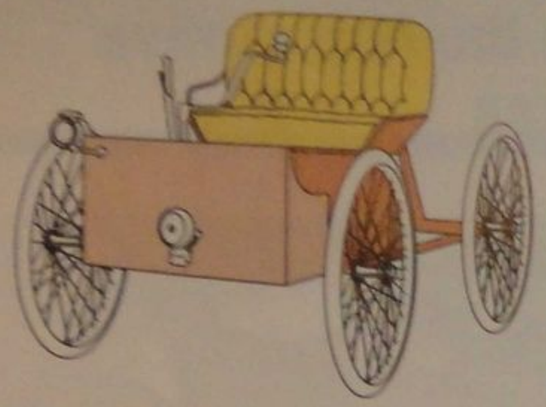


Figure 1–1 A Ford Quadricycle built by Henry Ford.



Figure 1–2 Most vehicle bodies were constructed with a wood framework until the 1920s.

BODIES

Early motor vehicles used horse-drawn carriages as the basis with the engine attached. Most bodies were wood. See Figure 1–2.

The bodies evolved until in the 1930s, all-steel-enclosed bodies became the most used type. All bodies depended on a frame of wood or steel to support the chassis components.

CHASSIS SYSTEMS OVERVIEW

The chassis system of the vehicle includes the following components:

1. Frame or body of the vehicle, which is used to provide the support for the suspension and steering components as well as the power train.
2. The suspension system of the vehicle, which provides a smooth ride to the driver and passengers and helps the tires remain on the road even when the vehicle is traveling over rough roads. The suspension system includes springs and control arms which allow the wheel to move up and down and keep the tires on the road.
3. The braking system of the vehicle is used to slow and stop the rotation of the wheels, which in turn stops the vehicle. The braking system includes the brake pedal, master cylinder, plus wheel brakes to each wheel. Two types of wheel brakes are used. Disc brakes usually used only on the front include a caliper, which applies force to brake pads on both sides of a rotating disc or rotor. Drum brakes use brake shoes which are applied by hydraulic pressure outward against a rotating brake drum. The brake drum is attached to and stops the rotation of the wheels. Drum brakes are often used on the rear of most vehicles.
4. Wheels and tires—The wheels are attached to the bearing hubs on the axles. The tires must provide traction for accelerating, braking, and cornering, as well as provide a comfortable ride. Wheels are constructed of steel or aluminum alloy and mount to the hubs of the vehicle using lug nuts, which must be tightened correctly to the proper torque.

The chassis components include:

- Front and rear suspension
- Axles and hubs (to support the wheels and tires)
- Steering mechanism
- Engine and transmission
- Final drive differential and axles



Figure 1–3 A chassis of a 1950s era vehicle showing the engine, drivetrain, frame, and suspension.

Often, these chassis were so complete that they could be driven without a body. Figure 1–3.

Many of the expensive automakers in the 1920s and 1930s had bodies built by another company. Eventually, most bodies were constructed of steel and many without the need for a frame to support the drivetrain and suspension.

Body Terms The roof of a vehicle is supported by **pillars** and they are labeled A, B, C, and D from the front to the rear of the vehicle. All vehicles have an A pillar at the windshield but many, such as a hard top, do not have a B pillar. Station wagons and sport utility vehicles (SUVs) often have a D pillar at the rear of the vehicle. See Figure 1–4.

TECH TIP ✔ **Treat a Vehicle Body with Respect**

Do not sit on a vehicle. The metal can easily be distorted, which could cost hundreds of dollars to repair. This includes sitting on the hood, roof, and deck (trunk) lid, as well as fenders. Also, do not hang on any opened door as this can distort the hinge area causing the door not to close properly.

FRAMES

Frame construction usually consists of channel-shaped steel beams welded and/or fastened together. Vehicles with a separate frame

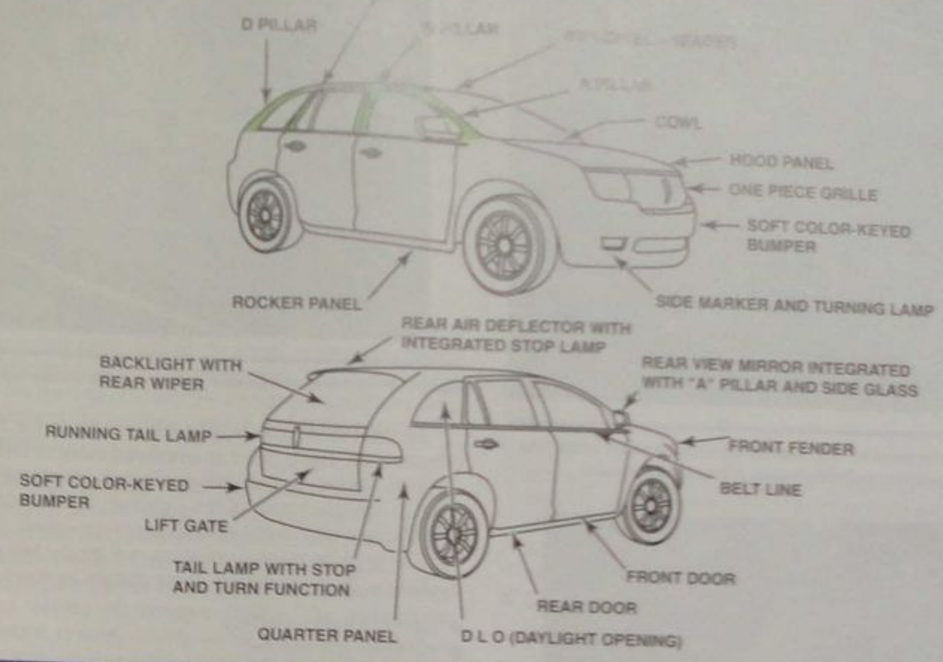


Figure 1–4 Body and terms.

and body are usually called **body-on-frame** vehicles **(BOF).** Many terms are used to label or describe the frame of a vehicle including:

Unit-Body Construction Unit-body construction (sometimes called **unibody**) is a design that combines the body with the structure of the frame. The body is composed of many individual stamped-steel panels welded together. The strength of this type of construction lies in the *shape* of the assembly. The typical vehicle uses 300 separate stamped-steel panels that are spot-welded together to form a vehicle's body. See Figure 1–5.

NOTE: A typical vehicle contains about 10,000 separate individual parts.

Space-Frame Construction Space-frame construction consists of formed sheet steel used to construct a framework of the entire vehicle. The vehicle is drivable without the body, which uses plastic or steel panels to cover the steel framework. See Figure 1–6.

ENGINE DESIGN EVOLUTION

All gasoline and diesel engines are called **internal combustion engines** and were designed to compress an ignitable mixture. This mixture was ignited by using a spark (gasoline) or by heat of compression (diesel). Early engines used valves that were in the engine block, which also contained the round cylinders where pistons were fitted. The pistons are connected to a crankshaft, which connects the up and down motion of the pistons to a rotary force which is used to propel the vehicle.



Figure 1–5 Note the ribbing and the many different pieces of sheet metal used in the construction of this body.

Inline versus V-Type Design Most early engines used four or six cylinders arranged inline. These were called **inline engines** and are still produced today. Some engines with 4, 6, 8, 12, or 16 cylinders were arranged with half of the cylinders on each set of a "V" and connected to a common crankshaft in the bottom of the "V." The crankshaft changed the up-and-down motion of the piston to rotary motion, allowing the engine to power the drive wheels.



Figure 1–6 A Corvette without the body. Notice that the vehicle is complete enough to be driven. This photo was taken at the Corvette Museum in Bowling Green, Kentucky.



Figure 1–7 A Ford flathead V-8 engine. This engine design was used by Ford Motor Company from 1932 through 1953.

Valve Location Design The design where the valves were located in the engine block is called **flathead** design because the cylinder head simply covered the combustion chamber and included a hole for the spark plug. The engine block contains passages for coolant as well as lubricating oil and is the support for all other engine systems. See Figure 1–7.

FREQUENTLY ASKED QUESTION ???

What is the Monroney Label?

The Monroney label is the sticker on the vehicle that lists the **manufacturer's suggested retail price,** usually abbreviated **MSRP.** The law that requires this label on all vehicles is called the Monroney Law, named for the congressman who sponsored the bill, Almer S. Monroney (1902–1980), a U.S. farm representative from Oklahoma from 1939–1951 and a U.S. Senator from 1951 to 1969.

Before the Monroney label law was passed in 1958, the price of a vehicle was unknown to new vehicle buyers who had to rely on the dealer for pricing. Besides all of the standard and optional equipment on the vehicle, the Monroney label also includes fuel economy and exhaust emission information. See Figure 1–8.



Figure 1–8 A Monroney label as shown on the side window of a new vehicle.

By the 1950s, most engine designs placed the valves in the cylinder head. This is called an **overhead valve** or **OHV** design.

Even newer engine designs feature **overhead camshafts (OHC).** The placement of the camshaft, which results in better flow of intake air into and exhaust out of the engine.

The need for reduced emissions and greater fuel economy led to advances in engine design. These changes included:

- Electronic ignition systems
- Electronic fuel injection
- Computerized engine controls
- Emission control devices, including the catalytic converter used in the exhaust system to reduce emissions
- Improved engine oils that help reduce friction and reduce emissions

ENGINE SYSTEMS OVERVIEW

Every engine requires many systems to function correctly.

Cooling System While some older engines were air cooled, all engines currently in production are liquid cooled. Coolant is pumped by a **water pump** through passages in the cylinder block and head called **water jackets.** The **coolant** is a mixture of antifreeze and water to provide corrosion and freezing protection. After the coolant picks up the heat from the engine, it flows through a **radiator,** which cools the coolant by releasing the heat into the air. The temperature of the coolant is maintained by using a **thermostat** located in the coolant passage, which opens to allow coolant to flow to the radiator or closes until the coolant is hot enough to need cooling.

Lubrication System All engines need a supply of lubricating oil to reduce friction and help to cool the engine. Most engines are equipped with an **oil pan,** also called an **oil sump,** containing 3 to 7 quarts (liters) of oil. An engine driven **oil pump** forces the oil under pressure through an **oil filter,** then to passages in the block and head called **oil galleries,** and then to all of the moving parts.

Air Intake System All engines, both gasoline and diesel engines, draw air from the atmosphere. It requires about 9,000 gallons of air for each gallon of gasoline used. The air must be drawn where deep water in the road cannot be drawn into the engine. The air is then filtered by a replaceable **air filter.** After the air is filtered, it passes through a throttle valve and then into the engine through an **intake manifold.**

Fuel System The fuel system includes the following components and systems:

- Fuel tank
- Fuel lines and filter(s)
- Fuel injectors
- Electronic control of the fuel pump and fuel injection

The fuel injectors are designed to atomize the liquid gasoline into small droplets so they can be mixed with the air entering the engine. This mixture of fuel and air is then ignited by the spark plug.

- Engine starting and charging systems, which include the battery, starting (cranking) system and charging system components and circuits

Ignition System The ignition system uses battery voltage and creates a high-voltage spark through the use of an **ignition control module (ICM)** that is sent to the spark plugs. The arc across the electrodes of the spark plug ignites the air-fuel mixture in the combustion chamber and the resulting pressure pushes the piston down on the power stroke.

Emission Control System The control of vehicle emissions includes controlling gasoline vapors from being released into the atmosphere in addition to reducing the emissions from the exhaust. Unburned gasoline emissions are called **hydrocarbon (HC)** emissions and exhaust gases that are controlled include **carbon monoxide (CO)** and **oxides of nitrogen (NO_x).** The **evaporative emission control system,** usually called the **EVAP system,** is designed to prevent gasoline fumes and vapors from being released. Other emission control systems include:

- **Positive crankcase ventilation (PCV).** This system uses a valve called a **PCV valve** to regulate the flow of gases created in the crankcase of a running engine, which are routed back into the intake manifold. The engine will then draw these gases into the combustion chamber where they are burned to help prevent the release of the gases into the atmosphere.
- **Exhaust gas recirculation (EGR).** The EGR system meters about 3% to 7% of the exhaust gases back into the intake where the gases reduce the peak combustion temperature and prevent the oxygen (O_2) and nitrogen (NO) from the air from combining to form oxides of nitrogen.
- **Catalytic converter.** The catalytic converter is a unit located in the exhaust system usually close to the engine, which causes changes in the exhaust gases.
- On-board diagnostics means that the engine as well as the engine management systems can test itself for proper operation and alert the driver if a fault is detected. The warning lamp is called the **malfunction indicator light (MIL)** and is labeled "Check Engine" or "Service Engine Soon." The on-board diagnostic system is currently in the second generation and is called **OBD-II.** Electronic hand-held testers, called **scan tools,** are needed to access (retrieve) stored diagnostic trouble codes (DTCs) and view sensor and system data.

POWER TRAIN OVERVIEW

The purpose of the power train is to transfer the torque output of the engine to the drive wheels.

Rear-Wheel-Drive Power Train A rear-wheel-drive vehicle uses the following components to transfer engine torque to the rear drive wheels:

- **Transmission.** In a manually shifted transmission, the drivetrain contains a clutch assembly, which allows the driver to disengage



Figure 1–9 A dash control panel used by the driver to control the four-wheel-drive system.

engine torque from the transmission to allow the driver to shift from one gear ratio to another. The transmission contains gears and other assemblies that provide high torque output at low speeds for acceleration and lower torque output but at higher speeds for maximum fuel economy at highway speeds.

- **Drive Shaft.** A **drive shaft,** also called a **propeller shaft,** is used to connect and transmit engine torque from the transmission to the rear differential. **Universal joints (U-joints)** are used to allow the rear differential to move up and down on the rear suspension and still be able to transmit engine torque.
- **Differential.** A differential is used at the rear of the vehicle and performs two functions:
  - The differential increases the torque applied to the rear drive wheels by reducing the speed.
  - The differential also changes the direction of the applied engine torque and uses axle shafts to transfer the torque to the drive wheels.

Front-Wheel-Drive Power Train A front-wheel-drive vehicle uses a **transaxle,** which is a combination of a transmission and differential in one assembly. Drive axle shafts then transfer the engine torque to the front drive wheels from the output of the transaxle.

Four-Wheel-Drive System There are many types of methods of powering all four wheels. Many include a **transfer case** to split engine torque to both the front and the rear wheels. See Figure 1–9.

ELECTRICAL/ELECTRONIC SYSTEMS OVERVIEW

Early vehicles did not have an electrical system because even the ignition did not require a battery. Early engines used a magneto to create a spark instead of using electrical power from a battery as used today.

The first electrical components on vehicles were battery-powered lights, not only for the driver to see the road, but also so others could see an approaching vehicle at night.

Only after 1912 and the invention of the self-starter did the use of a battery become commonplace. Charles F. Kettering also invented the point-type ignition system about the same time as the self-starter. Therefore, the early batteries were often referred to as SLI batteries meaning starting, lighting, and ignition. From the 1920s into the 1950s other electrical components were added, such as radios, defroster fans, and horns. It was not until the 1960s



Figure 1–10 The generator (alternator) is in the heart of the electrical system.



Figure 1–11 Test registration booklet that includes details on all vehicle-related certification tests given by ASE.

that electrical accessories, such as air conditioning, power seats, and power windows, became common.

Today's vehicles require generators (alternators) that are capable of producing a higher amount of electricity than was needed in the past, and the number of electronic components has grown to include every system in the vehicle, including:

- A tire pressure monitoring system for the tires
- Heated and cooled seats
- Automatic climate control
- Power windows
- Security systems
- Electric power steering
- Electronic suspension

See Figure 1–10.

HEATING, VENTILATION, AND AIR CONDITIONING OVERVIEW

Early model vehicles did not include any heaters or other methods to provide comfort for the driver and passengers. Most early vehicles were open with a simple removable top. Some had optional side curtains that provided all-weather protection. In the 1930s and 1940s when fully enclosed bodies became common, the vehicle manufacturers started to include heaters, which were small radiators with engine coolant flowing through them. About the same time and into the 1950s, about the only options that many vehicles had were a radio and heater, abbreviated R & H.

Today, air-conditioning systems are purchased on most vehicles and incorporate defrosters and passenger compartment heating, often in two zones for maximum comfort of the driver and passenger. Additional related comfort options today include heated and cooled seats and heated steering wheels.

EIGHT AREAS OF AUTOMOTIVE SERVICE

In 1972, the National Institute for Automotive Service Excellence, a non-profit organization known as simply ASE, created a series of eight tests that cover the major vehicle systems. See Figure 1–11.

Engine Repair (A1) This content area includes questions related to engine block and cylinder head diagnosis and service, as well as the lubrication, cooling, fuel, ignition, and exhaust systems inspection and service.

Automatic Transmission (A2) This content area includes general automatic transmission/transaxle diagnosis, including hydraulic and electronic related systems.

Manual Drive Train and Axles (A3) This content area includes clutch diagnosis and repair, manual transmission diagnosis and repair, as well as drive shaft, universal, and constant velocity joint diagnosis and service. Also included in this content area are rear differential diagnosis and repair plus four-wheel-drive component diagnosis and repair.

Suspension and Steering (A4) This content area includes steering and suspension system diagnosis and repair, including wheel alignment diagnosis and adjustments, and wheel and tire diagnosis and repair procedures.

Brakes (A5) The brake content area includes the diagnosis and repair of the hydraulic system, drum and disc brake systems, plus power assist units, antilock braking, and traction control systems.

Electrical/Electronic Systems (A6) This content area includes many systems, including the battery, starting, charging, lighting, gauges, and accessory circuit diagnosis and repair.

Heating and Air Conditioning (A7) The heating and air-conditioning content area includes air-conditioning service, refrigeration systems, heating and engine cooling systems diagnosis and repair, as well as refrigerant recovery, recycling, handling, and retrofit.

Engine Performance (A8) The engine performance content area includes diagnosis and testing of those systems responsible for the proper running and operation of the engine. Included in this area are general engine diagnosis, ignition and fuel systems, as well as emission control and computerized engine control diagnosis and repair.

This textbook covers the content of all eight ASE areas plus all of the background and fundamental information needed by technicians.

SUMMARY

1. Major automobile milestones include: the OTTO cycle engine (1876), the first diesel engine (1892), Henry Ford's first car (1896), Oldsmobile's large-scale production (1902), the first Model T Ford (1908), the first car with four-wheel hydraulic brakes (1922), the first automatic transmission (1940), the first vehicle to use a four-wheel antilock braking system (1985), and the first vehicle with electronic stability control (1997).
2. The chassis of the vehicle consists of a frame or body which has attached to it the front and rear suspension, the brake system, the engine and transmission, as well as the steering system.
3. A vehicle frame is the main structural support for the body.
4. Engine design has changed from inline flathead 4-, 6-, and 8-cylinder engines to new double-overhead camshaft designs, which are computer controlled.
5. The engine consists of the following systems: air intake cooling, lubrication, fuel, ignition, and emission control.
6. Major advances have also been made to electrical systems and controls from no electrical circuits in the early days of self-propelled vehicles to computer-controlled accessory and climate control systems today.
7. The eight areas of automotive service include: engine repair (A1), automatic transmission/transaxle (A2), manual transmission/transaxle (A3), suspension and steering (A4), brakes (A5), electrical and electronic systems (A6), heating and air conditioning (A7), and engine performance (A8).

REVIEW QUESTIONS

1. In 1900, what was the most produced vehicle powered by?
2. What parts are included in the vehicle chassis?
3. Why were early engines called flat heads?
4. What is the difference between a unit-body and body-on-frame vehicle?
5. The power train consists of what components?
6. What are the eight automotive service content areas?

CHAPTER QUIZ

1. The first self-propelled vehicle that used an OTTO cycle four-stroke gasoline engine was produced in _____.
   a. 1885
   b. 1900
   c. 1902
   d. 1908
2. Early vehicles were constructed mostly of what material?
   a. Steel
   b. Cast iron
   c. Wood
   d. Tin
3. Which component is *not* part of the chassis system?
   a. Frame
   b. Electrical system
   c. Suspension
   d. Brakes
4. Early engines used [illegible] because they _____.
   a. Were only inline engines
   b. Did not have valves
   c. Used valves beside the cylinder
   d. Used spark plugs at the top of the cylinders
5. A Wright engine could have how many cylinders?
   a. 4
   b. 6
   c. 8
   d. All of the above
6. What component regulates the temperature of the coolant in an engine?
   a. Cooling (water) jackets
   b. Thermostat
   c. Cooling fan(s)
   d. Radiator
7. A malfunction indicator light (MIL) on the dash may be labeled _____.
   a. Check engine
   b. Service vehicle soon
   c. MIL
   d. MAL
8. To retrieve stored diagnostic trouble codes, a service technician needs a _____.
   a. Paper clip
   b. Laptop computer
   c. Wireless connection to an electronic tester
   d. Scan tool
9. A four-wheel-drive vehicle often uses a _____ to transmit engine torque to all four wheels _____.
   a. Drive shaft
   b. U-joint
   c. Transaxle
   d. Transfer case
10. Automotive service systems are generally separated into how many content areas?
    a. 4
    b. 6
    c. 8
    d. 10

CHAPTER 2 Careers in the Automotive Service Industry

OBJECTIVES: After studying Chapter 2, the reader will be able to: Describe automotive service-related positions. • Discuss the level of training and experience needed for each position. • Describe the technical skills needed for each position. • Explain the relationship of the service manager to others in a shop and company.

KEY TERMS: entrepreneur • on-the-job training (OJT) • parts counter person • service advisor • service consultant • service manager • service writer • shop foreman • team leader • technician (tech) • VIN • work order

THE NEED FOR AUTOMOTIVE TECHNICIANS

The need for trained and skilled automotive **technicians** is greater than ever for several reasons, including:

- Vehicles are becoming more complex and require a higher level of knowledge and skills.
- Electrical and electronic components and sensors are included throughout the vehicle.
- Construction of parts and materials being used has changed over the last few years, meaning that all service work must be done to specified procedures to help avoid damage being done to the vehicle.
- Increasing numbers of lubricants and coolants make even routine service challenging.

All of the above issues take proper training and the ability to follow factory specified procedures to ensure customer satisfaction. The number of service technicians needed is increasing due to more vehicles on the road. A good service technician can find work in almost any city or town in the country, making the career as a professional service technician an excellent choice.

THE NEED FOR CONTINUOUS VEHICLE SERVICE

Vehicles are lasting longer due to improved materials and more exacting tolerances. Every year, vehicles are being driven further than ever before. It used to be (in the 1950s) that the life of a vehicle was considered to be 100,000 miles or 10 years. Now achieving 200,000 miles without a major repair is common with proper maintenance and routine service. However, even the amount of needed routine service has been reduced due to changes in the vehicles, such as radial tires that now last 40,000 miles instead of older tires which were worn out and needed to be replaced every 15,000 miles.

Warranties A warranty is a guarantee to the purchaser of a vehicle that it will function as specified. The warranty covers the quality and performance of the product and states the conditions under which the warranty will be honored. Vehicle warranties vary but all warranties indicate a time and mileage restriction. The expressed warranties often include the following areas:

- New vehicle limited warranty that covers all components (except two) and is commonly called a bumper-to-bumper policy.
- Power train warranty covers the engine, transmission/transaxle and final drive units. This coverage usually is longer than the bumper-to-bumper coverage.
- Sheet metal rust through warranty is usually longer than the bumper-to-bumper and power train warranty and covers rust if a hole occurs starting from inside the outer metal surface of the body.
- Emission control device warranties depend on the emission rating, the coverage of the power train control module (PCM), and the catalytic converter and are covered for 8 years and 80,000 miles up to 10 years and 150,000 miles.

Vehicle warranties, unless an emergency repair, must be performed at a dealership, which is certified by the vehicle manufacturer to perform the repairs. At the dealership, the technician performing the repair must also be certified by the vehicle manufacturer.

All technicians should be familiar with what may be covered by the factory warranties to help ensure that the customer does not have to pay for a repair that may be covered. While warranties do cover many components of the vehicle, wear and service items are not covered by a warranty in most cases and therefore, offer excellent opportunity for trained service technicians.

Increasing Age of a Vehicle The average age of a vehicle on the road today has increased to older than seven years. This trend means that more vehicles than ever are not covered by a factory warranty and are often in need of repair. Aftermarket warranties also can be used at most repair facilities, making it very convenient for vehicle owners.

TECHNICIAN WORK SITES

Service technician work takes place in a variety of work sites including:

New Vehicle Dealerships Most dealerships handle one or more brands of vehicle, and the technician employed at dealerships usually has to meet minimum training standards. The training is usually provided at no cost to the technician at regional training centers. The dealer usually pays the service technician for the day(s) spent in training as well as provides or pays for transportation, meals, and lodging. See Figure 2–1.

Independent Service Facilities These small- to medium-size repair facilities usually work on a variety of vehicles. Technicians employed at independent service facilities usually have to depend on aftermarket manufacturers' seminars or the local vocational school or college to keep technically up-to-date. See Figure 2–2.

Mass Merchandiser Large national chains of vehicle repair facilities are common in most medium- and large-size cities. Some



Figure 2–1 A service technician working on the brakes of a vehicle in a new-vehicle dealership service department.



Figure 2–2 A typical independent service facility. Independent garages often work on a variety of vehicles and perform many different types of vehicle repairs and service. Some independent garages specialize in just one or two areas of service work or in just one or two makes of vehicles.



Figure 2–3 This NAPA parts store also performs service work from the garage area on the side of the building.

examples of these chains include Sears, Goodyear, Firestone, and NAPA, as shown in Figure 2–3. Technicians employed by these chains usually work on a wide variety of vehicles. Many of the companies have their own local or regional training sites designed to train beginning service technicians and to provide update training for existing technicians.

Specialty Service Facilities Specialty service facilities usually limit their service work to selected systems or components of the vehicle and/or to a particular brand of vehicle. Examples of specialty service facilities include Midas, Speedy, and AAMCO Transmissions. Many of the franchised specialty facilities have their own technician training for both beginning and advanced technicians.

Fleet Facilities Many city, county, and state governments have their own vehicle service facilities for the maintenance and repair of their vehicles. Service technicians are usually employees of the city, county, or state and are usually paid by the hour rather than on a commission basis.

TECHNICIAN JOB CLASSIFICATIONS

There are many positions and jobs in the vehicle service industry. In smaller service facilities (shops), the duties of many positions may be combined in one job. A large city dealership may have all of the following vehicle service positions. A technician is often referred to as a **tech.**

Lube Tech/Quick Service Technician A lubrication technician should be trained in the proper use of hand tools and instructed how to properly service various types of vehicles. The training could be **on-the-job (OTJ)** or could be the result of high school or college automotive training. Some larger companies provide in-house training for new technicians and as a result they are trained to perform according to a specified standard. It is important that the lubrication technician double-check the work to be certain that the correct viscosity oil has been installed and to the specified level. The oil plug and oil filter must also be checked for leakage.

Lubrication technicians are trained to perform routine services including:

- Oil and oil filter change
- Chassis lubrication
- Fluids check and refill
- Tire inflation checks
- Accessory drive belt inspection
- Air filter check and replacement
- Cabin filter replacement
- Windshield wiper blade replacement

As a result of these tasks the lubrication technician should be skilled at lubing the vehicle and able to handle the tasks efficiently and in minimum time.

New Vehicle Preparation for Delivery A new entry-level position at a dealership often includes preparing new vehicles for delivery to the customer. This is often referred to as "new car prep." The duties performed for new vehicle preparation are generally learned on the job. The vehicle manufacturer publishes guidelines that should be followed and it is the responsibility of the new vehicle preparation person to see that all items are checked and serviced, and all associated paperwork is completed. The activities normally associated with preparing a new vehicle for delivery include:

- Installing wheel center caps or wheel covers (if used)
- Installing roof racks, running boards, and other dealer-installed options
- Checking and correcting tire pressures

NOTE: Many vehicle manufacturers ship the vehicles to the dealer with the tires overinflated to help prevent movement of the vehicle during shipping.

- Checking all fluids
- Checking that everything works including the remote key fob and all accessories
- Ordering any parts found to be broken, missing, and damaged in transit
- Removing all protective covering and plastic from the seats, carpet, and steering wheel
- Washing the vehicle

FREQUENTLY ASKED QUESTION ???

Why Is the Work Order Important?

The **work order** is a legal document that includes the description of the vehicle and the work requested by the customer. The customer then signs the work order authorizing that the stated work be performed. If there are additional faults found then the shop must notify the customer and get permission to change the amount or extent of the work originally authorized. As work is performed on the vehicle, the parts used and the labor operation performed are added. This creates a complete file on the repair. This means that the vehicle has to be properly identified by including the **vehicle identification number (VIN)** on the work order. There is only one vehicle with that VIN, yet there may be many "white Chevrolet pickup trucks."

The work order is the paper trail that shows all operations, labor times, and parts used when the vehicle was in control of the shop. A work order is often required even when the technician is working on his or her own vehicle.

General Service Technician A general service technician usually has training as an automotive technician either in one or more of the following:

- High school—Technical or vocational school or a comprehensive high school that has an Automotive Youth Education System (AYES) program.
- College or technical school—Usually a two-year program that can earn the student an associate's degree.
- Career college or institute—Usually a 6-month to 12-month program earning the graduate a certificate.

Automotive service technicians perform preventative maintenance, diagnose faults, and repair automotive vehicles and light trucks.

Automotive service technicians adjust, test, and repair engines, steering systems, braking systems, drivetrains, vehicle suspensions, electrical systems and air-conditioning systems, and perform wheel alignments. In large shops, some technicians specialize in repairing, rebuilding, and servicing specific parts, such as braking systems, suspension, and steering systems. In smaller shops, automotive service technicians may work on a wider variety of repair jobs.

Automotive service technicians begin by reading the work order and examining the vehicle. To locate the cause of faulty operation and repair it, a technician will:

- Use testing equipment, take the vehicle for a test-drive, and/or refer to manufacturer's specifications and manuals
- Dismantle faulty assemblies, repair, or replace worn or damaged parts
- Reassemble, adjust, and test the repaired mechanism

Automotive service technicians also may:

- Perform scheduled maintenance services, such as oil changes, lubrications, and filter replacement
- Advise customers on work performed, general vehicle conditions, and future repair requirements

Working Conditions Most automotive service technicians work a 40-hour, five-day week. Some evening, weekend, or holiday work may be required. The work is sometimes noisy and dirty. There is some risk of injury involved in working with power tools and near exhaust gases.

Skills and Abilities The work is most rewarding for those who enjoy doing precise work that is varied and challenging. Also, technicians usually achieve job security and a feeling of independence.

To be successful in the trade, automotive service technicians need:

- Good hearing, eyesight, and manual dexterity (ability to work with hands)
- Mechanical aptitude and interest
- The ability to lift between 25 and 50 pounds (11 and 25 kilograms)
- The willingness to keep up-to-date with changing technology

A working knowledge of electricity, electronics, and computers is also required for many service procedures.

Employment and Advancement Automotive service technicians are employed by automotive repair shops, specialty repair shops, service facilities, car and truck dealerships, and by large organizations that own fleets of vehicles.

Experienced automotive service technicians may advance to service manager or shop foreman. Some automotive service technicians open their own repair facilities.

Many technicians can also start work in a shop or dealership and learn on the job. Most technicians keep up-to-date by attending update seminars or training classes on specific topics throughout the year.

Specific tasks performed by a general service technician can include the following:

- All of the tasks performed by the lubrication technician.
- Engine repairs including intake manifold gasket replacement; cylinder head replacement; and oil and water pump replacement plus other engine-related tasks.
- Brake system service and repair including disc brakes; drum brakes; parking brake; and antilock brake (ABS) diagnosis and service.
- Suspension-related service including tire inspection and replacement; shock and strut replacement; servicing or replacing wheel bearings; performing steering component inspection and parts replacement; and performing wheel alignment and vibration diagnosis.
- Electrical-related diagnosis and repair including starting and charging problems; correcting lighting and accessory faults; and general service such as light bulb replacement and key fob reprogramming.
- Engine performance-related diagnosis and repair including replacing fuel pumps and filters; cleaning or replacing fuel injectors; solving emissions-related failures; and determining the cause and correcting "Check Engine" lights.
- Manual transmission service and repairs including replacing clutches; adjusting, or replacing clutch linkage; and performing four-wheel-drive diagnosis and service procedures.
- Automatic transmission service and repairs including performing routine automatic transmission service; removing and replacing automatic transmissions; and performing diagnosis and service checks including fluid pressure and scan tool diagnosis.

The vehicle is then driven by the service technician to verify the repair.

Technician Team Leader A **team leader** is an experienced service technician who is capable of performing most if not all of the work that the shop normally handles. The team leader then assigns work to others in the group based on the experience or competency of the technician. The team leader then checks the work after it has been completed to be sure that it has been correctly performed. The number of hours of labor for each member of the team is totaled each pay period. Each member of the team is paid an equal share of the time but at different rates. The team leader gets a higher per hour rate than the others on the team. The rate of pay per hour is based on the level of training and experience. A beginning technician may or may not be paid as part of the total team hours depending on how the team system is organized. While some shops do not use teams, many large shops or dealerships have two or more teams. The advantage of a team-type organization is that everyone on the team looks out and helps each other if needed because they are all paid based on the number of hours the team generates. The team leader performs the duties of a shop foreman but only for those members on the team and not the entire shop. The team leader is under the direction and control of the service manager.

Shop Foreman A **shop foreman** (usually employed in larger dealerships and vehicle repair facilities) is an experienced service technician who is usually paid a salary (so much a week, month, or year). A shop foreman is a knowledgeable and experienced service technician who keeps up-to-date with the latest vehicle systems, tools, and equipment. Typical shop foreman's duties include:

- Test-driving the customer's vehicle to verify the customer concern (complaint)
- Assigning work to the service technicians
- Assisting the service technicians
- Assisting the service manager
- Verifying that the repair is completed satisfactorily

The shop foreman is under the direction and control of the service manager.

Service Advisor A **service advisor,** also called a **service writer** or **service consultant,** is the person at the dealership or shop designated to communicate the needs of the customer and accurately complete a work order.

A service advisor should:

- Have a professional appearance
- Be able to speak clearly
- Be able to listen carefully to the customer
- Write neatly and/or type accurately
- Be familiar with industry and shop standards and procedures

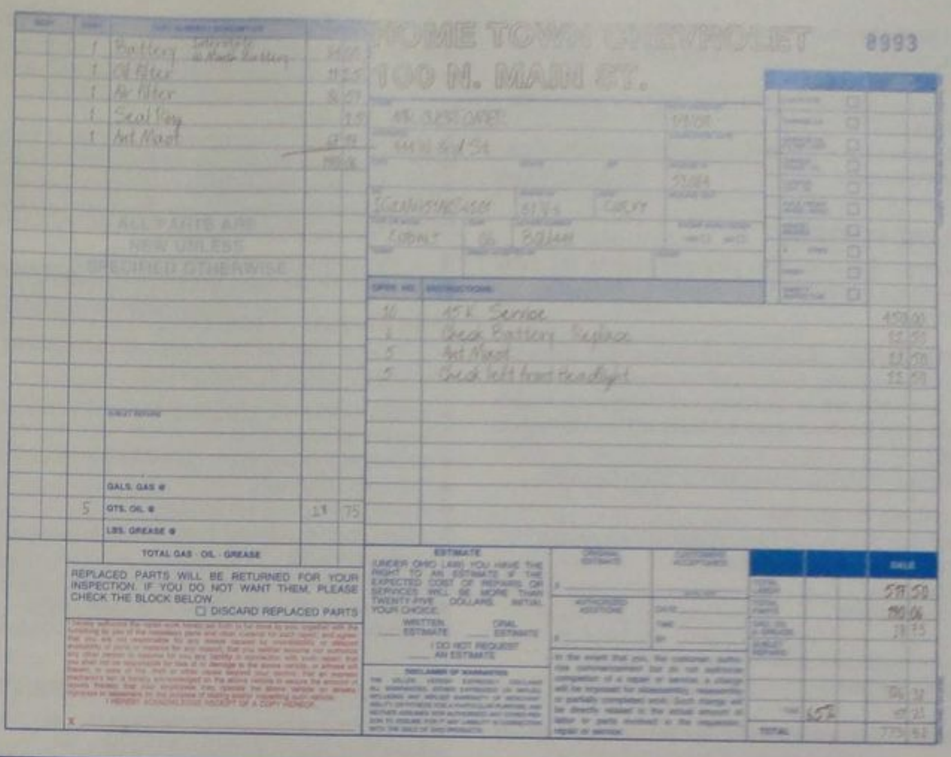

HOME TOWN CHEVROLET 8993
100 N. MAIN ST.
1 Battery
1 Oil filter
1 Air filter
1 Seal Key
1 Ant Mirror
ALL PARTS ARE NEW UNLESS SPECIFIED OTHERWISE
10 45K Service 150.00
1 Check Battery Replace 12.95
1 Ant Mirror 11.50
1 Check left head headlight 15.00
GALS. GAS @
5 QTS. OIL @ 11 75
LBS. GREASE @
TOTAL GAS · OIL · GREASE
REPLACED PARTS WILL BE RETURNED FOR YOUR INSPECTION. IF YOU DO NOT WANT THEM, PLEASE CHECK THE BLOCK BELOW.
☐ DISCARD REPLACED PARTS
ESTIMATE
UNLESS OHIO LAW REQUIRES YOU HAVE THE RIGHT TO AN ESTIMATE IF THE EXPECTED COST OF REPAIRS OR SERVICES WILL BE MORE THAN TWENTY FIVE DOLLARS. INITIAL YOUR CHOICE.
WRITTEN ESTIMATE ORAL ESTIMATE
I DO NOT REQUEST AN ESTIMATE
DISCLAIMER OF WARRANTIES
SALE
5.00
90.00
11.75
TOTAL 776.61

Figure 2–4 Typical work order. *(Courtesy of Reynolds and Reynolds Company)*

Most service advisors would benefit from taking a short course on service advising skill development and interpersonal relationship building. A service advisor should be familiar with the operation of the vehicle, but not to the same level as a service technician. A service advisor should not diagnose the problem, but rather state clearly on the work order what, when, and where the problem occurs so that the service technician has all the needed information to make an accurate diagnosis. See Figure 2–4 for an example of a typical work order.

The service advisor's duties include:

1. Recording the vehicle identification number (VIN) of the vehicle on the work order
2. Recording the make, model, year, and mileage on the work order
3. Carefully recording what the customer's complaint (concern) is so that the service technician can verify the complaint and make the proper repair
4. Reviewing the customer's vehicle history file and identifying additional required service
5. Keeping the customer informed as to the progress of the service work

A service advisor must be at the shop early in the morning to greet the customers and often needs to stay after the shop closes for business to be available when the customer returns at the end of the day.

TECH TIP ✓ **Check the Vehicle before Work Is Started**

As part of the work order writing process, the service advisor should look over the vehicle and make a written note of any body damage that may already exist. If any damage is noted it should be mentioned to the customer and noted on the work order. Often the customer is not aware of any damage especially on the passenger side and thus would blame the shop for the damage after the service work was performed.

Service Manager The **service manager** rarely works on a vehicle but instead organizes the service facility and keeps it operating smoothly. A service manager can be a former service technician or in many larger dealerships, a business major graduate who is skilled at organization and record keeping. The service manager typically handles all of the paperwork associated with operating a service department.

NOTE: In a small shop, the shop owner usually performs all of the duties of a shop foreman and service manager, as well as the lead technician in many cases.

Typical duties of a service manager include:

- Establishing guidelines to determine the technicians' efficiency
- Supervising any warranty claims submitted to the vehicle manufacturer or independent insurer

- Evaluating and budgeting for shop tools and equipment
- Establishing service department hours of operation and employee schedules
- Assigning working hours and pay for technicians and others in the service department
- Establishing procedures and policies to keep the service area clean and properly maintained

PARTS-RELATED POSITIONS

The parts manager and other parts personnel such as the **parts counter person** are responsible for getting the correct part for the service technician.

Parts Counter Person A parts counter person often learns the details by on-the-job training. A good parts counter person must be able to greet and easily talk to customers and technicians. A parts counter person must also have computer skills and the willingness to help others.

The parts counter person usually has the following duties:

- Greet the customer or technician
- Locate the correct parts for the service technician or customer
- Suggest related parts (retail customers)
- Stock shelves
- Check in delivered parts
- Take inventory
- Keep the parts department clean
- Help the parts manager

Parts Manager The specific duties of a parts manager usually include:

- Ordering parts from the vehicle manufacturers and aftermarket companies
- Stocking parts
- Organizing the parts department in a clear and orderly fashion
- Locating parts quickly within the parts department
- Developing contacts with parts departments in other local dealerships so that parts that are not in stock can be purchased quickly and at a reasonable cost

SALES JOBS—USED VEHICLES; NEW VEHICLES

Salesperson When a vehicle is sold, it generates a potential customer for the service department. New and many used vehicle sales dealerships employ salespeople to help the customer select and purchase a vehicle. The salesperson should have excellent interpersonal skills, as well as be familiar with the local and regional laws and taxes to be able to complete all of the paperwork associated with the sale of a vehicle. The usual duties of a vehicle salesperson include:

- Greet the customer
- Introduce yourself and welcome the customer to the store
- Qualify the customer as to the ability to purchase a vehicle
- Demonstrate and ride with the customer on a test-drive
- Be able to find the answer to any question the customer may ask about the vehicle and/or financing
- Be able to complete the necessary paperwork
- Follow up the sale with a telephone call or card

Sales Manager A sales manager is an experienced salesperson who is able to organize and manage several individual salespeople. The duties of a sales manager include:

- Establish a schedule where salespeople will be available during all hours of operation
- Consult with salespeople as needed on individual sales
- Train new salespeople
- Conduct sales promotion activities
- Attend or assign someone to attend vehicle auctions to sell and/or purchase vehicles
- Keep up-to-date with the automotive market
- Purchase vehicles that sell well in the local market
- Answer to the general manager or dealership principal

OTHER CAREERS IN THE AUTOMOTIVE INDUSTRY

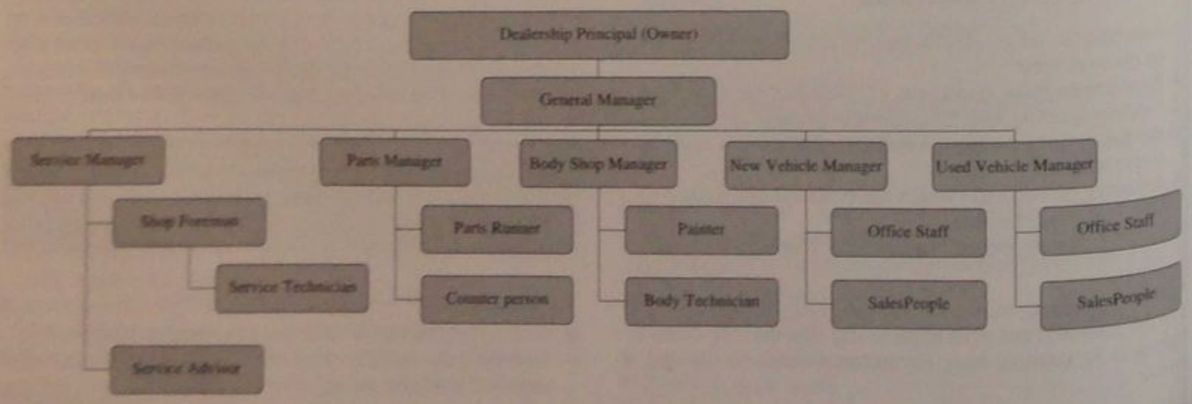
Other careers in the automotive industry include:

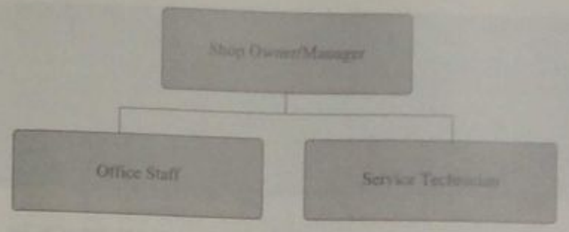
- Sales representative for automotive tools and equipment
- Technical trainers
- Technical school instructors
- Wholesale parts warehouse management
- Insurance adjuster
- Automotive technical writer
- Warranty claim examiner

TYPICAL AUTOMOTIVE ORGANIZATION ARRANGEMENT

Large Comprehensive New Vehicle Dealer

Independent Shop An independent shop may or may not have a shop foreman depending on the number of technicians and the volume of work. Larger independent shops have a shop foreman, whereas at smaller shops, the owner is the shop foreman.





FREQUENTLY ASKED QUESTION ???

What Is an Entrepreneur?

An **entrepreneur** is a person who starts and operates a business. Many service technicians want to eventually own their own shop and become an entrepreneur. However, operating a shop involves many duties and responsibilities that many service technicians lack, including:

- Bookkeeping and accounting skills
- Tax preparation (local, state, and federal)
- Sales tax collection and payment
- Health insurance arrangements for employees
- Unemployment compensation payments
- Workers' compensation payments
- Uniform payment
- Real estate taxes
- Garage keepers liability insurance

While at first it may seem like owning your own shop would be great, a good technician can often make more money, and have fewer headaches, by simply working for someone else.

SUMMARY

1. A service advisor is the person at a dealership or shop who greets the customer and writes the work order stating what repairs and service the customer wants.
2. A lube or quick service technician performs routine service, such as oil changes, cabin and air filter replacement, and other common service procedures.
3. A new vehicle preparation technician is a person who prepares a new vehicle for delivery to the customer.
4. A general service technician has training and experience in a wide range of automotive systems, including engines, brakes, suspensions, manual transmissions, electrical, heat, air conditioning, engine performance, and automatic transmissions.
5. A shop foreman is an experienced service technician who performs diagnosis, as well as helping other technicians.
6. A service manager handles financial responsibilities associated with the proper operation of the service department or shop, including budgets, equipment purchases, and maintenance arrangement, as well as working hours, pay rate determination, and efficiency ratings.
7. Parts departments are a key part of a dealership and parts delivery and/or inventory is a large part of any shop operation.
8. Vehicle sales, both new and used, generate the need for vehicle service, and the salespeople must have good interpersonal skills.

REVIEW QUESTIONS

1. What should be included on a work order?
2. Why should a vehicle be inspected when the work order is being written?
3. What tasks are usually performed by a general service technician?
4. What duties are performed by the shop foreman and service manager?
5. What duties are performed by a parts counter person?
6. What duties are performed by vehicle salespeople?

CHAPTER QUIZ

1. A service advisor is called a _____.
   a. Shop foreman
   b. Service Manager
   c. Service writer
   d. Technician
2. What is *not* included on a work order?
   a. Customer's mother's maiden name
   b. VIN
   c. Mileage
   d. Description of work requested
3. All of the following are usual duties of a lube technician *except* _____.
   a. Oil change
   b. Air filter replacement
   c. Water pump replacement
   d. Accessory drive belt inspection
4. New vehicle preparation is usually an entry-level vehicle service position and usually involves what duties?
   a. Installing dealer-installed options
   b. Correcting tire pressures
   c. Removal of all protective coverings and plastic
   d. All of the above
5. What is not a duty of a general service technician?
   a. Have the customer sign the work order
   b. Order the parts needed
   c. Diagnose the customer's concern
   d. Perform vehicle repair procedures
6. Which description best fits the role of a service advisor?
   a. A skilled technician
   b. A beginning technician
   c. A customer service representative
   d. A money manager
7. Two technicians are discussing the duties of a shop foreman and a service manager. Technician A says that a shop foreman works on vehicles. Technician B says that the service manager diagnoses vehicle problems. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Who is the person that greets the service customer and completes the work order?
   a. Service manager
   b. Service advisor
   c. Service writer
   d. Either b or c
9. Which job would be concerned with the maintenance of the shop equipment?
   a. Service manager
   b. Shop foreman
   c. Shop owner
   d. Any of the above
10. Which job would be concerned with payroll?
    a. Service manager
    b. Shop foreman
    c. Service advisor
    d. Service technician

CHAPTER 3

Starting a Career in the Automotive Industry

OBJECTIVES: After studying Chapter 3, the reader will be able to: Explain the steps and processes for applying for a job. • Describe what the resume should include. • Explain why having a good driving record is important to a shop owner.

KEY TERMS: apprentice program • clock-in • clock time • commission pay • cooperative education • entrepreneur • federal tax • FICA • flat-rate Gross • housing expense • incentive pay • job shadowing • net • part-time employment • references • resume • soft skills • state tax • straight time

PREPARING FOR AN AUTOMOTIVE SERVICE CAREER

Desire and Interest If a person has an interest in automobiles and trucks and likes computers, the automotive service field may be a good career choice. Computer skills are needed in addition to hands-on skills for several reasons, including:

- Service information, such as diagnostic procedures and specifications, is commonly available in electronic format.
- Work orders are commonly written and sent to the technician electronically. The technician therefore needs typing skills to type the steps taken during the service or repair procedures.
- Warranty claims are often submitted by the Internet and computer skills are needed to quickly and accurately submit claims and answer questions from the insurance company.

Interest in vehicles is also very important toward being successful as a professional service technician. Most technicians enjoy working on vehicles, not only professionally, but also during their spare time. Many technicians own a project vehicle, which could include:

- Drag race vehicle
- Race vehicle used in road racing
- A fun vehicle used on sunny weekend days and evenings
- Motorcycle
- Snowmobile or jet ski
- Truck for rock crawling

Technical Knowledge and Skills The enjoyment of being involved with vehicles is very important because the job of servicing and repairing automobiles and trucks can be hard and dirty work. Many men and women enjoy being around and learning about the details of vehicle operation. With these desires and interest, working in the automotive service field is a great career. Technical information, skills, and tools needed include:

- **Hand tools and tool usage.** Owning and experience using hand tools is important for a service technician. All service technicians are expected to be able to remove and replace parts and components as needed in a timely manner.
- **Technical knowledge.** While knowing how all aspects of the vehicle works is not expected of a beginning service technician, it is important that the technician have a basic understanding of the parts and procedures needed at least for routine service procedures.

TECH TIP ✔ **If in Doubt, Ask**

No one expects a beginning service technician to know everything, but other technicians do not know what you do or do not know. It is usually assumed that the beginning technician will ask for help if they think they need the help. However, asking for help is very rare and requires the beginning technician to admit that they do not know something. Not asking for help can cause harm to the vehicle or the service technician. If in doubt—always ask. No one will be upset and learning the answer to your question will help in the learning experience.

Job Shadowing A great way to see what it is really like to work as a service technician is to follow a professional around for a day or more. **Job shadowing** is usually arranged through an automotive program, and the shop or dealership has agreed to allow someone into the shop area to observe.

While it does allow the student to observe, job shadowing does not allow the person to perform any work or help the technician in any way. During the day, the person who is job shadowing has to wear all personal protective equipment as required by the technician and must observe all safety regulations. The advantages of job shadowing include:

- Being able to observe a typical day in the life of an automotive technician
- Being able to talk to the working technician about what is being done and why
- Being able to observe other technicians and seeing the various skill levels that often exist in a shop

Cooperative Education Programs **Cooperative education** programs are formal programs of study at a high school or college where the student attends classes at the school, and also works at a local shop or dealership.

If a cooperative education program is held at the high school level, the work at the shop or dealership occurs during the afternoon or evening and during the summer between the junior and senior year. The most common high school cooperative program is called AYES, which means Automotive Youth Education System (see *www.ayes.org*). The vehicle manufacturers involved in this program include:

- General Motors
- Chrysler
- Toyota
- Honda
- Nissan
- BMW
- Kia
- Subaru
- Hyundai

If the cooperative education program is held at a community college, the work at the dealership occurs around the training sessions, usually the first or second half of a semester or on alternative semesters. The most common college programs include:

- General Motors ASEP (Automotive Service Educational Program) (see *www.gmasepbsep.com*)
- Ford ASSET (Automotive Student Service Educational Program) (see *www.fordasset.com*)
- Chrysler CAP (College Automotive Program) (see *www.chryslercap.com*)
- Toyota T-TEN (Toyota Technician Education Network) (see *www.toyota.com/about/tten/index.html*)

Another factory sponsored program open to those who have already completed a postsecondary automotive program is BMW STEP (Service Technician Education Program) (see *www.bmwusa.com/about/techtraining.htm*).

Apprentice Programs An **apprentice program** involves a beginning service technician working at a shop or dealership during the day and attending training classes in the evening. The key advantage to this type of program is that money is being earned due to full-time employment and getting on-the-job training (OJT) during the day. Often the shop or dealership will help pay for training. While this program usually takes more than two years to complete, the work performed at the shop or dealership usually becomes more technical as the apprentice becomes more knowledgeable and gets more experienced.

Part-Time Employment Working part time in the automotive service industry is an excellent way to get hands-on experience, which makes it easier to relate classroom knowledge to everyday problems and service issues. Working part time gives the student technician some flexibility as to college schedules and provides an income needed for expenses. Often **part-time employment** becomes full-time employment so it is important to keep attending technical classes toward becoming an asset to the company.

DEVELOPING AN EMPLOYMENT PLAN

An employment plan is an evaluation of your skills, interest, and talents. Selecting a career is different than getting a job. A typical job, while it does involve some training, usually can be learned in a few days to several months. However, a career requires many years to achieve competence. Therefore, selecting a career should require a thorough self-examination to determine what your true interest is in a particular career field. Some items that you should enjoy or would be willing and able to learn include:

- Working with your hands, using tools and equipment
- Computer usage, including typing skills
- Working in an area where lifting is often required
- Being able to read, understand, and follow service information, technical service bulletins, and work orders
- Being able to perform diagnostic work and figure out the root cause of a problem

Soft Skills In addition, any career, including being a service technician, requires many people skills, often called **soft skills.** These people-related skills include:

- Working cooperatively with other people
- Communicating effectively with others verbally (speech) and in writing
- Working as a member of a team for the benefit of all
- Being able to work by yourself to achieve a goal or complete a job assignment
- Being able to lead or supervise others
- Willingness to work with others with a different background or country of origin

While it is almost impossible to be able to answer all of these questions, just looking at these items and trying to identify your interests and talents will help in your selection of a career that gives you lifelong satisfaction.

Locating Employment Possibilities Locating where you wish to work is a very important part of your career. Of course, where you would like to work may not have an opening and you may have to work hard to locate a suitable employer. First, try to select a shop or dealership where you think you would like to work because of location, vehicles serviced, or other factors. Ask other technicians who have worked or are presently working there to be sure that the location would meet your needs.

If looking for employment through a want ad in a newspaper or employment Web site, check the following:

- **Job description.** Is this a position that could advance into a more technical position?
- **Tools needed.** Most professional service technician positions require that the technician provide their own tools. (The shop or dealership provides the shop equipment.) Do you have the tools needed to do the job?
- **Hours needed.** Are you available during the hours specified in the ad?
- **Drug testing.** Is a drug test needed for employment and are you prepared to pass?

PREPARING A RESUME

A **resume** is a one-page description of your skills, talents, and education. It is used by prospective employers to help narrow the field of applicants for a job or position. The number one purpose of a resume is to obtain a job interview. A good resume should include the following items:

Personal Information

- Full given name (avoid nicknames)
- Mailing address (do not use a post office (PO) box)
- Telephone and/or cell phone number
- E-mail address
- Avoid using dates which could indicate your age

Educational Information

- Highest education level achieved
- Major, if in a college or in a training program

Experience and Skills

- Work or volunteer experience that may be helpful or useful to an employer. For example, if you took a course in welding, this may be useful to a shop owner who is looking for a service technician who could do welding, even though this fact was not included in the job posting.

- A valid driver's license is a must for most professional service technicians.
- A good driving record. Often the shop insurance company will not allow a shop owner to hire a technician with a poor driving record.

References A **reference** is someone who is willing to tell a possible employer about you, including your skills and talents, as well as your truthfulness and work habits.

Most employers would like to see someone who is familiar with you and your family, such as a priest, minister, or elder in your church. Some teachers or coaches also can be asked to be a reference. Always ask the person for approval before including the person on your list of references. Ask the reference to supply you with a written recommendation. Some references prefer to simply fill out a reference questionnaire sent by many companies. If a reference sends you a written recommendation, have copies made so they can be included with your resume.

Sample Resume

Personal Information:

James Hartman
301 Main Street
City, State 40005
Telephone: (555) 555-0170
Cell: (555) 555-1139

Career Goal:

I want to become a certified ASE master technician and work at a new vehicle dealership.

Experience:

2006 to the present—I work part time (20 hours per week) at Miller Service performing routine vehicle service, including oil changes, tire balancing, brake repairs, timing belt replacement, and intake manifold gasket replacement. I have assisted with suspension and air-conditioning repairs.

Education:

High school diploma from Central High School, City, State 40010. I am finishing a two-year automotive technician training program at City College, City, State 40010 (to be completed May 15).

Additional Training and Certification:

ASE certified in Brakes and Engine Repair.
Attended a seminar on wide-band oxygen sensors and electronic throttle control at a local automotive service exposition.

Other Skills and Interests:

I am restoring a 1969 Chevrolet Camaro, including all mechanical repairs and upgraded suspension system.

References:

Available upon request.

PREPARING A COVER LETTER

When answering an advertisement in a newspaper or magazine, be sure to include the details of where you saw the ad in your cover letter to the employer. For example: "I am applying for the position as an entry-level service technician as published in the August 15 edition of the Daily News."

If the requirements for the position are listed, be sure to include that you do have the specified training and/or experience and the tools needed for the job.

If calling about a position, be sure to state that you are applying for the position posted and ask to speak to the correct person or to the person mentioned in the ad.

Sample Cover Letter

301 Main Street
City, State 40005
Telephone: (555) 555-0170
Cell: (555) 555-1139

Date

Mr. John Smith
Smith Dealership
800 North Street
City, State 40010

Dear Mr. Smith:

I am applying for the position of general service technician at your dealership as advertised in the Sunday, January 7, edition of the Daily News.

I am currently finishing my studies in Automotive Technology at City College and have worked part time at Miller Service for the past two years. I am ASE certified in Brakes and Engine Repair and plan to become certified in all eight areas. I have my own tools and currently can work in the afternoons and evenings. After May 15, I will be able to work full time after completing my automotive courses.

I look forward to an interview when I can discuss my skills and my resume with you. Thank you for your consideration.

Sincerely,

James Hartman

Enclosure (1)

TECH TIP **Always Be Truthful**

No one is smart enough to be a liar. If you say something that is not true, then you have to remember what was said forever or your lie will often be discovered. If asked about your experience or knowledge, try to be as truthful as possible. Facts and skills can be learned and not knowing how to do everything that a shop may be involved with is not an indication that you will be rejected from the job opening.

CONTACTING POTENTIAL EMPLOYERS

When a job opening is posted in a newspaper or it is mentioned by a friend, most experts recommend that you visit the shop or dealership in person to see where the job is located, the condition of the buildings, and the surrounding areas. This trip could also be used for you to submit your resume and cover letter in person unless the company indicates otherwise. Be prepared to be interviewed when submitting your resume. Even if the position has already been filled, the trip gives you experience in meeting people and seeing the shop, which helps increase your confidence during the job search. Searching for a job is a full-time job in itself. Be prepared every day to answer ads and travel to shops or dealerships.

COMPLETING THE EMPLOYMENT APPLICATION

Most businesses require that an employment application be completed because it not only asks for all necessary personal information needed, but also references and emergency contacts. Most employment application forms ask for previous employers, the names and telephone numbers of contact people, and other information which you may not remember. It is wise to have all of the information written down ahead of time and take it with you for reference when completing the application. Always answer questions honestly and as thoroughly as possible. Never lie on an employment application.

THE INTERVIEW

When meeting for the job interview, be sure to dress appropriately for the position. For example, a suit and tie would not be appropriate for an interview for a service technician position. However, the following may be a helpful guide:

- Wear shoes that are not sneakers and be sure they are clean
- Wear slacks, not jeans
- Wear a shirt with a collar
- Do not wear a hat
- Be clean shaven or have beard/mustache neatly trimmed
- Have clean hair
- Avoid facial jewelry

During the interview, try to answer every question honestly. Emphasize what you are capable of providing to the shop including:

- Enthusiasm
- Experience
- Willingness to work
- Willingness to work long hours and/or long weeks

AFTER THE INTERVIEW

After the interview, follow up with a letter thanking the shop for the interview. In the letter include when the interview occurred and that from the information you received, that you are very interested in becoming a part of the organization (shop or dealership). Also include contact information such as your cell phone number and e-mail address so the service manager can easily get in contact with you. A quick review of your skills and talent will also be helpful to the shop owner or service manager.

ACCEPTING EMPLOYMENT

When a job is offered, there will likely be some paperwork that needs to be filled out and decisions made. Some of the requested information could include:

- Social security number (social insurance number in Canada)
- W-4 tax withholding form
- Emergency contact people
- Retirement plan selection (This is usually given to you to study and return at a later date.)
- Other information which may be unique to the shop or dealership

After accepting the employment position, be sure to determine exactly what day and time you should report to work and try to determine where your tools should be placed. Most places will show you around and introduce you to others you will work with.

TECHNICIAN PAY METHODS

Straight-Time Pay Methods When the particular service or repair is not covered or mentioned in a flat-rate guide, it is common practice for the technician to **clock-in** and use the actual time spent on the repair as a basis for payment. The technician uses a flat-rate time ticket and a time clock to record the actual time. Being paid for the actual time spent is often called **straight time** or **clock time.** Difficult engine performance repairs are often calculated using the technician's straight time.

Flat-Rate Pay Methods Beginning service technicians are usually paid by the hour. The hourly rate can vary greatly depending on the experience of the technician and type of work being performed. Most experienced service technicians are paid by a method called **flat-rate.** The flat-rate method of pay is also called **incentive** or **commission pay.** "Flat-rate" means that the technician is paid a set amount of time (flat-rate) for every service operation. The amount of time allocated is published in a flat-rate manual. For example, if a bumper requires replacement, the flat-rate manual may call for 1.0 hour (time is always expressed in tenths of an hour). Each hour has 60 minutes. Each tenth of an hour is 1/10 of 60 or 6 minutes.

0.1 hour = 6 minutes
0.2 hour = 12 minutes
0.3 hour = 18 minutes
0.4 hour = 24 minutes
0.5 hour = 30 minutes
0.6 hour = 36 minutes
0.7 hour = 42 minutes
0.8 hour = 48 minutes
0.9 hour = 54 minutes
1.0 hour = 60 minutes

Many service operations are greater than 1 hour and are expressed as such:

2.4 hours = 2 hours and 24 minutes
3.6 hours = 3 hours and 36 minutes

The service technician would therefore get paid the flat-rate time regardless of how long it actually took to complete the job. Often, the technician can "beat flat-rate" by performing the operation in less time than the published time. It is therefore important that the technician not waste time and work efficiently to get paid the most for a day's work. The technician also has to be careful to perform the service procedure correctly because if the job needs to be done again due to an error, the technician does the repair at no pay. Therefore, the technician needs to be fast and careful at the same time.

The vehicle manufacturer determines the flat-rate for each labor operation by having a team of technicians perform the operation several times. The average of all of these times is often published as the allocated time. The flat-rate method was originally developed to determine a fair and equitable way to pay dealerships for covered warranty repairs. Because the labor rate differs throughout the country, a fixed dollar amount would not be fair compensation. However, if a time could be established for each operation, then the vehicle manufacturer could reimburse the dealership for the set number of hours multiplied by the labor rate approved for that dealership. For example, if the approved labor rate is $60.00 per hour and:

Technician A performed 6.2 hours × $60.00 = $372.00
Technician B performed 4.8 hours × $60.00 = $288.00
The total paid to the dealership by the manufacturer = $660.00

This does not mean that the service technician gets paid $60.00 per hour. Sorry, no! This means that the dealership gets reimbursed for labor at the $60.00 per hour rate. The service technician usually gets paid a lot less than half of the total labor charge.

Depending on the part of the country and the size of the dealership and community, the technician's flat-rate per hour income can vary from $7.00 to $20.00 or more per flat-rate hour. Remember, a high pay rate ($20 for example) does not necessarily mean that the service technician will be earning $800.00 per week (40 hours × $20.00 per hour = $800.00). If the dealership is not busy or it is a slow time of year, maybe the technician will only have the opportunity to "turn" 20 hours per week. So it is not really the pay rate that determines what a technician will earn but rather a combination of all of the following:

- Pay rate
- Number of service repairs performed
- Skill and speed of the service technician
- Type of service work (a routine brake service may be completed faster and easier than a difficult engine performance problem)

A service technician earns more at a busy dealership with a lower pay rate than at a smaller or less busy dealership with a higher pay rate.

PAYROLL DEDUCTIONS

Gross versus Net Compensation Most beginning technicians start by receiving a certain amount of money per hours worked. **Gross** earnings are the total amount you earned during the pay period. The paycheck you receive will be for an amount called **net** earnings. Taxes and deductions that are taken from your paycheck may include all or most of the following:

- **Federal** income **tax**
- **State** income **tax** (not all states)
- Social Security taxes (labeled **FICA,** which stands for Federal Insurance Contribution Act)
- Health/dental/eye insurance deductions
- In addition to the above, uniform costs, savings plan deductions, parts account deductions, as well as weekly payments for tools, may also reduce the amount of your net or "take-home" pay.

TECH TIP **Hourly Rate to Annual Income**

To calculate the amount of income that will be earned using an hourly rate, do the following:

Multiply the hourly rate times 2 and then times 1000.

For example: $10 per hour × 2 × 1000 = $20,000 per year.

This easy-to-use formula assumes working 50 weeks (instead of 52 weeks in the year).

The reverse can also be easily calculated:

Divide the yearly income by 2 and then by 1000 = hourly rate

For example: $36,000 per year ÷ 2 = $18,000 ÷1000 = $18 per hour

Retirement Information and Payments Some shops or dealerships offer some retirement savings plan but the most commonly used is an employer-sponsored 401(k) account named after a section of the U.S. Internal Revenue Code. A 401(k) account allows a worker to save for retirement while deferring taxes on the saved money and earnings until withdrawal. Most 401(k) plans allow the employer to select from stock mutual funds or other investments. A 401(k) retirement plan offers two advantages compared to a simple savings account.

- The contributions (money deposited into the account) are tax deferred. The amount will increase due to interest and no taxes are due until the money is withdrawn.
- Many employers provide matching contributions to your 401(k) account which can range from 0% (no matching contributions) to 100%.

The savings really add up over time. For example, if you start saving at age 25 and your income averages $3,000 per month ($36,000 per year) and you contribute 6% of your pay and the employer contributes 3%, after 40 years at age 65, the account will be worth $1,700,000 (one million, seven hundred thousand dollars) assuming a 10% average return.

In retirement, most experts agree that 4% of the total can be withdrawn each year and not reduce the capital investment. Four percent of $1,700,000 is $68,000 per year or over $5,600 per month every month for the rest of your life.

Additional Service Technician Benefits Many larger dealerships and service facilities often offer some or all of the following:

- Paid uniforms/cleaning
- Vacation time
- Update training (especially new vehicle dealerships)
- Some sort of retirement (usually a contributing 401(k)) program
- Health and dental insurance (usually not fully paid)
- Discounts on parts and vehicles purchased at the dealership or shop

Not all service facilities offer all of these additional benefits.

HOUSING AND LIVING EXPENSES

As a general guideline, **housing expenses** such as rent or a mortgage payment should not exceed 30% of the gross monthly income. For example,

FREQUENTLY ASKED QUESTION ???

Where Does All the Money Go?

Money earned does seem to quickly disappear. For example, if a soft drink and a bag of chips were purchased every day at work for $2.50, this amounts to $12.50 per week or $50 per month, which is $600 per year. Use the following chart to see where the money goes.

Income

Labor rate per hour × number of hours worked = _____
Overtime pay, if applicable = _____
Part-time work on weekends = _____
TOTAL WEEKLY INCOME = _____
Multiply by 4.3 to get the **MONTHLY INCOME** = _____

Monthly Expenses

Car/truck payment = _____
Rent/mortgage = _____
Gasoline = _____
Food (groceries) = _____
Fast food or restaurants = _____
Heat and electric (heat/air conditioning) = _____
Water and sewer = _____
Telephone (cell) = _____
Cable TV/Internet access = _____
Clothing (including cleaning) = _____
Credit card payment = _____
TOTAL MONTHLY EXPENSES = _____

Hopefully, the total income is more than the total expenses!

Ten dollars per hour times 40 hours per week = $400 per week times 4 weeks in a month = $1600 per month. Thirty percent of $1600 is $480 per month for rent or a mortgage payment.

FREQUENTLY ASKED QUESTION ???

Employee or Contract Labor?

Most shops and dealerships hire service technicians as employees. However, some shops or businesses will pay a technician for services performed on a contract basis. This means that they are not hiring you as an employee, but simply paying for a service similar to having a plumber repair a toilet. The plumber is performing a service and is paid for the job rather than as an employee of the shop. An employer/employee relationship exists if the shop meets two factors.

1. **Direction**—This means that the employer can direct the technician to report to work to perform service work.
2. **Control**—This means that the employer can direct the hours and days when the work is to be performed and at the employer's location.

A contract labor association exists if the repairs are performed without both direction and control of the shop.

If a contract labor basis is established, then no taxes are withheld. It is then the responsibility of the technician to make the necessary and required general tax payments and pay all taxes on time.

A vehicle payment should not exceed 25% of the gross earnings. In the example where the pay was $10 per hour, the maximum recommended vehicle payment should be $400 per month.

BECOMING A SHOP OWNER

Many service technicians want to start and operate their own shop. Becoming a shop owner results in handling many non-automotive related duties that some technicians do not feel qualified to handle, including:

- Handling customers
- Ordering and paying for shop equipment and supplies
- Bookkeeping, including payroll
- Budgeting for and paying for garage owner's insurance and workers' compensation
- Paying rent, as well as heat/air-conditioning bills
- Advertising expenses
- Hiring and firing employees

TECH TIP ✓ Find Three Key People

An **entrepreneur** is a person who organizes and manages their own business assuming the risk for the sake of a profit. Many service technicians have the desire to own their own repair facility. The wise business owner (entrepreneur) seeks the advice of the following people when starting and operating their own business.

1. **Attorney (lawyer)**—This professional will help guide you to make sure that your employees and your customers are protected by the laws of your community, state, and federal regulations.
2. **Accountant**—This professional will help you with the journals and records that must be kept by all businesses and to help with elements such as payroll taxes, unemployment taxes, and workmen's compensation that all businesses have to pay.
3. **Insurance Agent**—This professional will help you select the coverage needed to protect you and your business from major losses.

SUMMARY

1. When applying for a job, list in your cover letter where you saw the opening and also mention that you meet all of the requirements for the position.
2. A resume is a brief description of your education and experience.
3. Present a professional appearance during an interview.
4. Net pay is gross pay minus all deductions, such as federal taxes and FICA.
5. Housing and vehicle payments each should not exceed 25% of your monthly income.
6. Becoming a shop owner involves more paperwork than most service technicians realize.

REVIEW QUESTIONS

1. What facts should be included on the resume?
2. What are five interviewing tips?
3. What is the difference between gross pay and net pay?
4. What taxes are usually withheld from a paycheck?
5. What are five duties of a shop owner?

CHAPTER QUIZ

1. A resume should be how many pages long?
   a. 1
   b. 2
   c. 3
   d. 4 or more
2. What personal information should *not* be included on the resume?
   a. Address
   b. Cell or telephone number
   c. Age
   d. Work experience
3. Why is having a good driving record good for the shop?
   a. Allows the use of a company vehicle
   b. Lowers insurance costs
   c. Allows you to drive customers' vehicles
   d. Permits you to use your vehicle to get parts
4. Which is *not* recommended during an interview?
   a. Wear shoes that are not sneakers
   b. Wear a shirt with a collar
   c. Have clean hair
   d. Wear jeans
5. During an interview, try to _____.
   a. Show enthusiasm
   b. Explain your work experience
   c. State your willingness to work
   d. All of the above
6. Ten dollars per hour is about how much income per year?
   a. $20,000
   b. $25,000
   c. $30,000
   d. $35,000
7. One of the deductions from a paycheck is for Social Security. This item is usually shown on the pay stub as _____.
   a. Social Security
   b. SSA
   c. FICA
   d. U.S. government deduction
8. Technician A says that the net pay amount is usually higher than the gross pay amount. Technician B says that the gross pay amount is usually higher than the net pay. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A beginning service technician earns $400 per week. How much should the technician spend on apartment rent?
   a. $400 per month
   b. $500 per month
   c. $800 per month
   d. $1000 per month
10. Which activity does not allow a person to perform any work while at the shop?
    a. Cooperative education program
    b. Apprenticeship program
    c. Job shadowing
    d. Part-time employment

CHAPTER 4 Working as a Professional Service Technician

OBJECTIVES: After studying Chapter 4, the reader will be able to: Discuss how to start a new job. • Describe the advantages of having a mentor. • Explain how a mentor can improve on-the-job learning. • Discuss the role of the trainee with a mentor. • Explain formal and informal evaluations. • Describe the role of a service technician. • Explain how the flat-rate pay plan works. • Describe the type and pricing of parts.

KEY TERMS: advisor • advocate • aftermarket parts • coach • core • core charge • counselor • critical thinking • customer pay (CP) • flagging • formal evaluation • informal evaluation • jobber • mentor • original equipment (OE) • rebuilt • remove and inspect (R & I) • remove and replace (R & R) • renewal parts • repair order (RO) • role model • service bay • stall • teacher • three Cs (concern, cause, correction) • trainee • warehouse distributor

PROFESSIONALISM

Professionalism and personal credibility are important and can determine success as a service technician or as a customer service provider. A true professional does the following on a regular basis.

1. **Practice consistency.** Be positive, professional, and warm at all times.
2. **Keep your word.** Follow through with the commitments that you make. People will not have faith in you if you break your promises.
3. **Develop technical expertise.** Become very knowledgeable about the vehicles being serviced. Attend regular update training classes to keep up with the latest technical information and equipment.
4. **Become a teammate with your co-workers.** Working successfully with others shows that you have common goals and can benefit from the specific skills of others.
5. **Apologize if you are wrong.** Practice honesty all of the time.

TECH TIP ✓ Clean Clothes Are a Must

Anyone who meets the public in any business must not only be dressed appropriately, but the clothing should be clean. Also be sure that leather shoes have been shined. Dull, dirty, or scuffed shoes or messy appearance reflects an unprofessional look.

Ethics Ethics are a set of principles that govern the conduct of an individual or group. Sometimes ethical decisions are easy to recognize and are perceived as popular choices of behavior by the people around us. At other times the spectrum of potential choices falls into gray areas in which the "right" or "wrong" course of action is difficult or nearly impossible to identify. When faced with an ethically challenging situation, ask yourself the following questions:

- Is it legal? (Is it against local, state, or federal laws?)
- Is it fair? (Is it harmful to me or to others?)
- How do I feel about it? (Is it against the teachings of my parents or my religion?)
- Would the court of public opinion find my behavior incorrect? (Would it disappoint my family?)
- Am I fearful of what those I trust would say about my actions? (Would I be hurt or upset if someone did this to me?)

The above questions can be quite revealing when attempting to choose an ethical course of action.

COMMUNICATIONS

The five main methods of communication used in effective customer service interaction include listening, talking, nonverbal communications, reading, and writing.

Listening Active listening is the ability to hear and understand what the speaker is saying. To listen to your customers or other technicians is to show them that you care about and respect their questions and concerns. It is not easy to be a good listener; it takes practice and dedication to improve your listening techniques. Listening is a skill that must continuously be developed.

Several barriers to good listening exist. A listener may be distracted from what is being said, have a closed mind to the speaker and the message, won't stop talking, or is lazy and unwilling to make the commitment to be a good listener.

Listening requires the listener to stop talking and to hear what the speaker is saying. It has been said that humans were given two ears and one mouth because we are supposed to listen twice as much as we speak. The best way to keep your mind focused on the speaker and to avoid becoming distracted is to pay attention. We can think about 10 times faster than we can speak, so frequently we have processed what speakers have said and are waiting for them to catch up with us. By focusing on speakers and on what is being said we are less likely to miss the messages being delivered. Putting that into practice is not as easy as it sounds.

A good listener does the following:

- Focuses on the speaker and what is being said.
- Looks at the speaker and makes eye contact when possible.
- Listens with an open mind.
- Rephrases what was said to clarify that the intended message is understood.
- A good listener knows the joy of sharing and communicating with others. Work to become the best listener you can be.

Talking Talking means speaking, using words and terminology that others can comprehend. Eye contact is always important when we are communicating with others. Eye contact is allowing our eyes to make visual contact with someone else's. In our culture, eye contact conveys sincerity and interest. Avoiding eye contact may suggest a lack of concern or lack of honesty. Customers may perceive that a customer service provider is not interested in what they are saying if they do not periodically make eye contact with the customer.

When dealing with people from other cultures, customer service providers should be aware of cultural differences. In many other cultures eye avoidance is a sign of respect. Be sensitive to others but use eye contact whenever possible.

TECH TIP ✓ **Never Use Profanity**

Regardless of the situation, a true professional never resorts to the use of profanity. If tensions are high and the discussion becomes heated, try to defuse the situation by turning the situation over to someone else.

Nonverbal Communication The tone and inflection of the voice, facial expressions, posture, and eye contact are all forms of nonverbal communications. These nonverbal indicators can contradict the message conveyed through another method of communication.

Nonverbal communication includes body posture such as having the arms crossed. When a person crosses their arms, or looks at other things rather than paying attention to what you are discussing, these actions could indicate one of several things including:

1. They are not interested in what you are saying
2. They don't believe what you are saying
3. They are not listening

If this type of nonverbal communication is noticed, there are several things that could be done to overcome this barrier including:

1. Ask questions, which would require them to pay attention plus it shows that you are interested in what they think.
2. Give the customer options rather than just ask them what they want such as saying "would you prefer to have this work done all at the same time or spread out over several weeks?"

Telephone Communication A large percentage of customers make first contact with a shop or dealer service department by telephone. Service technicians normally do not talk to customers directly but may be asked to help clarify a repair or a service procedure.

Some suggestions when talking on the telephone include:

- Use proper titles for the people with whom you communicate. If in doubt about whether to use a first name, call the person by the more formal *Mr.* or *Ms.* If they prefer the more informal first name, they will say so. It is better to be a little too formal than overly familiar.
- Thank people for calling. "Thank you" is the most powerful phrase in human relations and it reassures customers that you are interested in serving.
- Try to avoid technical terms and abbreviations such as EGR and other terms commonly used in the trade but will not be understood by the customer. Try to phrase the technical description by saying that you replaced or serviced a part in the emission control system and include the entire name of the part such as the "exhaust gas recirculation valve."
- Keep your comments positive and focused toward solving the problem or concern.
- Avoid saying anything that makes people or your shop look unprofessional or uncaring. When dealing with customers, some words are more positive and appropriate to use. Some customer service providers find it helpful to list words to use and words to avoid on a card so that it is available for easy reference.
- Speak clearly and distinctly. Hold the telephone mouthpiece about a half-inch from your lips. Speak naturally and comfortably. Talk to your caller as you would to a friend.

TECH TIP ✓ **Always Have Paper and a Pen Within Reach on the Telephone**

When talking to a customer, whether in person or on the telephone, have paper and a pencil or pen to record the necessary information. In this case, the customer service representative at a Saturn dealer is using a preprinted form to record the service procedures to be performed on a customer's vehicle. See Figure 4–1.



Figure 4–1 When answering the telephone, be sure to have paper and pen or pencil handy to record the customer information.

TECH TIP ✓ **Smile While You Talk**

If you smile while talking on the telephone, your voice will reflect a positive and helpful attitude, which customers or vendors will easily recognize over the telephone. See Figure 4–2.



Figure 4–2 If you smile while talking on the telephone, your attitude will be transmitted to the customer.

Writing Writing is communicating by using the written word so that others can understand the intended message. Service technicians are required to document the work that was performed on a vehicle. For some technicians this is the most difficult part of the service. Writing or typing in the description of the steps performed during the diagnosis and repair of the vehicle should be worded as if the technician is talking to the customer. For example, if a coolant leak

was repaired by replacing the water pump the technician should write out the following steps and operations on the work order:

1. Visually verified coolant leaking.
2. Performed a pressure test of the cooling system and located the leak as coming from the water pump.
3. Replaced the water pump and added new coolant and bled the system of trapped air.
4. Pressure tested the cooling system to verify that the leak was corrected—no leaks found.

TECH TIP ✓ **Use Internet Translation**

If the customer is non-English speaking, type the information into a text document and search for a translation on the Internet. Give the copy of the translated document to the customer. The customer request could also be translated into English if needed to help the shop understand exactly what the customer is requesting and needs.

Reading Reading means the ability to read and comprehend the written word. All service technicians need to be able to read, understand, and follow written instructions and repair procedures. If some words are not understood use a dictionary or ask another technician for help. For example, a beginning technician read in the service information that the wiring connector was "adjacent to the coolant reservoir." The technician did not understand what the word adjacent meant and found out from another technician that it meant "next or close to."

If reading a note from a customer in another language you do not understand try to ask if someone else in the shop can read it for you.

TECH TIP ✓ **Google Is Your Friend**

If unsure as to how something works or if you need more detailed information about something, go to www.google.com® and search for the topic. Using the Internet can help with locating hard-to-find facts and can even be used to help with a service procedure that you have not done before. For a link to all factory service information, go to the Web site of National Automotive Service Task Force at www.nastf.org. Look at the work scheduled for the next day and try to determine as much about the job as possible so you can be prepared the next day to tackle the procedure. Using the International Automotive Technicians Network at www.iatn.net is also very helpful for technical information and can help pin down hard-to-find problems.

WHAT HAPPENS THE FIRST DAY?

The first day on the job, someone, usually the shop owner or shop foreman, should:

- Introduce the new technician to key people at the shop.
- Show the new technician the facility, parking, rules, and regulations of the organization.
- Establish the new technician's work area.
- Ask questions of the new technician regarding their skills and talents.

After each training session, the shop owner or foreman should:

- Review the training tasks that were completed in school.
- Try to direct work to the new technician that covers the new training material.

The first day on the job the beginning technician should:

- Smile and ask questions if needed to clarify procedures and regulations.
- Be prepared to take and pass a drug test.
- Assure the service manager or shop owner that you are serious about a career as an automotive technician.

TECH TIP ✓ **Don't Touch Other Technician's Tools**

A beginning technician seldom has all of the tools needed to perform all of the service and repair tasks. However, a technician's tools are very important and if a tool is needed, the beginning technician should ask to borrow the tool and be sure to show where the tool was returned and in clean condition.

A work order, also called a **repair order** or **RO** is assigned to a technician who is best qualified to perform the work. The technician gets the keys and drives the vehicle to an assigned **service bay** (also called a **stall**), gets the necessary parts from the parts department, and completes the repair.

After the service work has been performed, the service technician should then fill out the work order and describe what work was performed. These are called the **"three Cs."**

1. **Concern**—Write on the work order what was done to confirm the customer's concern. For example, "Drove the vehicle at highway speed and verified a vibration."
2. **Cause**—The service technician should write the cause of the problem. For example, "Used a scan tool and discovered that cylinder #3 was misfiring."
3. **Correction**—The service technician should write what was done to correct the problem. For example, "Removed the spark plug wire from cylinder number three and by visual inspection found that the boot had been arcing to the cylinder head. Replaced the spark plug wire and verified that the misfire was corrected."

TECH TIP ✓ **Regulated Terms to Use**

In some states or areas where automotive service is regulated, such as in California or Michigan, it is important that the term used to describe a labor operation is the term defined by the state agency. This means that some terms used in parts and time guides may not be the same terms used by the state. Always check that the terms used are in compliance with all regulations. Some terms that could be affected include rebuild, repair, overhaul, inspection and R & R (remove and replace), and safety inspection.

TECH TIP ✓ **If Late—Call**

You may know you will only be a few minutes late to work, but your boss does not know that when you are not there on time. If you are going to be late, even by a few minutes, call the shop and let them know. This does not eliminate your being late from your record, but it does show correctly to your service manager and other technicians who are counting on your being on time to work every day that you do care.

DUTIES OF A SERVICE TECHNICIAN

Reading the Work Order A work order is selected or assigned to a service technician who then performs the listed tasks. The work order should be written so that the technician knows exactly what needs to be done. However, if there is any doubt, the technician should clarify the needed task with the service advisor or the person who spoke to the customer.

TECH TIP ✓ **Ask Me about This**

A good service advisor will document what the customer wants done on the work order. However, there are times when the explanation and description would take too long and too much space to be practical. In these cases, the wise service advisor simply states on the work order for the service technician to see the service advisor to discuss the situation. The service advisor can write the basic request to document what is needed.

Talking to Customers The typical service technician usually does not talk directly to a customer. However, there may be cases where the technician will be asked to clarify a procedure or repair to a customer. Many technicians do not like to talk to the customers and fear that they may say too much or not enough. If a technician is asked to talk to a customer, try to keep the discussion to the following without being too technical.

- **Concern (customer complaint).** The service technician should repeat the original concern. This is to simply verify to the customer and the technician the goal of the service or repair.
- **Cause.** The cause of the fault should be mentioned. If further diagnostic steps needed to find the cause are requested, discuss the steps followed and the equipment or tools used.
- **Correction.** Discuss what was done to solve the concern, including what part or parts were replaced. This step may also include what other service operations were needed to complete the repair, such as reprogramming the computer.

NOTE: If the customer speaks a foreign language that you do not understand, excuse yourself and locate someone in the shop who can assist you with communicating with the customer. Avoid using slang or abbreviation of technical terms. Ask the person if they understand and be willing to restate, if needed, until the situation is understood. This can often be difficult if discussing technical situations to persons of another language or culture.

TECH TIP ✓ **Car, Truck, or Vehicle?**

When discussing a vehicle with a customer, it is best to avoid creating problems. For example, if a technician asked about a customer's "car," the customer could become concerned because they drive a truck and many owners of trucks do not want their vehicle called a car. Use of the term "vehicle," a generic term, is often recommended when talking to customers to avoid possible concerns.

Estimating a Repair Sometimes a service technician is asked to help create an estimate for the customer. It is usually the responsibility of the service advisor or shop owner to create estimates. The technician may be helpful by pointing out all of the needed operations that need to be performed to achieve a repair. The estimate for a repair includes:

- **Parts needed**—This list would also include any gaskets and/or supplies needed. The technician can help identify if extra supplies may be needed.
- **Labor**—A published time guide is usually used but many vehicle options such as rear air conditioning or four-wheel drive may add substantial time to the operation. The technician can help verify the estimate by making sure that the options are pointed out to the service advisor or shop owner.

Documenting the Work Order The service technician must document the work order. This means that the service technician must write (or type) what all was done to the vehicle. The documentation is often called "telling the story" and should include the following:

- The test equipment used to diagnose the problem. For example: Used a Tech 2 scan tool to retrieve P0300 random misfire diagnostic trouble code.
- Used a digital multimeter to determine a spark plug wire was defective.
- List what parts or service operations were performed. For example: Replaced the spark plug wire on cylinder number 3. Used a scan tool to clear the diagnostic trouble codes and verify that the engine is operating correctly.

Following Recommended Procedures All service technicians should follow the diagnostic and service procedures specified by the vehicle manufacturer. Following service information procedures includes the following:

- Follow and document the diagnostic procedure. Writing down the test results helps the customer see all that was involved in the procedure and monitors the proper paper trail for future reference, if needed.
- Follow the recommended removal and reinstallation (R & R) procedures. This step helps prevent the possibility of doing harm to the vehicle if an alternative method is attempted.
- Always torque fasteners to factory specifications. This step is very important because under-or overtightened fasteners can cause problems that were not present until after the repair. The wise technician will document torque specifications on the work order.

Customer Pay Customer pay (CP) means that the customer will be paying for the service work at a dealership rather than the warranty. Often the same factory flat-rate number of hours is used to calculate the technician's pay, but customer pay often pays the service technician at a higher rate. For example, a service technician earning $15.00 per flat-rate hour for warranty work may be paid $18.00 per hour for customer-pay work. Obviously, service technicians prefer to work on vehicles that require customer-pay service work rather than factory-warranty service work.

FREQUENTLY ASKED QUESTION ???

What Can a Service Technician Do to Earn More Money?

Because service technicians are paid on a commission basis (flat-rate), the more work that is completed, the more hours the technician can "turn." Therefore, to earn the most money, the service technician could do the following to increase the amount of work performed:

- Keep up-to-date and learn the latest technical information
- Practice good habits that help avoid errors or incomplete repairs
- Learn from experienced and successful fellow technicians and try to approach the repair the same way the successful technician does
- Purchase the proper tools to do the work efficiently

NOTE: This does not mean that every technician needs to purchase all possible tools. Purchase only those tools that you know you will need and use.

Nondealership, Flat-Rate Technicians who work for independent service facilities or at other nondealership locations use one or both of the following to set rates of pay:

- Mitchell Parts and Time Guide
- Motors Parts and Time Guide
- Chilton Labor Time Guide

These guides contain service operation and flat-rate times. Generally, these are about 20% higher (longer) than those specified by the factory flat-rate to compensate for rust or corrosion and other factors of time and mileage that often lengthen the time necessary to complete a repair. Again, the service technician is usually paid a dollar amount per flat-rate hour based on one of these aftermarket flat-rate guides. The guides also provide a list price for the parts for each vehicle. This information allows the service advisor to accurately estimate the total cost of the repair.

TECH TIP ✓ **Technician Skill Level and Severe Service**

Most aftermarket service information includes a guideline for the relative level of the technician's skill required to perform the listed service procedures. These include:

A = Highly skilled and experienced technician

B = Skilled technician who is capable of performing diagnosis of vehicle systems

C = Semi-skilled technician who is capable of performing routine service work without direct supervision

Many time guides provide additional time for vehicles that may be excessively rusted due to climate conditions or have been subjected to abuse. Be sure to quote the higher rate if any of these conditions are present on the customer's vehicle. See Figure 4–3.

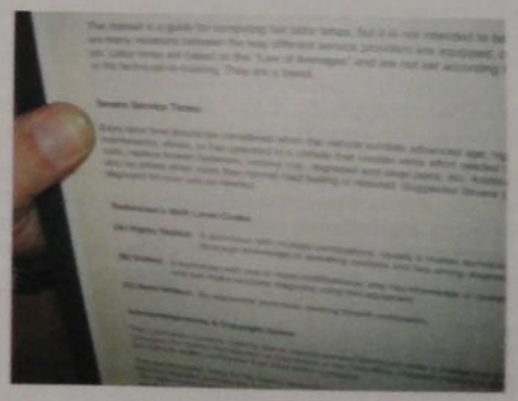


Figure 4–3 Note the skill levels of the technician and the extra time that should be added if work is being performed on a vehicle that has excessive rust or other factors as stated in the time guide.

FLAGGING A WORK ORDER

When a service technician completes a service procedure or repair, a sticker is completed indicating the following:

- Technician number (number rather than a name is often used not only to shorten the identification but also to shield the actual identity of the technician from the customer)

- Work order number
- Amount of time allocated to the repair expressed in hours and tenths of an hour

The application of the service technician's sticker to the back of the work order is often called **flagging the work order.**

NOTE: The actual assignment of the time is often done by another person at the dealership or service facility. This procedure assures that the correct number of hours is posted to the work order and to the technician's ticket.

SUBLET REPAIRS

Often a repair (or a part of a repair) is performed by another person or company outside of the dealership or service facility. For example, an engine needing repair that also has a defective or leaking radiator would be repaired by the original repair facility, but the radiator may be sent to a specialty radiator repair shop. The radiator repair cost is then entered on the work order as a sublet repair.

PARTS REPLACEMENT

Parts replacement is often called **R & R,** meaning **remove and replace.**

NOTE: R & R can also mean **remove and repair,** but this meaning is generally not used as much now as it used to be when components such as starters and air-conditioning compressors were repaired rather than replaced as an assembly.

R & I is often used to indicate **remove and inspect** to check a component for damage. The old replaced part is often returned for remanufacturing and is called a **core.** A **core charge** is often charged by parts stores when a new (or remanufactured) part is purchased. This core charge usually represents the value of the old component. Because it is needed by the remanufacturer as a starting point for the remanufacturing process, the core charge is also an incentive to return the old part for credit (or refund) of the core charge.

Original Equipment Parts Parts at a new vehicle dealership come either directly from the vehicle manufacturer or a regional dealership. If one dealership purchases from another dealership, the cost of the part is higher, but no waiting is required. If a dealership orders a part from the manufacturer directly, the cost is lower, but there is often a 7- to 10-day waiting period. **Original equipment** parts, abbreviated **OE,** are generally of the highest quality because they have to meet performance and durability standards not required of replacement parts manufacturers.

NOTE: Many service technicians will use only OE parts for certain critical systems such as fuel injection and ignition system components because, in their experience, even though the price is often higher, the extra quality seems to be worth the cost not only to the owner of the vehicle but also to the service technician who does not have to worry about having to replace the same part twice.

Aftermarket Parts Parts manufactured to be sold for use after the vehicle is made are often referred to as **aftermarket parts** or **renewal parts.** Most aftermarket parts are sold at automotive parts stores or **jobbers.** A jobber or parts retailer usually gets parts from a large regional **warehouse distributor.** The warehouse distributor can either purchase parts directly from the manufacturer or from an even larger central warehouse. Because each business needs to make a profit (typically, 35%), the cost to the end user may not be lower than it is for the same part purchased at a dealership (two-step process instead of the typical three-step process) even though it costs more to manufacture the original equipment part. To determine what a 35% margin increase is for any product, simply divide the cost by 0.65. To illustrate how this works, compare the end cost of a part (part A) from a dealership and a parts store.

Retail Parts Store	New Vehicle Dealership
Manufacturer's selling price = $17.00	Manufacturer's selling price = $25.00
Warehouse distributor's selling price = $26.15 ($17.00 ÷ 0.65 = $26.15)	Parts department selling price = $38.46 ($25.00 ÷ 0.65 = $38.46)
Retail store selling price = $40.23 ($26.15 ÷ 0.65 = $40.23)	

NOTE: The cost of the part to the customer where service work is performed is increased about 35% over the base cost of the part. For example, a part that cost the repair facility $40.23 will be billed to the customer at about $61.00. The retail service customer at the dealer may pay $59.17 ($38.46 ÷ 0.65 = $59.17).

New versus Remanufactured Parts New parts are manufactured from raw materials and have never been used on a vehicle. A remanufactured component (also called **rebuilt**) has been used on a vehicle until the component wore out or failed. A remanufacturer totally disassembles the component, cleans, machines, and performs all the necessary steps to restore the part to a "like new" look and function. If properly remanufactured, the component can be expected to deliver the same length of service as a new component part.

The cost of a remanufactured component is often less than the cost of a new part.

CAUTION: Do not always assume that a remanufactured component is less expensive than a new component. Due to the three-step distribution process, the final cost to the end user (you) may be close to the same!

Used Parts Used parts offer another alternative to either new or remanufactured parts. The cost of a used component is typically one-half the cost of the component if purchased new. Wrecking and salvage yards use a Hollander manual that lists original equipment part numbers and cost and cross-references them to other parts that are the same.

WORKING WITH A MENTOR

A mentor is a person at the job site who helps the beginning service technician, also called the **trainee.** The word **mentor** comes from Greek mythology. In Homer's *The Odyssey,* Mentor was the faithful companion and friend of Ulysses (Odysseus), the King of Ithaca. Before Ulysses went to the Trojan Wars, he instructed Mentor to stay and take full charge of the royal household. This meant that Mentor had to be father figure, teacher, role model, counselor, trusted advisor, challenger, and encourager to the King's son in order that he become a wise and good ruler.

Therefore, a good definition of a mentor would be, "A highly qualified individual who is entrusted with the protection and development of the young."

A mentor therefore fulfills many roles, such as:

- **Teacher**—helps teach information and procedures
- **Coach**—has trainee practice service procedures
- **Counselor**—concerned about, but not trained to offer advice
- **Advisor**—helps with career-type decisions, such as what tools are needed
- **Advocate** (stands up for the trainee)—represents and helps the trainee's concerns be expressed to others
- **Role model**—presents a positive role model every day

Qualifications of a Good Mentor A good mentor should be assigned to a new technician. Qualifications of a good mentor include:

- **Trade proficiency**—The person selected should be a highly skilled technician.
- Good coaching/mentoring skills and techniques—The mentor has to have patience and be willing to help the trainee by explaining each step needed to complete a service procedure.
- **Leadership/role model**—The mentor should take pride in being a professional service technician and have high ethical and professional standards.

Mentoring a trainee can be frustrating for an experienced technician. This occurs because the mentor needs to verify almost everything the trainee does until satisfied that competence has been achieved. Even very basic procedures need to be watched, such as hoisting the vehicle, changing the oil and oil filter, plus many other operations. As a result, the time taken to help the beginning technician will reduce the efficiency, and therefore, the pay of the mentor. However, after several weeks, the trainee can start helping the mentor, thereby increasing efficiency.

TECH TIP ✔ **Work Habit Hints**

The following statements reflect the expectations of service managers or shop owners for their technicians:

1. Report to work every day on time. Being several minutes early every day is an easy way to show your service manager and fellow technicians that you are serious about your job and career.
2. If you *must* be late or absent, call your service manager as soon as possible.
3. Keep busy. If not assigned to a specific job, ask what activities the service manager or supervisor wants you to do.
4. Report any mistakes or accidents *immediately* to your supervisor or team leader. *Never* allow a customer to be the first to discover a mistake.
5. Never lie to your employer or to a customer.
6. Always return any borrowed tools as soon as you are done with them and in *clean* condition. *Show* the person you borrowed the tools from that you are returning them to the toolbox or workbench.
7. Keep your work area neat and orderly.
8. Always use fender covers when working under the hood.
9. Double-check your work to be sure that everything is correct.
   a. Remember: "If you are forcing something, you are probably doing something wrong."
   b. Ask for help if unclear as to what to do or how to do it.
10. Do not smoke in a customer's vehicle.
11. Avoid profanity.
12. DO NOT TOUCH THE RADIO! If the radio is turned on and prevents you from hearing noises, turn the volume down. Try to return the vehicle to the owner with the radio at the same volume as originally set.

NOTE: Some shops have a policy that requires employees to turn the radio off.

13. Keep yourself neatly groomed including:
    a. Shirttail tucked into pants (unless shirt is designed to be worn outside)
    b. Daily bathing and use of deodorant
    c. Clean hair, regular haircuts, and hair tied back if long
    d. Men: daily shave or keep beard and/or mustache neatly trimmed
    e. Women: makeup and jewelry kept to a minimum

TECH TIP ✔ **Adhere to the Times**

When starting a new job at a shop or dealership, be sure to ask about the following:

- *What time should I arrive at work?* This may be different than the scheduled work starting time. For example, the work day could start at 8 a.m. but the shop owner or service manager may want all technicians to arrive and start to get ready to work at 7:50 a.m.
- *When is break time?* Breaks may or may not be regularly scheduled and it is important for the beginning technician to know and adhere to break times.
- *When is lunch time?* In some busy shops, the lunch period is staggered to be sure that some technicians are always available for work. Always be willing to adhere to the requested lunch period.

TEAMWORK

Team Building A team is a group of individuals working together to achieve a common goal. Even shops or service departments that do not use a team system with a group of technicians is still a team. All members of the service department are really part of a team effort working together to achieve efficient vehicle service and customer satisfaction. The key to building a team that works together is selecting employees that are willing to work together. While the shop owner or service manager at a dealership has hiring authority, every technician should consider what is best for the entire group to help increase repeat business and satisfied customers.

Leadership Roles As a technician gains experience, he or she often asks for guidance, not only for technical answers, but also for how to handle other issues in the shop, such as paperwork, use of aftermarket parts, and other issues. Therefore, the more experience the technician has, the more likely he or she will be placed in a leadership and role model position.

ADVANCEMENT SKILLS

The job of a service technician becomes more valuable to the shop or dealership if work can be accomplished quickly and without any mistakes. Therefore, being careful to avoid errors is the first consideration for any service technician. Then, with experience, the speed of accomplishing tasks can and will increase.

More than speed is needed to become a master technician. It requires problem solving and critical thinking skills, too. While beginning technicians are usually not required to diagnose problems,

troubleshooting skills are very important toward becoming a master technician. Most master technicians follow a plan which includes:

1. Always verify the customer concern.
2. Perform a thorough visual inspection and check for possible causes of the problem, including damage from road debris or accidents.
3. Use a scan tool and check for stored diagnostic trouble codes (DTCs).
4. Check service information for technical service bulletins (TSBs).
5. Check service information and follow all diagnostic trouble charts.
6. Locate and correct the root cause of the problem.
7. Verify the repair and document the work order.

The hardest part of the diagnostic process is to locate the root cause of the problem. The process of analyzing and evaluating information and making a conclusion is called **critical thinking.**

HOUSEKEEPING DUTIES

A professional service technician is usually responsible for keeping his or her work area clean and tidy. Good housekeeping includes all of the following:

- **Clean floor**—If coolant or oil is spilled on the floor during a repair procedure, it should be cleaned before starting another job.
- **Items kept off the floor**—It is easy to allow parts and other items to be stored in and around the toolbox and in corners. However, having items on the floor makes keeping the area clean and neat looking very difficult.

TECH TIP ✓ **Keeping "Things" off the Floor**

To make cleaning easier and for a more professional shop appearance, keep only those items on the floor that have to be on the floor and find a place off the floor for all other items.

- **Keep areas around exits and fire extinguishers clear.** Do not store or place parts, boxes, or shop equipment, such as floor jacks and testers, near exits and fire extinguishers. This helps ensure that people can have easy access to exits or the fire extinguishers in the event of an emergency.
- **Avoid spraying chemicals in the air.** To help keep the air in the shop clean, keep the use of spray chemicals, such as brake cleaner, to a minimum and avoid spraying where it could result in affecting the air others breathe.

SELF-MANAGEMENT

A professional service technician should try to maintain a professional appearance at all times. For example, if coolant or automatic transmission fluid (ATF) gets onto a shirt or pants, the wise technician would change into a clean uniform before working on another vehicle. Many shop owners and service managers recommend that shirttails always be tucked into pants to ensure a more professional appearance.

TECH TIP ✓ **Look at the Shop from a Customer's Point of View**

To determine if the shop and other technicians look professional, step outside and enter the shop through the same door as a customer. Now look around. Look at the shop and the other technicians. Does the shop give the appearance of a professional service facility? If not, try to improve the look by asking the shop owner or service manager to do the same thing in an attempt to create a more professional looking shop.

TECH TIP ✓ **Write It Down**

If a technician needs to have another technician finish a repair due to illness or some other reason, be sure to write down exactly what was done and what needs to be done. Verbal communication, while very effective, is often not a good way to explain multiple steps or processes. For example, the other technician could easily forget that the oil had not yet been added to the engine, which could cause a serious problem if the engine were to be started. If in doubt, write it down.

JOB EVALUATION

In most jobs, there is an evaluation of performance. A beginning technician is not expected to perform at the same level as an experienced master technician but should be able to do the following:

- **Follow instructions.** The trainee should follow the instructions of the mentor or service manager. This includes making sure that the person is notified when the job has been completed and if there were any problems.
- **Do no harm.** Avoid exerting a lot of force to door panels or other components to help avoid breaking clips or components. Always use the right tool for the job. For example, never use pliers to remove a bolt or nut, which could round off the flats of the fastener. Always think before acting, "Am I going to hurt something by doing this?"
- **Keep a neat and clean appearance.** It is normal to get dirty while performing service work on a vehicle. However, after each job is completed or even during the repair, try to keep as clean as possible.
- **Ask that your work be checked.** Even though the trainee thinks that the service or repair was done correctly, until confidence has been established, it is wise to ask to have all work double-checked.

CAUTION: Never allow a mistake to reach the customer. It is only a problem if it cannot be corrected.

Formal Evaluation The mentor and/or service manager may or may not conduct a written evaluation on a regular basis. If a written evaluation is performed, this is called a **formal evaluation.** A formal evaluation usually includes many points of discussion. See the sample evaluation form.

TECH TIP ✓ **Don't Cover Up Mistakes**

Everyone makes mistakes. While a damaged component or vehicle is never a good thing to have happen, the wise technician should notify the service manager or other person in charge as soon as a problem or accident occurs. Only then can work begin to correct the problem. If a mistake is hidden, eventually someone will learn about the error and then people will not think it was wise to ignore or to cover up the situation.

Informal Evaluation In many cases, a beginning technician's activities are simply observed and noted, which is a type of **informal evaluation.** Both are usually done and both can influence the technician's pay.

NOTE: Most employees are fired from a job as the result of not being able to get along with others, rather than a lack of technical skills.

Sample Technician Evaluation

Please check one of the spaces to the left of each characteristic which best expresses your judgment of the technician:

ATTITUDE-APPLICATION TO WORK
_____outstanding in enthusiasm
_____very interested and industrious
_____average in diligence and interest
_____somewhat indifferent
_____definitely not interested

DEPENDABILITY
_____completely dependable
_____above average in dependability
_____usually dependable
_____sometimes neglectful or careless
_____unreliable

QUALITY OF WORK
_____excellent
_____very good
_____average
_____below average
_____very poor

MATURITY
_____shows confidence
_____has good self-assurance
_____average maturity
_____seldom assertive
_____timid
_____brash

ABILITY TO LEARN
_____learned work exceptionally well
_____learned work readily
_____average in understanding work
_____rather slow in learning
_____very slow to learn

INITIATIVE
_____proceeds well on his or her own
_____proceeds independently at times
_____does all assigned work
_____hesitates
_____must be pushed frequently

RELATIONS WITH OTHERS
_____exceptionally well accepted
_____works well with others
_____gets along satisfactorily
_____has difficulty working w/ others
_____works very poorly with others

QUANTITY OR WORK
_____usually high output
_____more than average
_____normal amount
_____below average
_____low output, slow

JUDGMENT
_____exceptionally mature
_____above average
_____usually makes the right decision
_____often uses poor judgment

ATTENDANCE
_____regular
_____irregular

PUNCTUALITY
_____regular
_____irregular

SUMMARY

1. Professionalism and personal credibility are important to the success of any service technician.
2. A mentor is an experienced technician who helps a beginning technician in all aspects of the trade.
3. A mentor can help a beginning service technician not only quickly learn how to perform automotive service and repair procedures, but also can provide career and personal development guidance.
4. The beginning service technician (trainee) has the responsibility to ask questions and act in a professional manner.
5. Evaluations can be formal or informal.
6. Before a technician starts to work on a vehicle, the work order should be read carefully to determine exactly what service needs to be performed.
7. If a technician is asked to talk to a customer about a repair, discuss the original problem (concern), what was found (cause), and what was done to correct the fault (correction).
8. A technician should always document the work order and follow the vehicle manufacturer's recommended procedures.
9. Most technicians are paid on a flat-rate basis.

REVIEW QUESTIONS

1. What factors are part of being a professional service technician?
2. What is a mentor?
3. What are the roles of a mentor?
4. What are the responsibilities the beginning technician has to the shop and/or mentor?

5. A formal evaluation could include what items?
6. What are the three Cs?
7. What should be included on the work order after the repair has been completed?
8. How is the flat-rate pay method calculated?

CHAPTER QUIZ

1. Professionalism includes which factor?
   a. Keeping your word
   b. Becoming a teammate with your co-workers
   c. Apologizing if you are wrong
   d. All of the above
2. Type of communications include _____.
   a. Verbal
   b. Written
   c. Nonverbal
   d. All of the above
3. The three Cs include _____, _____, and _____.
   a. Correction, correct torque, and customer name
   b. Concern, cause, and correction
   c. Cause, cost, and caller name
   d. Captured data, cause, and cost (of the repair)
4. When documenting the work order, what things should be listed?
   a. The test equipment used in the diagnosis
   b. The test procedure that was followed
   c. The parts that were replaced
   d. All of the above
5. Technician A says that customer-pay rate is sometimes higher than the factory flat-rate. Technician B says that the factory flat-rate times are usually lower (given more time) compared to aftermarket flat-rate time guides. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Why is it important that a service technician have a valid driver's license and a good driving record?
   a. Driving vehicles in and out of the shop is required in most shops
   b. Vehicles need to be tested on public roads to verify concerns and repairs
   c. Insurance companies often require that shops only hire technicians with a good driving record
   d. All of the above
7. If running late, the wise technician should .
   a. Call the shop and let them know you will be late
   b. Speed up
   c. Call the shop and take the day off
   d. Stop and eat a good breakfast before going to the shop
8. Flat-rate pay means _____.
   a. The same pay (flat-rate) every week
   b. The same number of hours every week
   c. The technician is paid according to the job, not by the number of hours worked
   d. The technician is paid overtime
9. Customer pay (CP) means _____.
   a. Customer pays for the repair or service
   b. Warranty does not pay for the repair or service
   c. The technician often gets paid more for each job
   d. All of the above
10. A mentor performs all of the following *except* _____.
    a. Helps guide diagnosis of a problem
    b. Signs paychecks
    c. Offers advice on how to do a job
    d. Advises on professional behavior

CHAPTER 5 Technician Certification

OBJECTIVES: After studying Chapter 5, the reader will be able to: Explain the requirements for becoming an ASE certified technician. • Describe the type of test questions asked on the certification tests. • Explain how to prepare to take the ASE certification tests. • Describe test taking skills needed to help pass the certification tests. • Explain how to register and take the ASE certification tests.

KEY TERMS: all-except-type question • ASE (National Institute for Automotive service Excellence) • distracter • experience-based questions • IP certification • key • least-likely-type question • master certified technician • most-likely-type question • multiple-choice question • technician A and B question • work experience

AUTOMOBILE TECHNICIAN CERTIFICATION TESTS

Even though individual franchises and companies often certify their own technicians, there is a nationally recognized certificate organization, the **National Institute for Automotive Service Excellence,** better known by its abbreviation, **ASE.** See Figure 5–1.

ASE is a nonprofit association founded in 1972, and its main goal is to improve the quality of vehicle service through standardized testing and volunteer certification.



Figure 5–1 The ASE logo. *(Courtesy of ASE)*

What Areas of Vehicle Service Are Covered by the ASE Tests? Automobile test service areas include:

A1 Engine Repair
A2 Automatic Transmission/Transaxle
A3 Manual Drive Train and Axles
A4 Suspension and Steering
A5 Brakes
A6 Electrical/Electronic Systems
A7 Heating and Air Conditioning
A8 Engine Performance

If a technician takes and passes all eight of the automobile tests and has achieved two or more years of work experience, ASE will award the designation of **ASE Certified Master Automobile Technician.** Contact ASE for other certification areas.

How Can I Contact ASE?

ASE
101 Blue Seal Drive, SE
Suite 101
Leesburg, VA 20175

Toll-free: 1-877-ASE-TECH (273-8324)
1-703-669-6600
Web site: *www.ase.com*

When Are the Tests Given and Where? The ASE written tests are given at hundreds of test sites in early May and early November of *each* year.

NOTE: ASE also offers tests at other times of the year electronically. Go to the ASE Web site for details.

Deadline for registration is usually in late March for the May tests and in late September for the November tests. Consult the ASE registration packet or the Web site for details and locations of the test sites.

What Do I Have to Do to Register? You can register for the ASE tests in four ways:

1. Mail in the registration form that is in the registration booklet.
2. Register online at www.ase.com
3. Telephone at (866) 427-3273

Call ASE toll-free at 1-888-ASE-TEST or visit the Web site for details about cost and dates.

How Many Years of Work Experience Are Needed? ASE requires that you have two or more years of full-time, hands-on **working experience** either as an automobile, truck, truck equipment, or school bus technician, engine machinist, or in collision repair, refinishing, or damage analysis and estimating for certification, except as noted below. If you have *not* previously provided work experience information, you will receive a Work Experience Report Form with your admission ticket. You *must* complete and return this form to receive a certificate.

Substitutions for Work Experience You may receive credit for up to one year of the two-year work experience requirement by substituting relevant formal training in one, or a combination, of the following:

High School Training: Three full years of training, either in automobile/truck/school bus repair or in collision repair, refinishing, or damage estimating, may be substituted for one year of work experience.

Post-High School Training: Two full years of post-high school training in a public or private trade school, technical institute, community or four-year college, or in an apprenticeship program may be counted as one year of work experience.

Short Courses: For shorter periods of post-high school training, you may substitute two months of training for one month of work experience.

You may receive full credit for the two-year work experience requirement with the following:

Completion of Apprenticeship: Satisfactory completion of either a three- or four-year bona fide apprenticeship program.

Are There Any Hands-On Activities on the ASE Test? No. All ASE tests are written using objective-type questions, meaning that you must select the correct answer from four possible alternatives.

Who Writes the ASE Questions? All ASE test questions are written by a panel of industry experts, educators, and experienced ASE certified service technicians. Each question is reviewed by the committee and it is checked for the following:

- **Technically accurate.** All test questions use the correct terms and only test for vehicle manufacturer's recommended service procedures. Slang is not used nor are any aftermarket accessories included on the ASE test.
- **Manufacturer neutral.** All efforts are made to avoid using vehicle or procedures that are manufacturer specific such as to General Motors vehicles or to Toyotas. A service technician should feel comfortable about being able to answer the questions regardless of the type or brand of vehicle.
- **Logical answers.** All effort is made to be sure that all answers (not just the correct answers) are possible. While this may seem to

make the test tricky. It is designed to test for real knowledge of the subject.

- **Random answer.** All efforts are made to be sure that the correct answers are not always the longest answer or that one letter, such as **c**, is not used more than any other letter.
- **Experience-based questions.** The questions asked are generally not knowledge-based questions, but rather require experience to answer correctly. Specifications are not asked for, but instead a question as to what would most likely occur if the unit is out-of-specifications could be asked.

Key and Distracter The **key** is the correct answer. As part of the test writing sessions, the committee is asked to create other answers which sound feasible but are not correct. These incorrect answers are called **distracters**.

What Types of Questions Are Asked on the ASE Test? All ASE test questions are objective. This means that there will not be questions where you will have to write an answer. Instead, all you have to do is select one of the four possible answers and place a mark in the correct place on the score sheet.

- **Multiple-choice questions.** This type of question has one correct (or mostly correct) answer (called the key) and three incorrect answers. A multiple-choice question example:
  What part of an automotive engine does not move?

  a. Piston
  b. Connecting rod
  c. Block
  d. Valve

  The correct answer is **c** (block). This type of question asks for a specific answer. Answer **a** (piston), **b** (connecting rod), and **d** (valve) all move during normal engine operation. The best answer is **c** (block) because even though it may vibrate, it does not move as the other parts do.

- **Technician A and Technician B questions.** This type of question is generally considered to be the most difficult according to service technicians who take the ASE test. A situation or condition is usually stated and two technicians (A and B) say what they think could be the correct answer and you must decide which technician is correct.

  a. Technician A only
  b. Technician B only
  c. Both Technicians A and B
  d. Neither Technician A nor B

  The best way to answer this type of question is to carefully read the question and consider Technician A and Technician B answers to be solutions to a true or false question. If Technician A is correct, mark on the test by Technician A the letter T for true. (Yes, you can write on the test.) If Technician B is also correct, write the letter T for true by Technician B. Then mark **c** on your test score sheet, for both technicians are correct.

  Example:

  Two technicians are discussing an engine that has lower than specified fuel pressure. Technician A says that the fuel pump could be the cause. Technician B says that the fuel pressure regulator could be the cause.
  Which technician is correct?

  a. Technician A only
  b. Technician B only
  c. Both Technicians A and B
  d. Neither Technician A nor B

  Analysis:

  Is Technician A correct? The answer is yes because if the fuel pump was defective, the pump pressure could be lower than specified by the vehicle manufacturer. Is Technician B correct? The answer is yes because a stuck open regulator with a weak spring could be the cause of lower than specified fuel pressure. The correct answer is therefore **c** (Both Technicians A and B are correct).

- **Most-likely-type questions.** This type of question asks which of the four possible items listed is the most likely to cause the problem or symptom. This type of question is often considered to be difficult because recent experience may lead you to answer the question incorrectly because even though it is possible, it is not the "most likely."

  Example:

  Which of the items below is the most likely to cause blue exhaust at engine start?

  a. Valve stem seals
  b. Piston rings
  c. Clogged PCV valve
  d. A stuck oil pump regulator valve

  Analysis:

  The correct answer is **a** because valve stem seals are the most likely to cause this problem. Answer **b** is not correct because even though worn piston rings can cause the engine to burn oil and produce blue exhaust smoke, it is not the most likely cause of blue smoke at engine start. Answers **c** and **d** are not correct because even though these items could contribute to the engine burning oil and producing blue exhaust smoke, they are not the most likely.

- **Except-type questions.** ASE will sometimes use a question that includes answers that are all correct except one. You have to determine which of the four answers is not correct.

  Example:

  A radiator is being pressure tested using a hand-operated tester. This test will check for leaks in all except:

  a. Radiator
  b. Heater core
  c. Water pump
  d. Evaporator

  Analysis:

  The correct answer is **d** because the evaporator is not included in the cooling system and will not be pressurized during this test. Answers **a** (radiator), **b** (heater core), and **c** (water pump) are all being tested under pressure exerted on the cooling system by the pressure tester.

- **Least-likely-type questions.** Another type of question asked on many ASE tests is a question that asks which of the following is least likely to be the cause of a problem or symptom. In other words, all of the answers are possible, but it is up to the reader to determine which answer is the least likely to be correct.

  Example:

  Which of the following is the least likely cause of low oil pressure?

  a. Clogged oil pump screen
  b. Worn main bearing
  c. Worn camshaft bearing
  d. Worn oil pump

  Analysis:

  The correct answer is **c** because even though worn camshaft bearings can cause low oil pressure, the other answers are more likely to be the cause.

Should I Guess If I Don't Know the Answer? Yes. ASE tests simply record the correct answers, and by guessing, you will have at least a 25% (1 out of 4) chance. If you leave the answer blank, it will be scored as being incorrect. Instead of guessing entirely, try to eliminate as many of the answers as possible as not being very likely. If you can eliminate two out of the four, you have increased your chance of guessing to 50% (two out of four).

TECH TIP ✓ **Never Change an Answer**

Some research has shown that your first answer is most likely to be correct. It is human nature to read too much into the question rather than accept the question as it was written.

Is Each Test the Same Every Time I Take It? No. ASE writes many questions for each area and selects from this "test bank" for each test session. You may see some of the same questions if you take the same test in the spring and then again in the fall, but you will also see many different questions.

Can I Write or Draw on the Test Form? Yes. You may write or figure on the test, but do not write on the answer form or it can be misread during scanning and affect your score. You turn in your test and the answer form at the end of the session and the test is not reused.

Can I Skip Questions I Don't Know and Come Back to Answer Later? Yes. You may skip a question if you wish, but be sure to mark the question and return to answer the question later. It is often recommended to answer the question or guess and go on with the test so that you do not run out of time to go back over the questions.

How Much Time Do I Have to Take the Tests? All ASE test sessions are 4 hours and 15 minutes long. This is usually enough time for you to take up to four certification tests. ASE recommends that you do not attempt to take more than 225 questions or four tests at any one session. The ASE tests are spread over four days so it is possible to take all eight ASE test areas during a test period (spring or fall).

Will I Have to Know Specifications and Gauge Readings? Yes and no. You will be asked the correct range for a particular component or operation and you must know about what the specification should be. Otherwise, the questions will state that the value is less than or greater than the allowable specification. The question will deal with how the service technician should proceed or what action should be taken.

Can I Take a Break during the Test? Yes, you may use the restroom after receiving permission from the proctor of the test site.

Can I Leave Early If I Have Completed the Test(s)? Yes, you may leave quietly after you have completed the test(s). You must return the score sheet(s) and the test booklets as you leave.

How Are the Tests Scored? The ASE tests are machine scored and the results tabulated by American College Testing (ACT).

What Percentage Do I Need to Achieve to Pass the ASE Test? While there is no exact number of questions that must be answered correctly in each area, an analysis of the test results indicate that the percentage needed to pass varies from 61% to 69%. Therefore, in order to pass the Engine Repair (A1) ASE certification test, you will have to answer about 39 questions correct out of 60. In other words, you can miss about 21 questions and still pass.

What Happens If I Do Not Pass? Do I Have to Wait a Year Before Trying Again? No. If you fail to achieve a passing score on any ASE test, you can take the test again at the next testing session (in May or November).

Do I Have to Pay Another Registration Fee If I Already Paid It Once? Yes. The registration fee is due at every test session in May or November, whether you select to take one or more ASE tests. Therefore, it is wise to take as many tests as you can at each test session.

How Long Do I Have to Wait to Know the Results? You will receive written notice within two months after the test. Notification is sent out in July for the May test and in January for the November test sessions. You will be notified that you either "passed" a test(s) or that "more preparation is needed," meaning that you did not score high enough to pass the test and be rewarded with certification in the content area.

Will I Receive Notice of Which Questions I Missed? ASE sends out a summary of your test results, which shows how many questions you missed in each category, but not individual questions.

Will ASE Send Me the Correct Answers to the Questions I Missed So I Will Know How to Answer Them in the Future? No. ASE will not send you the answers to test questions.

TEST-TAKING TIPS

Start Now Even if you have been working on vehicles for a long time, taking an ASE certification test can be difficult. The questions will not include how things work or other "textbook" knowledge. The questions are based on "real-world" diagnosis and service. The tests may seem tricky to some because the wrong answers are designed to be similar to the correct answer.

If this is your first time taking the test or you are going to recertify, start now to prepare. Allocate time each day to study.

Practice Is Important Many service technicians do not like taking tests. As a result, many technicians rush through the test to get the pain over with quickly. Also, many service technicians have lots of experience on many different vehicles. This is what makes them good at what they do, but when an everyday problem is put into a question format (multiple choice), the answer may not be as clear as your experience has taught you.

Keys to Success The keys to successful test taking include:

- Practice answering similar-type questions.
- Carefully read each question two times to make sure you understand the question.
- Read each answer.
- Pick the best answer.
- Avoid reading too much into each question.
- Do not change an answer unless you are sure that the answer is definitely wrong.
- Look over the glossary of automotive terms for words that are not familiar to you.

The best preparation is practice, practice, and more practice. This is where using the ASE Test Prep practice tests can help.

Prepare Mentally Practicing also helps relieve another potential problem many people have called "chronic test syndrome." This condition is basically an inability to concentrate or focus during a test. The slightest noise, fear of failure, and worries about other things all contribute. The best medicine is practice, practice, and more practice. With practice, test taking becomes almost second nature.

Prepare Physically Be prepared physically. Get enough sleep and eat right.

One Month before the Test

- Budget your time for studying. On average you will need four to six hours of study for each test that you are taking.
- Use the ASE Test Prep Online test preparation service three or more times a week for your practice.
- Study with a friend or a group if possible.

The Week before the Test

- Studying should consist of about two hours of reviewing for each test being taken.
- Make sure you know how to get to the testing center. If possible drive to the test site and locate the room.
- Get plenty of rest.

The Day of the Test

- Study time is over.
- Keep your work schedule light or get the day off if possible.
- Eat a small, light meal the evening of the test.
- Drink a large glass of water one to two hours before the test. (The brain and body work on electrical impulses, and water is used as a conductor.)
- Arrive at least 30 minutes early at the test center. Be ready to start on time.

What to Bring to the Test

- A photo ID.
- Your Entry Ticket that came with your ASE packet.
- Two sharpened #2 pencils.

During the Test

- BREATHE (oxygen is the most important nutrient for the brain).
- Read every question TWICE.
- Read ALL the ANSWERS.
- If you have trouble with a question, leave it blank and continue. At the end of the test, go back and try any skipped questions. (Frequently, you will get a hint in another question that follows.)

There are eight automotive certifications including:

1. Engine Repair (A1) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. General Engine Diagnosis	15	28%
B. Cylinder Head and Valve Train Diagnosis and Repair	10	23%
C. Engine Block Diagnosis and Repair	10	23%
D. Lubrication and Cooling Systems Diagnosis and Repair	8	14%
E. Fuel, Electrical, Ignition, and Exhaust Systems Inspection and Service	7	12%
Total	**50**	**100%**

2. Automatic Transmission/Transaxles (A2) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. General Transmission/Transaxle Diagnosis 1. Mechanical/Hydraulic Systems (11) 2. Electronic Systems (14) B. Transmission/Transaxle Maintenance and Adjust	25 4	50% 8%
C. In-Vehicle Transmission/Transaxle Repair	8	16%
D. Off-Vehicle Transmission/Transaxle Repair 1. Removal, Disassembly, and Assembly (3) 2. Gear Train, Shafts, Bushings, Oil Pump, and Case (4) 3. Friction and Reaction Units (4)	13	26%
Total	**50**	**100%**

3. Manual Drive Train and Axles (A3) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. Clutch Diagnosis and Repair	6	15%
B. Transmission Diagnosis and Repair	7	18%
C. Transaxle Diagnosis and Repair	8	20%
D. Drive (Half) Shaft and Universal Joint/ Constant Velocity (CV) Joint Diagnosis and Repair (Front And Rear Wheel Drive)	5	13%
E. Rear Axle Diagnosis and Repair 1. Ring and Pinion Gears (3) 2. Differential Case Assembly (2) 3. Limited Slip Differential (1) 4. Axle Shafts (1)	7	17%
F. Four-Wheel Drive Component Diagnosis and Repair	7	17%
Total	**40**	**100%**

4. Suspension and Steering (A4) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. Steering Systems Diagnosis and Repair 1. Steering Columns and Manual Steering Gears (3) 2. Power-Assisted Steering Units (4) 3. Steering Linkage (3)	10	25%
B. Suspension Systems Diagnosis and Repair 1. Front Suspensions (6) 2. Rear Suspensions (5) 3. Miscellaneous Service (2)	11	28%
C. Related Suspension and Steering Service	2	5%
D. Wheel Alignment Diagnosis, Adjustment, and Repair	12	30%
E. Wheel and Tire Diagnosis and Repair	5	12%
Total	**40**	**100%**

5. Brakes (A5) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. Hydraulic System Diagnosis and Repair 1. Master Cylinders (non-ABS) (3) 2. Fluids, Lines, and Hoses (3) 3. Valves and Switches (non-ABS) (4) 4. Bleeding, Flushing, and Leak Testing (non-ABS) (4)	12	27%
B. Drum Brake Diagnosis and Repair	5	11%
C. Disc Brake Diagnosis and Repair	10	22%
D. Power Assist Units Diagnosis and Repair	4	8%
E. Miscellaneous Diagnosis and Repair	7	16%
F. Antilock Brake System Diagnosis and Repair	7	16%
Total	**45**	**100%**

6. Electrical Systems (A6) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. General Electrical/Electronic System Diagnosis	13	26%
B. Battery Diagnosis and Service	4	8%
C. Starting System Diagnosis and Repair	5	10%
D. Charging System Diagnosis and Repair	5	10%
E. Lighting Systems Diagnosis and Repair 1. Headlights, Parking Lights, Taillights, Dash Lights, and Courtesy Lights (3) 2. Stoplights, Turn Signals, Hazard Lights, and Back-up Lights (3)	6	12%
F. Gauges, Warning Devices, and Driver Information Systems Diagnosis and Repair	6	12%
G. Horn and Wiper/Washer Diagnosis and Repair	3	6%
H. Accessories Diagnosis and Repair 1. Body (4) 2. Miscellaneous (4)	8	16%
Total	**50**	**100%**

7. Heating and Air Conditioning (A7) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. A/C System Diagnosis and Repair	13	24%
B. Refrigeration System Component Diagnosis and Repair 1. Compressor and Clutch (5) 2. Evaporator, Condenser, and Related Components (5)	10	20%
C. Heating and Engine Cooling Systems Diagnosis and Repair	4	10%
D. Operating Systems and Related Controls Diagnosis and Repair 1. Electrical (9) 2. Vacuum/Mechanical (3) 3. Automatic and Semi-Automatic Heating, Ventilating, and A/C Systems (5)	19	34%
E. Refrigerant Recover, Recycling, and Handling	4	12%
Total	**50**	**100%**

8. Engine Performance (A8) ASE Task List

Content Area	Questions in Test	Percentage of Test
A. General Engine Diagnosis	10	17%
B. Ignition System Diagnosis and Repair	10	17%
C. Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair	11	18%
D. Emissions Control Systems Diagnosis and Repair 1. Positive Crankcase Ventilation (1) 2. Exhaust Gas Recirculation (3) 3. Secondary Air Injector (AIR) and Catalytic Converter (2) 4. Evaporative Emissions Controls (3)	9	15%
E. Computerized Engine Controls Diagnosis and Repair (Including OBD II)	16	27%
F. Engine Electrical Systems Diagnosis and Repair 1. Battery (1) 2. Starting System (1) 3. Charging System (2)	4	6%
Total	**60**	**100%**

To become certified by ASE, the service technician must have two years of experience and pass a test in each area. If a technician passes all eight automotive certification tests, then the technician is considered a master certified automobile service technician. Tests are administered twice a year, in May and again in November. Registration and payment are required to be sent in early April for the May test and in early October for the November test. Test results are mailed to your home or work address about six to eight weeks after the test(s) is taken.

CANADA'S AUTOMOTIVE APPRENTICESHIP PROGRAM (RED SEAL)

In Canada, in all provinces and territories but Quebec and British Columbia, an **Inter-Provincial (IP) Certificate** is required. An apprenticeship program is in place that takes a minimum of four years, combining ten months in a shop and about two months in school training in each of the four years. Most apprentices must undergo 7200 hours of training before they can complete the IP examination. ASE certifications are currently used on a voluntary basis since 1993, however an IP Certificate is still required. Other licensing of automotive technicians may be required in some cases, such as environmental substances, liquefied petroleum gas, or steam operators.

NOTE: A valid driver's license is a must for any automotive service technician.

UPDATE TRAINING

All ASE certifications expire after five years and the technician needs to take a recertification test to remain certified. As vehicles and technology change, it is important that all technicians attend update classes. Most experts recommend that each technician should have at least 40 hours (one full week) of update training every year. Update training classes can be found through many sources, including:

1. Many parts stores and warehouse distributors provide training classes throughout the year.
2. State or regional associations, such as the Automotive Service Association (www.asashop.org), offer update conferences.
3. Local colleges or training companies offer update training. Other training can be found listed on the International Automotive Technicians Network (www.iatn.net).

SUMMARY

1. ASE is an abbreviation for the National Institute for Automotive Service Excellence, a nonprofit association founded in 1972.
2. The eight ASE test content areas include: A1—Engine Repair, A2—Automatic Transmission, A3—Manual Drive Train and Axles, A4—Suspension and Steering, A5—Brakes, A6—Electrical/Electronic Systems, A7—Heating and Air Conditioning, and A8—Engine Performance.
3. To become an ASE certified technician, two years of experience are required plus achieving a passing test score on one or more ASE certification tests.
4. The types of questions used on an ASE certification test include: multiple-choice questions, Technician A and Technician B questions, most-likely-type questions, except-type questions, and least-likely-type questions.

REVIEW QUESTIONS

1. What are the eight ASE test areas?
2. When are the written ASE tests given?
3. What types of questions are asked on the ASE certification tests?
4. What can a technician do to help prepare to take the certification tests?

CHAPTER QUIZ

1. Which ASE certification test would cover experience in reading an electrical schematic?
   a. A6
   b. A7
   c. A8
   d. All of the above are possible
2. How many ASE tests must be passed to become a master automotive technician?
   a. 8
   b. 6
   c. 4
   d. 2
3. How many years of experience are required to achieve ASE certification?
   a. 8
   b. 6
   c. 4
   d. 2
4. Credit for how many years of work experience can be substituted by attending automotive service training?
   a. None—no substitution for work experience is permitted
   b. 1 year
   c. 2 years
   d. 3 years
5. When taking an ASE certification test, _____.
   a. You can write on the test itself if you wish
   b. No marks are allowed on the test
   c. Only one test can be taken
   d. Some hands-on activities may be required
6. A type of test question not asked on the ASE certification test is _____.
   a. Most likely
   b. Least likely
   c. Fill in the blank
   d. Multiple choice
7. Which type of question is the same as two true-and-false-type questions?
   a. All except type
   b. Technician A and Technician B
   c. Least likely type
   d. Most likely type
8. Technician A says that you should guess if you do not know the correct answer. Technician B says that ASE will send you the correct answers to the questions you missed with your test results. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. The written ASE tests are given every _____.
   a. January and June
   b. May and November
   c. February and September
   d. March and October
10. A technician should do all of the following to prepare to take the ASE certification test *except* _____.
    a. Get a good night's sleep the night before the test
    b. Try to keep work schedule light the day of the test
    c. Eat a big meal
    d. Have photo ID, entry ticket, and #2 pencils

SECTION II Safety, Environmental and Health Concerns

6 Shop Safety
7 Environmental and Health Concerns



CHAPTER 6

Shop Safety

OBJECTIVES: After studying Chapter 6, the reader will be able to: Identify situations where hearing protection should be worn. • Discuss how to safely handle tools and shop equipment. • Describe how to properly use a fire extinguisher. • Discuss shop safety procedures.

KEY TERMS: ANSI • bump cap • decibel (dB) • eye wash station • fire blankets • microbes • "PASS" • personal protective equipment (PPE) • spontaneous combustion

PERSONAL PROTECTIVE EQUIPMENT

Safety is not just a buzzword on a poster in the work area. Safe work habits can reduce accidents and injuries, ease the workload, and keep employees pain free.

Safety Glasses The most important **personal protective equipment (PPE)** a technician should wear all the time are safety glasses, which meet standard **ANSI** Z87.1. See Figure 6–1.

Steel-Toed Shoes Steel-toed safety shoes are also a good investment. See Figure 6–2. If safety shoes are not available, then leather-topped shoes offer more protection than canvas or cloth.

Gloves Wear gloves to protect your hands from rough or sharp surfaces. Thin rubber gloves are recommended when working around automotive liquids such as engine oil, antifreeze, transmission fluid, or any other liquids that may be hazardous. Several types of gloves and their characteristics include:

- **Latex surgical gloves.** These gloves are relatively inexpensive, but tend to stretch, swell, and weaken when exposed to gas, oil, or solvents.



Figure 6–1 Safety glasses should be worn at all times when working on or around any vehicle or servicing any component.



Figure 6–2 Steel-toed shoes are a worthwhile investment to help prevent foot injury due to falling objects. Even these well-worn shoes can protect the feet of this service technician.



Figure 6–3 Protective gloves such as these vinyl gloves are available in several sizes. Select the size that allows the gloves to fit snugly. Vinyl gloves last a long time and often can be worn all day to help protect your hands from dirt and possible hazardous materials.

- **Vinyl gloves.** These gloves are also inexpensive and are not affected by gas, oil, or solvents.
- **Polyurethane gloves.** These gloves are more expensive, yet very strong. Even though these gloves are also not affected by gas, oil, or solvents, they do tend to be slippery.
- **Nitrile gloves.** These gloves are exactly like latex gloves, but are not affected by gas, oil, or solvents, yet they tend to be expensive.
- **Mechanic's gloves.** These gloves are usually made of synthetic leather and spandex and provide thermo protection, as well as protection from dirt and grime. See Figure 6–3.

Bump Cap Service technicians working under a vehicle should wear a **bump cap** to protect the head against under-vehicle objects and the pads of the lift. See Figure 6–4.

Hands, Jewelry, and Clothing Remove jewelry that may get caught on something or act as a conductor to an exposed electrical circuit. See Figure 6–5.

Take care of your hands. Keep your hands clean by washing with soap and hot water that is at least 110°F (43°C). Avoid loose or dangling clothing. Also, ear protection should be worn if the sound around you requires that you raise your voice (sound level higher than 90 **decibels [dB]**).



Figure 6–4 One version of a bump cap is this padded plastic insert that is worn inside a regular cloth cap.



Figure 6–5 Remove all jewelry before performing service work on any vehicle.

NOTE: A typical lawnmower produces noise at a level of about 110 dB. This means that everyone who uses a lawnmower or other lawn or garden equipment should wear ear protection.

TECH TIP **Professional Behavior in the Shop Is a Must**

To be respected as a professional service technician and for safety, always behave in a professional manner. These behaviors include, but are not limited to the following:

- Show respect to other technicians and employees. For example, the shop owner or service manager may not always be right, but they are always the boss.
- Avoid horseplay or practical jokes.
- Act as if a customer is observing your behavior at all times because this is often the case.

SAFETY TIPS FOR TECHNICIANS

- When lifting any object, get a secure grip with solid footing. Keep the load close to your body to minimize the strain. Lift with your legs and arms, not your back.
- Do not twist your body when carrying a load. Instead, pivot your feet to help prevent strain on the spine.
- Ask for help when moving or lifting heavy objects.
- Push a heavy object rather than pull it. (This is opposite to the way you should work with tools—never push a wrench! If you do and a bolt or nut loosens, your entire weight is used to propel your hand(s) forward. This usually results in cuts, bruises, or other painful injury.)
- Always connect an exhaust hose to the tailpipe of any running vehicle to help prevent the build-up of carbon monoxide inside a closed garage space. See Figure 6–6.
- When standing, keep objects, parts, and tools with which you are working between chest height and waist height. If seated, work at tasks that are at elbow height.
- Always be sure the hood is securely held open. See Figure 6–7.

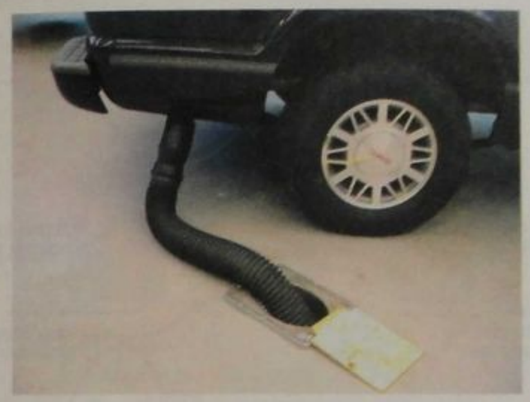
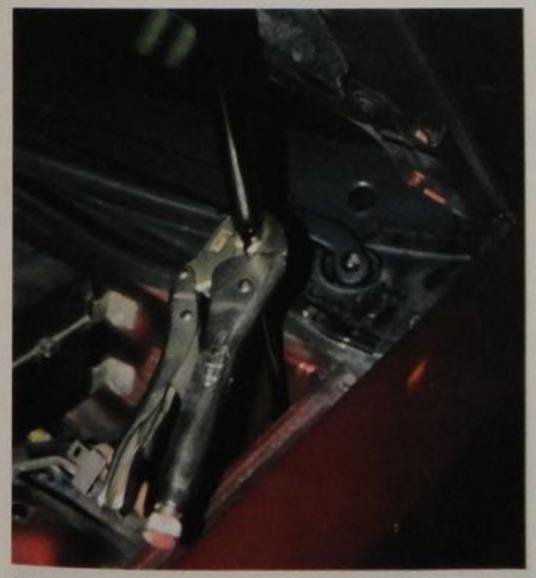
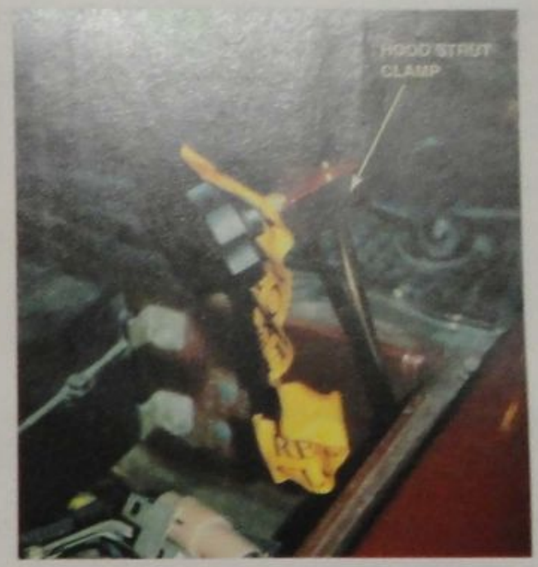


Figure 6–6 Always connect an exhaust hose to the tailpipe of the engine of a vehicle to be run inside a building.



(a)

Figure 6–7a A crude but effective method is to use locking pliers on the chrome-plated shaft of a hood strut. Locking pliers should only be used on defective struts because the jaws of the pliers can damage the strut shaft.



(b)

Figure 6–7b A commercially available hood clamp. This tool uses a bright orange tag to help remind the technician to remove the clamp before attempting to close the hood. The hood could be bent if force is used to close the hood with the clamp in place.

SAFETY TIP **Shop Cloth Disposal**

Always dispose of oily shop cloths in an enclosed container to prevent a fire. See Figure 6–8. Whenever oily cloths are thrown together on the floor or workbench, a chemical reaction can occur which can ignite the cloth even without an open flame. This process of ignition without an open flame is called **spontaneous combustion.**

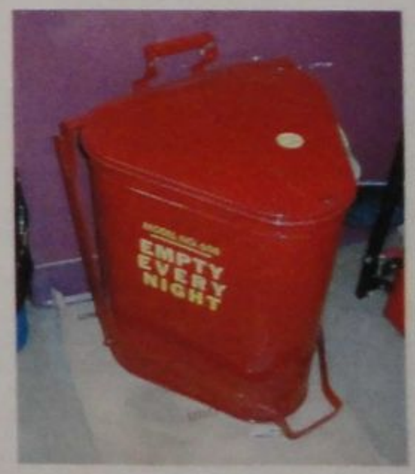


Figure 6–8 All oily shop cloths should be stored in a metal container equipped with a lid to help prevent spontaneous combustion.

TECH TIP **Pound with Something Softer**

If you must pound on something, be sure to use a tool that is softer than what you are about to pound on to avoid damage. Examples are given in the following table.

The Material Being Pounded	What to Pound with
Steel or cast iron	Brass or aluminum hammer or punch
Aluminum	Plastic or rawhide mallet or plastic-covered dead-blow hammer
Plastic	Rawhide mallet or plastic dead-blow hammer

CLEANING METHODS AND PROCESSES

There are four basic types of cleaning methods and processes used in vehicle service, including:

Power Washing Power washing uses an electric or gasoline powered compressor to increase the pressure of water and force it out of a nozzle. The pressure of the water itself is usually enough to remove dirt, grease, and grime from vehicle components. Sometimes a chemical cleaner, such as a detergent, is added to the water to help with cleaning.

Safe Use of Power Washers Because water is being sprayed at high pressure, a face shield should be worn when using a power washer to protect not only the eyes but to also protect the face in the event of the spray being splashed back toward the technician. Also use a pressure washer in an area where the runoff from the cleaning will not contaminate local groundwater or cause harm to plants or animals.

Chemical/Microbe Cleaning Chemical cleaning involves one of several cleaning solutions, including detergent, solvents, or small, living microorganisms called **microbes** that eat oil and grease. The microbes live in water and eat the hydrocarbons that are the basis of grease and oil.

Safe Use of Chemical Cleaning A face shield should be worn when cleaning parts using a chemical cleaner. Avoid spilling the cleaner on the floor to help prevent slipping accidents. Clean and replace the chemical cleaner regularly.

Abrasive Cleaning Abrasive cleaning is usually used to clean disassembled parts, such as engine blocks. The abrasives used include steel shot, ground walnut shells, or in the case of cleaning paint from a vehicle body, baking soda can be used.

Safe Use of Abrasive Cleaners Always wear a protective face shield and protective clothing, including gloves, long sleeves, and long pants.

Thermal Ovens Thermal cleaning uses heat to bake off grease and dirt with special high-temperature ovens. This method of cleaning does require the use of expensive equipment but does not use any hazardous chemicals and is environmentally safe.

Safe Use of Thermal Ovens Because thermal ovens operate at high temperatures, often exceeding 600°F (315°C), the oven should be turned off and allowed to cool overnight before removing the parts from the oven to avoid being exposed to the high temperature.

ELECTRICAL CORD SAFETY

Use correctly grounded three-prong sockets and extension cords to operate power tools. Some tools use only two-prong plugs. Make sure these are double insulated and repair or replace any electrical cords that are cut or damaged to prevent the possibility of an electrical shock. When not in use, keep electrical cords off the floor to prevent tripping over them. Tape the cords down if they are placed in high foot traffic areas.

JUMP-STARTING AND BATTERY SAFETY

To jump-start another vehicle with a dead battery, connect good-quality copper jumper cables as indicated in Figure 6–9 or use a jump box. The last connection made should always be on the engine block or an engine bracket as far from the battery as possible.

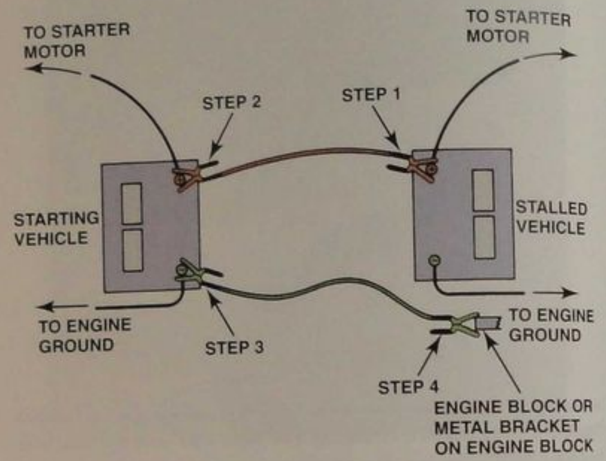


Figure 6–9 Jumper cable usage guide.

SAFETY TIP **Compressed Air Safety**

Improper use of an air nozzle can cause blindness or deafness. Compressed air must be reduced to less than 30 PSI (206 kPa). See Figure 6–10. If an air nozzle is used to dry and clean parts, make sure the air stream is directed away from anyone else in the immediate area. Coil and store air hoses when they are not in use.



Figure 6–10 The air pressure going to the nozzle should be reduced to 30 PSI or less.

It is normal for a spark to be created when the jumper cables finally complete the jumping circuit, and this spark could cause an explosion of the gases around the battery. Many newer vehicles have special ground connections built away from the battery just for the purpose of jump-starting. Check the owner's manual or service information for the exact location.

Batteries contain acid and should be handled with care to avoid tipping them greater than a 45-degree angle. Always remove jewelry when working around a battery to avoid the possibility of electrical shock or burns, which can occur when the metal comes in contact with a 12-volt circuit and ground, such as the body of the vehicle.

FIRE EXTINGUISHERS

There are four classes of fire extinguishers. Each class should be used on specific fires only:

- *Class A* is designed for use on general combustibles, such as cloth, paper, and wood.
- *Class B* is designed for use on flammable liquids and greases, including gasoline, oil, thinners, and solvents.
- *Class C* is used only on electrical fires.
- *Class D* is effective only on combustible metals such as powdered aluminum, sodium, or magnesium.

The class rating is clearly marked on the side of every fire extinguisher. Many extinguishers are good for multiple types of fires. See Figure 6–11.

When using a fire extinguisher, remember the word **"PASS."**

P = Pull the safety pin.

A = Aim the nozzle of the extinguisher at the base of the fire.

S = Squeeze the lever to actuate the extinguisher.

S = Sweep the nozzle from side-to-side.

See Figure 6–12.

Types of Fire Extinguishers Types of fire extinguishers include the following:

- **Water.** A water fire extinguisher, usually in a pressurized container, is good to use on Class A fires by reducing the temperature to the point where a fire cannot be sustained.
- **Carbon dioxide (CO_2).** A carbon dioxide fire extinguisher is good for almost any type of fire, especially Class B or Class C materials. A CO_2 fire extinguisher works by removing the oxygen from the fire and the cold CO_2 also helps reduce the temperature of the fire.

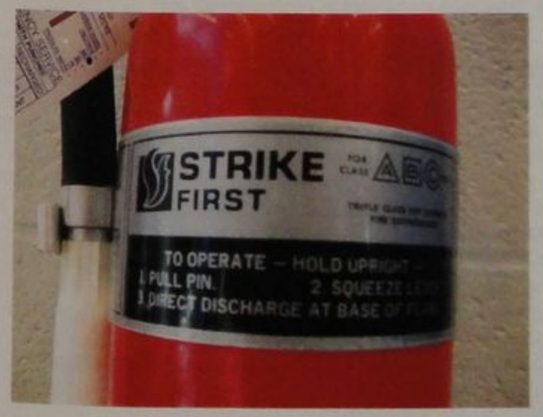


Figure 6–11 A typical fire extinguisher designed to be used on type A, B, or C fires.



Figure 6–12 A CO_2 fire extinguisher being used on a fire set in an open steel drum during a demonstration at a fire department training center.

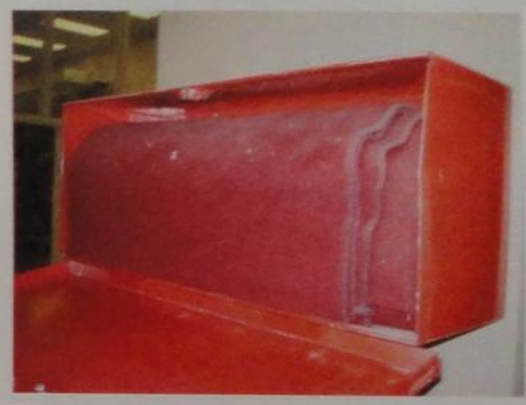


Figure 6–13 A treated wool blanket is kept in this easy-to-open wall-mounted holder and should be placed in a centralized location in the shop.

- **Dry chemical (yellow).** A dry chemical fire extinguisher is good for Class A, B, or C fires by coating the flammable materials, which eliminates the oxygen from the fire. A dry chemical fire extinguisher tends to be very corrosive and will cause damage to electronic devices.

FIRE BLANKETS

Fire blankets are required to be available in the shop areas. If a person is on fire, a fire blanket should be removed from its storage bag and thrown over and around the victim to smother the fire. See Figure 6–13 showing a typical fire blanket.

FIRST-AID AND EYE WASH STATIONS

All shop areas must be equipped with a first-aid kit and an eye wash station centrally located and kept stocked with emergency supplies.

First-Aid Kit A first-aid kit should include:

- Bandages (variety)
- Gauze pads
- Roll gauze
- Iodine swab sticks

- Antibiotic ointment
- Hydrocortisone cream
- Burn gel packets
- Eye wash solution
- Scissors
- Tweezers
- Gloves
- First-aid guide

See Figure 6–14. Every shop should have a person trained in first aid. If there is an accident, call for help immediately.

Eye Wash Station An **eye wash station** should be centrally located and used whenever any liquid or chemical gets into the eyes.



Figure 6–14 A first-aid box should be centrally located in the shop and kept stocked with the recommended supplies.



Figure 6–15 A typical eye wash station. Often a thorough flushing of the eyes with water is the best treatment in the event of eye contamination.

If such an emergency does occur, keep eyes in a constant stream of water and call for professional assistance. See Figure 6–15.

TECH TIP ✓ **Mark off the Service Area**

Some shops rope off the service bay area to help keep traffic and distractions to a minimum, which could prevent personal injury. See Figure 6–16.



Figure 6–16 This area has been blocked off to help keep visitors from the dangerous work area.

SUMMARY

1. All service technicians should wear safety glasses that meet standard ANSI Z87.1.
2. Ear protection should be worn anytime the noise level is at 90 decibels (dB) or higher.
3. Safety should be exercised when working with electrical cords or when jump-starting another vehicle.
4. If a fire extinguisher is needed, remember: pull the safety pin, aim the nozzle, squeeze the lever, and sweep the nozzle from side-to-side.

REVIEW QUESTIONS

1. List four items that are personal protective equipment (PPE).
2. What are the types of fire extinguishers and their usage?
3. What items are included in a typical first-aid box?

CHAPTER QUIZ

1. What do you call the service technician's protective head cover?
   a. Cap
   b. Hat
   c. Bump cap
   d. Helmet
2. All safety glasses should meet the standards set by _____.
   a. ANSI
   b. SAE
   c. ASE
   d. DOT
3. When washing hands, the water should be at what temperature?
   a. 98°F (37°C)
   b. 110°F (43°C)
   c. 125°F (52°C)
   d. 135°F (57°C)
4. Hearing protection should be worn anytime the noise level exceeds _____.
   a. 60 dB
   b. 70 dB
   c. 80 dB
   d. 90 dB
5. Two technicians are discussing the safe use of a wrench. Technician A says that a wrench should be pulled toward you. Technician B says that a wrench should be pushed away from you. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Exhaust hoses should be used because one of the exhaust gases is deadly in high concentration. This gas is _____.
   a. Carbon monoxide (CO)
   b. Carbon dioxide (CO_2)
   c. Hydrocarbons (HC)
   d. Oxides of nitrogen (NO_x)
7. The process of combustion occurring without an open flame is called _____.
   a. Direct ignition
   b. Non-open flame combustion
   c. Spontaneous combustion
   d. Cold fusion

CHAPTER **7**

Environmental and Health Concerns

OBJECTIVES: After studying Chapter 7, the reader will be able to: Explain the Occupational Safety and Health Act (OSHA). • Define the term Material Safety Data Sheet (MSDS). • Identify hazardous waste materials in accordance with state and federal regulations and follow proper safety precautions while handling hazardous waste materials. • Describe the steps required to safely handle and store automotive chemicals and waste.

KEY TERMS: Aboveground Storage Tank (AGST) • asbestosis • Battery Council International (BCI) • Clean Air Act (CAA) • Code of Federal Regulations (CFR) • Environmental Protection Agency (EPA) • hazardous waste material • Material Safety Data Sheets (MSDS) • mercury • mesothelioma • Occupational Safety and Health Act (OSHA) • Resource Conservation and Recovery Act (RCRA) • right-to-know laws • solvent • underground storage tank (UST) • Workplace Hazardous Materials Information Systems (WHMIS)

OCCUPATIONAL SAFETY AND HEALTH ACT

The United States Congress passed the **Occupational Safety and Health Act (OSHA)** in 1970. This legislation was designed to assist and encourage the citizens of the United States in their efforts to assure safe and healthful working conditions by providing research, information, education, and training in the field of occupational safety and health, as well as to assure safe and healthful working conditions for working men and women by authorizing enforcement of the standards developed under the Act. Since approximately 25% of workers are exposed to health and safety hazards on the job, the OSHA standards are necessary to monitor, control, and educate workers regarding health and safety in the workplace.

HAZARDOUS WASTE

CAUTION: When handling hazardous waste material, one must always wear the proper protective clothing and equipment detailed in the right-to-know laws. This includes respirator equipment. All recommended procedures must be followed accurately. Personal injury may result from improper clothing, equipment, and procedures when handling hazardous materials.

Hazardous waste materials are chemicals or components that the shop no longer needs that pose a danger to the environment

and people if they are disposed of in ordinary garbage cans or sewers. However, one should note that no material is considered hazardous waste until the shop has finished using it and is ready to dispose of it. The **Environmental Protection Agency (EPA)** publishes a list of hazardous materials that is included in the **Code of Federal Regulations (CFR).** The EPA considers waste hazardous if it is included on the EPA list of hazardous materials or if it has one or more of the following characteristics.

Reactive Any material which reacts violently with water or other chemicals is considered hazardous.

Corrosive If a material burns the skin, or dissolves metals and other materials, a technician should consider it hazardous. A pH scale is used, with the number 7 indicating neutral. Pure water has a pH of 7. Lower numbers indicate an acidic solution and higher numbers indicate a caustic solution. If a material releases cyanide gas, hydrogen sulfide gas, or similar gases when exposed to low pH acid solutions, it is considered hazardous.

Toxic Materials are hazardous if they leak one or more of eight different heavy metals in concentrations greater than 100 times the primary drinking water standard.

Ignitable A liquid is hazardous if it has a flash point below 140°F (60°C), and a solid is hazardous if it ignites spontaneously.

Radioactive Any substance that emits measurable levels of radiation is radioactive. When individuals bring containers of a highly radioactive substance into the shop environment, qualified personnel with the appropriate equipment must test them.

CAUTION: Hazardous waste disposal laws include serious penalties for anyone responsible for breaking these laws.

RESOURCE CONSERVATION AND RECOVERY ACT (RCRA)

Federal and state laws control the disposal of hazardous waste materials. Every shop employee must be familiar with these laws. Hazardous waste disposal laws include the **Resource Conservation and Recovery Act (RCRA).** This law states that hazardous material users are responsible for hazardous materials from the time they become a waste until the proper waste disposal is completed. Many shops hire an independent hazardous waste hauler to dispose of hazardous waste material. The shop owner or manager should have a written contract with the hazardous waste hauler. Rather than have hazardous waste material hauled to an approved hazardous waste disposal site, a shop may choose to recycle the material in the shop. Therefore, the user must store hazardous waste material properly and safely and be responsible for the transportation of this material until it arrives at an approved hazardous waste disposal site, where it can be processed according to the law. The RCRA controls these types of automotive waste:

- Paint and body repair products waste
- Solvents for parts and equipment cleaning
- Batteries and battery acid
- Mild acids used for metal cleaning and preparation
- Waste oil, and engine coolants or antifreeze
- Air-conditioning refrigerants and oils
- Engine oil filters

RIGHT-TO-KNOW LAWS

The **right-to-know laws** state that employees have a right to know when the materials they use at work are hazardous. The right-to-know laws started with the *Hazard Communication Standard* published by the Occupational Safety and Health Administration (OSHA) in 1983. Originally, this document was intended for chemical companies and manufacturers that required employees to handle hazardous materials in their work situation. Meanwhile, the federal courts have decided to apply these laws to all companies, including automotive service shops. Under the right-to-know laws, employers have responsibilities regarding the handling of hazardous materials by their employees. All employees must be trained about the types of hazardous materials they will encounter in the workplace. The employees must be informed about their rights under legislation regarding the handling of hazardous materials.

CLEAN AIR ACT

Air-conditioning (A/C) systems and refrigerant are regulated by the **Clean Air Act (CAA),** Title VI, Section 609. Technician certification and service equipment are also regulated. Any technician working on automotive A/C systems must be certified. A/C refrigerants must not be released or vented into the atmosphere, and used refrigerants must be recovered.

MATERIAL SAFETY DATA SHEETS (MSDS)

All hazardous materials must be properly labeled, and information about each hazardous material must be posted on **Material Safety Data Sheets (MSDS)** available from the manufacturer. See Figure 7–1. In Canada, these sheets are called **Workplace Hazardous Materials Information Systems (WHMIS).**

The employer has a responsibility to place Material Safety Data Sheets where they are easily accessible by all employees. The Material Safety Data Sheets provide the following information about the hazardous material: chemical name, physical characteristics, protective handling equipment, explosion/fire hazards, incompatible materials, health hazards, medical conditions aggravated by exposure, emergency and first-aid procedures, safe handling, and spill/leak procedures.

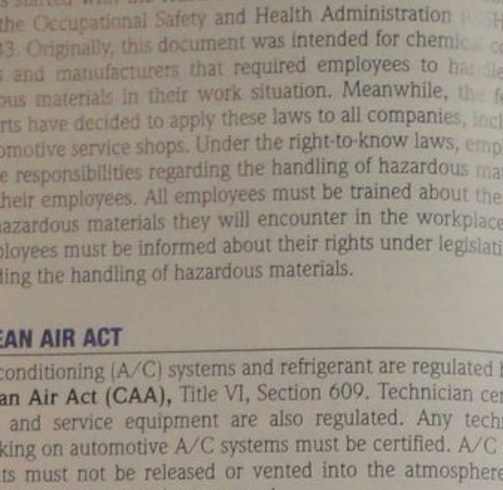


Figure 7–1 Material Safety Data Sheets (MSDS) should be readily available for use by anyone in the area who may come into contact with hazardous materials.

The employer also has a responsibility to make sure that hazardous materials are properly labeled. The labels and MSDS must include health, fire, and reactivity hazards posed by the material, as well as the protective equipment necessary to handle the material. The manufacturer must supply all warning and precautionary information about hazardous materials. This information must be read and understood by the employee before handling the material.

THE DANGERS OF EXPOSURE TO ASBESTOS

Friction materials, such as brake and clutch linings, often contain asbestos. While asbestos has been eliminated from most original equipment friction materials, the automotive service technician cannot know whether or not the vehicle being serviced is or is not equipped with friction materials containing asbestos. It is important that all friction materials be handled as if they do contain asbestos.

Asbestos exposure can cause scar tissue to form in the lungs. This condition is called **asbestosis.** It gradually causes increasing shortness of breath, and the scarring to the lungs is permanent.

Even low exposures to asbestos can cause **mesothelioma,** a type of fatal cancer of the lining of the chest or abdominal cavity. Asbestos exposure can also increase the risk of lung cancer as well as cancer of the voice box, stomach, and large intestine. It usually takes 15 to 30 years or more for cancer or asbestos lung scarring to show up after exposure. (Scientists call this the *latency period.*)

Government agencies recommend that asbestos exposure should be eliminated or controlled to the lowest level possible. These agencies have developed recommendations and standards that the automotive service technician and equipment manufacturer should follow. These U.S. federal agencies include the National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), and Environmental Protection Agency (EPA).

CAUTION: Never use compressed air to blow brake dust. The fine talc-like brake dust can create a health hazard even if asbestos is not present or is present in dust rather than fiber form.

Disposal of Brake Dust and Brake Shoes The hazard of asbestos occurs when asbestos fibers are airborne. Once the asbestos has been wetted down, it is then considered to be solid waste rather than hazardous waste. Old brake shoes and pads should be enclosed, preferably in a plastic bag, to help prevent any of the brake material from becoming airborne. *Always follow current federal and local laws concerning disposal of all waste.*

USED BRAKE FLUID

Most brake fluid is made from polyglycol, is water soluble, and can be considered hazardous if it has absorbed metals from the brake system. The following safety tips should be followed mind when handling used brake fluid:

- Collect brake fluid in containers clearly marked to indicate that it is designated for that purpose.
- If your waste brake fluid is hazardous, manage it appropriately and use only an authorized waste receiver for its disposal.
- If your waste brake fluid is nonhazardous (such as old, but unused), determine from your local solid waste collection provider what should be done for its proper disposal.

- Do not mix brake fluid with used engine oil unless otherwise notified by the service receiver.
- Do not pour brake fluid down drains or onto the ground.
- Recycle brake fluid through a registered recycler.

USED OIL

Used oil is any petroleum-based or synthetic oil that has been used. During normal use, impurities such as dirt, metal scrapings, water, or chemicals can get mixed in with the oil. Eventually, this used oil must be replaced with virgin or re-refined oil.

NOTE: The release of only 1 gallon of used oil (a typical oil change) can make a million gallons of fresh water undrinkable.

If used oil is dumped down the drain and enters a sewage treatment plant, concentrations as small as 50 to 100 ppm (parts per million) in the waste water can foul sewage treatment processes. Never mix a listed hazardous waste, gasoline, waste water, halogenated solvent, antifreeze, or an unknown waste material with used oil. Adding any of these substances will cause the used oil to become contaminated, which classifies it as hazardous waste.

Disposal of Used Oil Once oil has been used, it can be collected, recycled, and used over and over again. An estimated 380 million gallons of used oil are recycled each year. Recycled used oil can sometimes be used again for the same job or can take on a completely different task. For example, used engine oil can be re-refined and sold at the store as engine oil or processed for furnace fuel oil. After collecting used oil in an appropriate container (e.g., a 55-gallon steel drum), the material must be disposed of in one of two ways:

- Shipped off-site for recycling
- Burned in an onsite or offsite EPA-approved heater for energy recovery

Used Oil Storage Used oil must be stored in compliance with an existing **underground storage tank (UST)** or an **aboveground storage tank (AGST)** standard, or kept in separate containers. See Figure 7–2. Containers are portable receptacles, such as a 55-gallon steel drum.

Keep used oil storage drums in good condition. This means that drums should be covered, secured from vandals, properly labeled, and



Figure 7–2 An aboveground storage tank for used oil.

maintained in compliance with local fire codes. Frequent inspections for leaks, corrosion, and spills are an essential part of container maintenance. Used oil may also be stored in units that are permitted to store regulated hazardous waste.

Used Oil Filter Disposal Regulations Used oil filters contain used engine oil that may be hazardous. Before an oil filter is placed into the trash or sent to be recycled, it must be drained using one of the following hot draining methods approved by the EPA.

- Puncture the filter antidrainback valve or filter dome end and hot drain for at least 12 hours
- Hot drain and crush
- Dismantle and hot drain
- Perform any other hot draining method, which will remove all the used oil from the filter

After the oil has been drained from the oil filter, the filter housing can be disposed of in any of the following ways:

- Sent for recycling
- Picked up by a service contract company
- Disposed of in regular trash

SAFETY TIP **Wash Hands**

Service technicians should wash their hands with soap and water after handling engine oil or differential or transmission fluids, or wear protective rubber gloves. See Figure 7–3.

SOLVENT HAZARDS AND REGULATORY STATUS

Most **solvents** are classified as hazardous wastes. Other characteristics of solvents include the following:

- Solvents with flash points below 140°F (60°C) are considered flammable and, like gasoline, are federally regulated by the Department of Transportation (DOT).
- Solvents and oils with flash points above 140°F (60°) are considered combustible and, like engine oil, are also regulated by the DOT. See Figure 7–4.

It is the responsibility of the repair shop to determine if its spent solvent is hazardous waste. Waste solvents that are considered hazardous waste have a flash point below 140°F (60°C). Hot water or aqueous parts cleaners may be used to avoid disposing of spent solvent as hazardous waste. Solvent-type parts cleaners with filters are available to greatly extend solvent life and reduce spent solvent disposal costs. Solvent reclaimers are available that clean and restore the solvent so it lasts indefinitely.



Figure 7–3 Washing hands and removing jewelry are two important safety habits all service technicians should practice.



Figure 7–4 Typical fireproof flammable storage cabinet.

COOLANT DISPOSAL

Coolant is a mixture of antifreeze and water. New antifreeze is not considered to be hazardous even though it can cause death if ingested. Used antifreeze may be hazardous due to dissolved metals from the engine and other components of the cooling system. These metals can include iron, steel, aluminum, copper, brass, and lead (from older radiators and heater cores). Coolant can be disposed of in the following ways:

1. Coolant should be recycled either on-site or off-site.
2. Used coolant should be stored in a sealed and labeled container until it can be disposed of. See Figure 7–5.
3. Used coolant can often be disposed of into municipal sewers with a permit. Check with local authorities and obtain a permit before discharging used coolant into sanitary sewers.

LEAD-ACID BATTERY WASTE

About 70 million spent lead-acid batteries are generated each year in the United States alone. Lead is classified as a toxic metal, and the acid used in lead-acid batteries is highly corrosive. The vast majority (95% to 98%) of these batteries are recycled through lead reclamation operations and secondary lead smelters for use in the manufacture of new batteries.

Used lead-acid batteries must be reclaimed or recycled in order to be exempt from hazardous waste regulations. Leaking batteries must be stored and transported as hazardous waste. Some states have more strict regulations, which require special handling procedures and transportation. According to the **Battery Council International (BCI)**, battery laws usually include the following rules:

- Lead-acid battery disposal is prohibited in landfills or incinerators.
- Batteries are required to be disposed of at a battery retailer, wholesaler, recycling center, or lead smelter.



Figure 7–5 Used antifreeze coolant should be kept separate and stored in a leakproof container until it can be recycled or disposed of according to federal, state, and local laws. Note that the storage barrel is placed inside another container to catch any coolant that may spill out of the inside barrel.

- All retailers of automotive batteries are required to post a sign that displays the universal recycling symbol and indicates the retailer's specific requirements for accepting used batteries.

CAUTION: Battery electrolyte contains sulfuric acid, which is a very corrosive substance capable of causing serious personal injury, such as skin burns and eye damage. In addition, the battery plates contain lead, which is highly poisonous. For this reason, disposing of batteries improperly can cause environmental contamination and lead to severe health problems.

Battery Handling and Storage Batteries, whether new or used, should be kept indoors if possible. The storage location should be an area specifically designated for battery storage and must be well ventilated (to the outside). If outdoor storage is the only alternative, a sheltered and secured area with acid-resistant secondary containment is strongly recommended. It is also advisable that acid-resistant secondary containment be used for indoor storage. In addition, batteries should be placed on acid-resistant pallets and never stacked.

FUEL SAFETY AND STORAGE

Gasoline is a very explosive liquid. The expanding vapors that come from gasoline are extremely dangerous. These vapors are present even in cold temperatures. Vapors formed in gasoline tanks on many vehicles are controlled, but vapors from gasoline storage may escape from the can, resulting in a hazardous situation. Therefore, place gasoline storage containers in a well-ventilated space. Although diesel fuel is not as volatile as gasoline, the same basic rules apply to diesel fuel and gasoline storage. These rules include the following.

- Approved gasoline storage cans have a flash-arresting screen at the outlet. These screens prevent external ignition sources from igniting the gasoline within the can when someone pours the gasoline or diesel fuel.
- Technicians must always use *red* approved gasoline containers to allow for proper hazardous substance identification. See Figure 7–6.

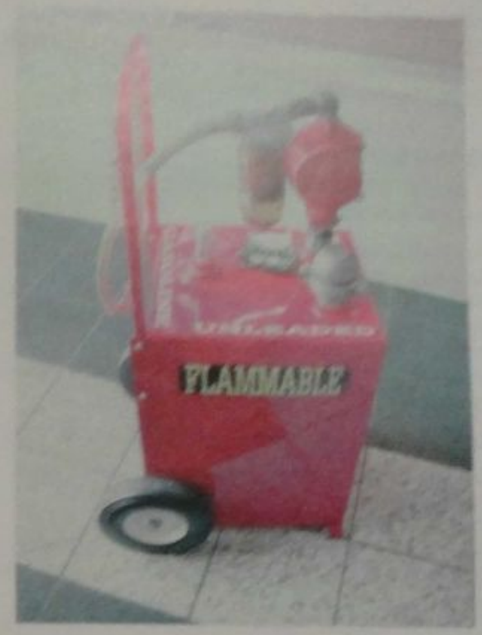


Figure 7–6 This red gasoline container holds about 30 gallons of gasoline and is used to fill vehicles used for training.

- Do not fill gasoline containers completely full. Always leave the level of gasoline at least 1 inch from the top of the container. This action allows expansion of the gasoline at higher temperatures. If gasoline containers are completely full, the gasoline will expand when the temperature increases. This expansion forces gasoline from the can and creates a dangerous spill.
- If gasoline or diesel fuel containers must be stored, place them in an approved storage locker or facility.
- Never leave gasoline containers open, except while filling or pouring gasoline from the container.
- Never use gasoline as a cleaning agent.
- Always connect a ground strap to containers when filling or transferring fuel or other flammable products from one container to another to prevent static electricity that could result in explosion and fire. These ground wires prevent the buildup of a static electric charge, which could result in a spark and disastrous explosion.

AIRBAG HANDLING

Airbag modules are pyrotechnic (explosive) devices that can be ignited if exposed to an electrical charge or if the body of the vehicle is subjected to a shock. Airbag safety should include the following precautions:

1. Disarm the airbag(s) if you will be working in the area where a discharged bag could make contact with any part of your body. Consult service information for the exact procedure to follow for the vehicle being serviced.
2. Do not expose an airbag to extreme heat or fire.
3. Always carry an airbag pointing away from your body.
4. Place an airbag module facing upward.
5. Always follow the manufacturer's recommended procedure for airbag disposal or recycling, including the proper packaging to use during shipment.

6. Always wash your hands or body thoroughly if exposed to a deployed airbag. The chemicals involved can cause skin irritation and possible rash development.
7. Wear protective gloves if handling a deployed airbag.

USED TIRE DISPOSAL

Used tires are an environmental concern for several reasons, including the following:

1. In a landfill, used tires tend to "float" up through the other trash and rise to the surface.
2. The inside of tires traps and holds rainwater, which is a breeding ground for mosquitoes. Mosquito-borne diseases include *encephalitis* and *dengue fever*.
3. Used tires present a fire hazard and, when burned, create a large amount of black smoke that contaminates the air.

Used tires should be disposed of in one of the following ways:

1. Used tires can be reused until the end of their useful life.
2. Tires can be retreaded.
3. Tires can be recycled or shredded for use in asphalt.
4. De-rimmed tires can be sent to a landfill (most landfill operators will shred the tires because it is illegal in many states to landfill whole tires).
5. Tires can be burned in cement kilns or other power plants where the smoke can be controlled.
6. A registered scrap tire handler can be used to transport tires for disposal or recycling.

AIR-CONDITIONING REFRIGERANT OIL DISPOSAL

Air-conditioning refrigerant oil contains dissolved refrigerant and is therefore considered to be hazardous waste. This oil must be kept separated from other waste oil, or the entire amount of oil must be treated as hazardous. Used refrigerant oil must be sent to a licensed hazardous waste disposal company for recycling or disposal. See Figure 7–7.

INFECTION CONTROL PRECAUTIONS

Working on a vehicle can result in personal injury including the possibility of being cut or hurt enough to cause bleeding. Some infections such as hepatitis B, HIV (which can cause acquired immunodeficiency syndrome, or AIDS), hepatitis C virus, and others are transmitted in the blood. These infections are commonly called **blood-borne pathogens.** Report any injury that involves blood to your supervisor and take the necessary precautions to avoid coming in contact with blood from another person.



Figure 7–7 Air-conditioning refrigerant oil must be kept separated from other oils because it contains traces of refrigerant and must be treated as hazardous waste.

TECH TIP **Remove Components That Contain Mercury**

Some vehicles have a placard near the driver's side door that lists the components that contain the heavy metal, **mercury.** See Figure 7–8.

These components should be removed from the vehicle before the rest of the body is sent to be recycled to help prevent releasing mercury into the environment.

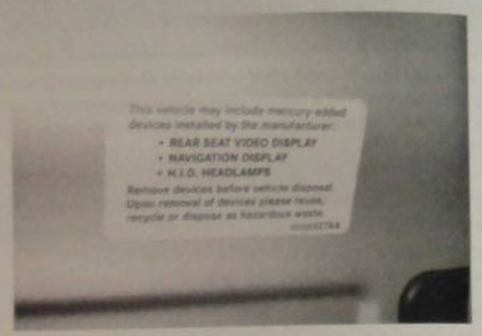


Figure 7–8 Placard near driver's door, including what devices in the vehicle contain mercury.

SUMMARY

1. Hazardous materials include common automotive chemicals, liquids, and lubricants.
2. Right-to-know laws require that all workers have access to Material Safety Data Sheets (MSDS).
3. Asbestos fibers should be avoided and removed according to current laws and regulations.
4. Used engine oil contains metals worn from parts and should be handled and disposed of properly.
5. Solvents represent a serious health risk and should be avoided as much as possible.
6. Coolant should be recycled.
7. Batteries are considered to be hazardous waste and should be discarded to a recycling facility.

REVIEW QUESTIONS

1. List five common automotive chemicals or products that may be considered hazardous materials.
2. List five precautions to which every technician should adhere when working with automotive products and chemicals.

CHAPTER QUIZ

1. Hazardous materials include all of the following *except* _____.
   a. Engine oil
   b. Asbestos
   c. Water
   d. Brake cleaner
2. To determine if a product or substance being used is hazardous, consult _____.
   a. A dictionary
   b. An MSDS
   c. SAE standards
   d. EPA guidelines
3. Exposure to asbestos dust can cause what condition?
   a. Asbestosis
   b. Mesothelioma
   c. Lung cancer
   d. All of the above are possible
4. Wetted asbestos dust is considered to be _____.
   a. Solid waste
   b. Hazardous waste
   c. Toxic
   d. Poisonous
5. An oil filter should be hot drained for how long before disposing of the filter?
   a. 30 to 60 minutes
   b. 4 hours
   c. 8 hours
   d. 12 hours
6. Used engine oil should be disposed of by all *except* the following methods.
   a. Disposed of in regular trash X
   b. Shipped off-site for recycling
   c. Burned on-site in a waste oil-approved heater
   d. Burned off-site in a waste oil-approved heater

7. All of the following are the proper ways to dispose of a drained oil filter *except* _____.
   a. Sent for recycling
   b. Picked up by a service contract company
   c. Disposed of in regular trash
   d. Considered to be hazardous waste and disposed of accordingly
8. Which act or organization regulates air-conditioning refrigerant?
   a. Clean Air Act (CAA)
   b. MSDS
   c. WHMIS
   d. Code of Federal Regulations (CFR)
9. Gasoline should be stored in approved containers that include what color(s)?
   a. A red container with yellow lettering
   b. A red container
   c. A yellow container
   d. A yellow container with red lettering
10. Which of the listed items is *not* considered to be personal protective equipment (PPE)?
    a. Safety glasses
    b. Safety socks
    c. Steel-toed shoes
    d. Gloves

SECTION III

Tools, Shop Equipment, and Measuring

8 Fasteners and Thread Repair
9 Hand Tools
10 Power Tools and Shop Equipment
11 Vehicle Lifting and Hoisting
12 Measuring Systems and Tools



CHAPTER 8

Fasteners and Thread Repair

OBJECTIVES: After studying Chapter 8, the reader will be able to: Explain the terms used to identify bolts and other threaded fasteners. • Explain the strength ratings of threaded fasteners. • Describe the proper use of nonthreaded fasteners. • Discuss how snap rings are used.

KEY TERMS: bolts • cap screws • capillary action • Christmas tree clips • cotter pins • crest • die • grade • Helical insert • Helicoil® • jam nut • metric bolts • pal nut • penetrating oil • pitch • pop rivet • prevailing torque nuts • self-tapping screw • snap ring • stud • tap • tensile strength • threaded insert • UNC (unified national coarse) • UNF (unified national fine) • washers

THREADED FASTENERS

Most of the threaded fasteners used on vehicles are cap screws. They are called **cap screws** when they are threaded into a casting. Automotive service technicians usually refer to these fasteners as **bolts,** regardless of how they are used. In this chapter, they are called bolts. Sometimes, studs are used for threaded fasteners. A **stud** is a short rod with threads on both ends. Often, a stud will have coarse threads on one end and fine threads on the other end. The end of the stud with coarse threads is screwed into the casting. A nut is used on the opposite end to hold the parts together.

The fastener threads *must* match the threads in the casting or nut. The threads may be measured either in fractions of an inch (called fractional) or in metric units. The size is measured across the outside of the threads, called the **crest** of the thread. See Figure 8–1.

Fractional threads are either coarse or fine. The coarse threads are called **Unified National Coarse (UNC),** and the fine threads are called **Unified National Fine (UNF).** Standard combinations of sizes and number of threads per inch (called **pitch**) are used. Pitch can be measured with a thread pitch gauge as shown in Figure 8–2.

Bolts are identified by their diameter and length as measured from below the head, and not by the size of the head or the size of the wrench used to remove or install the bolt. Bolts and screws have many different-shaped heads. See Figure 8–3.

Fractional thread sizes are specified by the diameter in fractions of an inch and the number of threads per inch. Typical UNC thread sizes would be 5/16-18 and 1/2-13. Similar UNF thread sizes would be 5/16-24 and 1/2-20. See Figure 8–4.

METRIC BOLTS

The size of a **metric bolt** is specified by the letter *M* followed by the diameter in millimeters (mm) across the outside (crest) of the

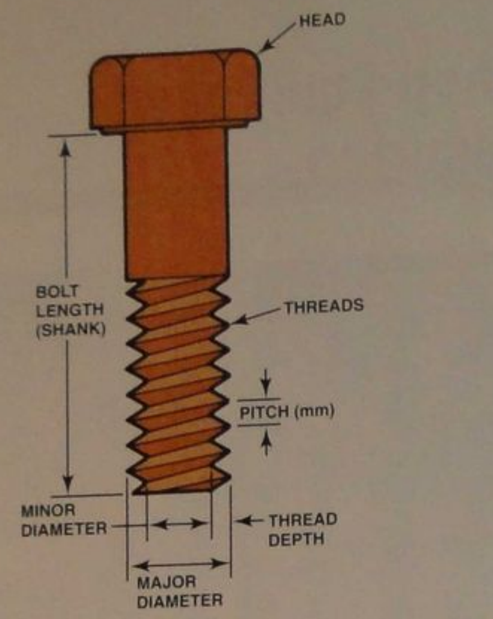


Figure 8–1 The dimensions of a typical bolt showing where sizes are measured.

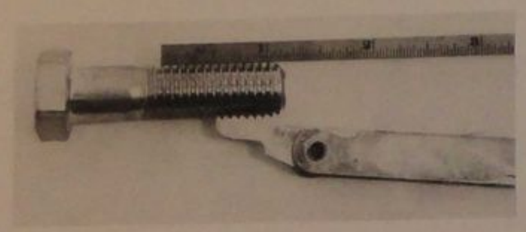


Figure 8–2 Thread pitch gauge used to measure the pitch of the thread. This bolt has 13 threads to the inch.

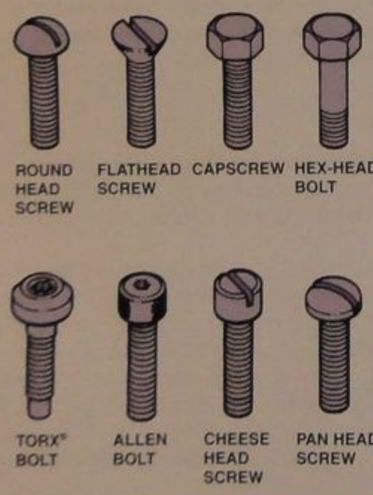


Figure 8–3 Bolts and screws have many different heads which determine what tool must be used.

Size	Threads per inch NC UNC	Threads per inch NF UNF	Outside Diameter Inches
0	..	80	0.0600
1	64	..	0.0730
1	..	72	0.0730
2	56	..	0.0860
2	..	64	0.0860
3	48	..	0.0990
3	..	56	0.0990
4	40	..	0.1120
4	..	48	0.1120
5	40	..	0.1250
5	..	44	0.1250
6	32	..	0.1380
6	..	40	0.1380
8	32	..	0.1640
8	..	36	0.1640
10	24	..	0.1900
10	..	32	0.1900
12	24	..	0.2160
12	..	28	0.2160
1/4	20	..	0.2500
1/4	..	28	0.2500
5/16	18	..	0.3125
5/16	..	24	0.3125
3/8	16	..	0.3750
3/8	..	24	0.3750
7/16	14	..	0.4375
7/16	..	20	0.4375
1/2	13	..	0.5000
1/2	..	20	0.5000
9/16	12	..	0.5625
9/16	..	18	0.5625
5/8	11	..	0.6250
5/8	..	18	0.6250
3/4	10	..	0.7500
3/4	..	16	0.7500
7/8	9	..	0.8750
7/8	..	14	0.8750
1	8	..	1.0000
1	..	12	1.0000
1 1/8	7	..	1.1250
1 1/8	..	12	1.1250
1 1/4	7	..	1.2500
1 1/4	..	12	1.2500
1 3/8	6	..	1.3750
1 3/8	..	12	1.3750
1 1/2	6	..	1.5000
1 1/2	..	12	1.5000
1 3/4	5	..	1.7500
2	4 1/2	..	2.0000
2 1/4	4 1/2	..	2.2500
2 1/2	4	..	2.5000
2 3/4	4	..	2.7500
3	4	..	3.0000
3 1/4	4	..	3.2500
3 1/2	4	..	3.5000
3 3/4	4	..	3.7500
4	4	..	4.0000

Figure 8–4 The American National System is one method of sizing fasteners.

threads. Typical metric sizes would be M8 and M12. Fine metric threads are specified by the thread diameter followed by *X* and the distance between the threads measured in millimeters (M8 × 1.5). See Figure 8–5.

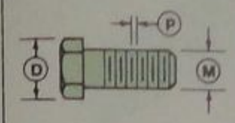
GRADES OF BOLTS

Bolts are made from many different types of steel, and for this reason some are stronger than others. The strength or classification of a bolt is called the **grade.** The bolt heads are marked to indicate their grade strength. Graded bolts are commonly used in the suspension parts of the vehicle but can be used almost anywhere on the vehicle.

The actual grade of bolts is two more than the number of lines on the bolt head. Metric bolts have a decimal number to

METRIC HEXAGON HEAD CAP SCREWS

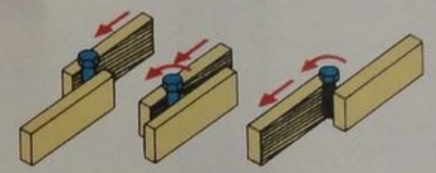
ALL MEASUREMENTS IN MILLIMETERS



M = NOMINAL THREAD DIAMETER
P = PITCH
D = HEAD SIZE ACROSS FLATS

M	P	D	M	P	D	M	P	D
1.6	0.35	3.2	10	1.00	17	20	1.50	30
1.7	0.35	3.5	10	1.25	17	20	2.50	30
2	0.40	4	10	1.50	17	22	1.50	32
2.3	0.40	4.5	12	1.25	19	22	2.50	32
2.5	0.45	5	12	1.50	19	24	2.00	36
3	0.50	5.5	12	1.75	19	24	3.00	36
3.5	0.60	6	14	1.50	22	27	3.00	41
4	0.70	7	14	2.00	22	30	3.50	46
5	0.80	8	16	1.50	24	33	3.50	50
6	1.00	10	16	2.00	24	36	4.00	55
7	1.00	11	18	1.50	27	39	4.00	60
8	1.00	13	18	2.50	27	42	4.50	65
8	1.25	13				45	4.50	70

Figure 8–5 The metric system specifies fasteners by diameter, length, and pitch.



ROLLING THREADS

Figure 8–6 Stronger threads are created by cold-rolling a heat-treated bolt blank instead of cutting the threads using a die.

indicate the grade. More lines or a higher grade number indicate a stronger bolt. Higher grade bolts usually have threads that are rolled rather than cut, which also makes them stronger. See Figure 8–6. In some cases, nuts and machine screws have similar grade markings.

CAUTION: *Never* use hardware store (nongraded) bolts, studs, or nuts on any vehicle steering, suspension, or brake component. Always use the exact size and grade of hardware that is specified and used by the vehicle manufacturer.

TENSILE STRENGTH

Graded fasteners have a higher tensile strength than nongraded fasteners. **Tensile strength** is the maximum stress used under tension (lengthwise force) without causing failure of the fastener. Tensile strength is specified in pounds per square inch (PSI). See the following chart that shows the grade and specified tensile strength.

The strength and type of steel used in a bolt is supposed to be indicated by a raised mark on the head of the bolt. The type of mark depends on the standard to which the bolt was manufactured. Most often, bolts used in machinery are made to SAE Standard J429.

Metric bolt tensile strength property class is shown on the head of the bolt as a number, such as 4.6, 8.8, 9.8, and 10.9; the higher the number, the stronger the bolt. See Figure 8–7.

SAE Bolt Designations

SAE Grade No.	Size range	Tensile strength, PSI	Material	Head marking
1	¼ through 1-½	60,000	Low or medium carbon steel	
2	¼ through ¾	74,000		
	⅞ through 1-½	60,000		
5	1/4 through 1	120,000	Medium carbon steel, quenched & tempered	
	1-⅛ through 1-½	105,000		
5.2	¼ through 1	120,000	Low carbon martensite steel*, quenched & tempered	
7	¼ through 1-½	133,000	Medium carbon alloy steel, quenched & tempered	
8	¼ through 1-½	150,000	Medium carbon alloy steel, quenched & tempered	
8.2	¼ through 1	150,000	Low carbon martensite steel*, quenched & tempered	

*Martensite steel is steel that has been cooled rapidly, thereby increasing its hardness. It is named after a German metallurgist, Adolf Martens.

TECH TIP ✓ **A 1/2-Inch Wrench Does Not Fit a 1/2-Inch Bolt**

A common mistake made by persons new to the automotive field is to think that the size of a bolt or nut is the size of the head. The size of the bolt or nut (outside diameter of the threads) is usually smaller than the size of the wrench or socket that fits the head of the bolt or nut. Examples are given in the following table:

Wrench Size	Thread Size
7/16 in.	1/4 in.
1/2 in.	5/16 in.
9/16 in.	3/8 in.
5/8 in.	7/16 in.
3/4 in.	1/2 in.
10 mm	6 mm
12 mm or 13 mm*	8 mm
14 mm or 17 mm*	10 mm

* European (Système International d'Unités-SI) metric

HINT: An open-end wrench can be used to gauge bolt sizes. A 3/8-in. wrench will fit the threads of a 3/8-in. bolt.

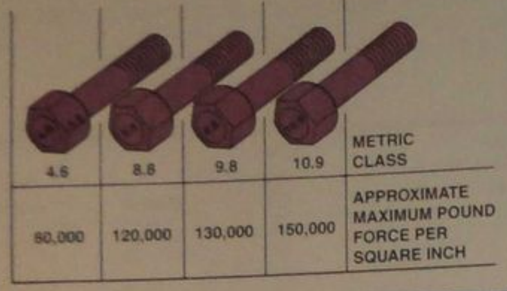


Figure 8–7 Metric bolt (cap screw) grade markings and approximate tensile strength.



Figure 8–8 Types of lock nuts. On the left, a nylon ring; in the center, a distorted shape; and on the right, a castle for use with a cotter key.

NUTS

Most nuts used on cap screws have the same hex size as the cap screw head. Some inexpensive nuts use a hex size larger than the cap screw head. Metric nuts are often marked with dimples to show their strength. More dimples indicate stronger nuts. Some nuts and cap screws use interference fit threads to keep them from accidentally loosening. This means that the shape of the nut is slightly distorted or that a section of the threads is deformed. Nuts can also be kept from loosening with a nylon washer fastened in the nut or with a nylon patch or strip on the threads. See Figure 8–8.

NOTE: Most of these "locking nuts" are grouped together and are commonly referred to as **prevailing torque nuts.** This means that the nut will hold its tightness or torque and not loosen with movement or vibration. Most prevailing torque nuts should be replaced whenever removed to ensure that the nut will not loosen during service. Always follow the manufacturer's recommendations. Anaerobic sealers, such as Loctite®, are used on the threads where the nut or cap screw must be both locked and sealed.

TAPS AND DIES

Taps and dies are used to cut threads. **Taps** are used to cut threads in holes drilled to an exact size depending on the size of the tap. A **die** is used to cut threads on round rods or studs. Most taps and dies come as a complete set for the most commonly used fractional and metric threads.

Taps There are two commonly used types of taps, including:

- **Tapered tap.** This is the most commonly used tap and is designed to cut threads by gradually enlarging the threaded hole.
- **Bottoming tap.** This tap has a flat bottom instead of a tapered tip to allow it to cut threads to the bottom of a drilled hole. See Figure 8–9.

All taps must be used in the proper size hole called a "tap drill size." This information is often stamped on the tap itself or in a chart that is included with a tap and die tool set. See Figure 8–10.

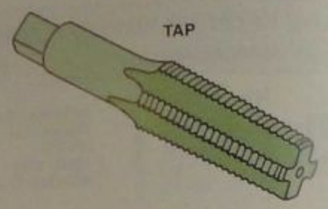


Figure 8–9 A typical bottoming tap used to create threads in holes that are not open, but stop in a casting, such as an engine block.

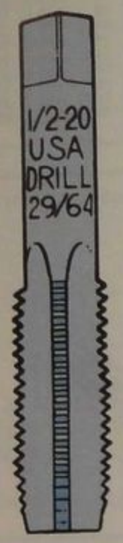


Figure 8–10 Many taps, especially larger ones, have the tap drill size printed on the top.

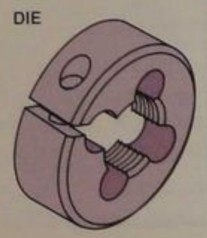


Figure 8–11 A die is used to cut threads on a metal rod.

Dies A die is a hardened steel round cutter with teeth on the inside of the center hole. See Figure 8–11. A die is rotated using a die handler over a rod to create threads.

Proper Use of Taps and Dies Taps and dies are used to cut threads on roll stock in the case of a die or in a hole for a tap. A small tap can be held using a T-handle but for larger taps a tap handle is needed to apply the needed force to cut threads. See Figure 8–12a and 8–12b.

Tap Usage Be sure that the hole is the correct size for the tap and start by inserting the tap straight into the hole. Lubricate the tap using tapping lubricant. Rotate the tap about one full turn clockwise, then reverse the direction of the tap one-half turn to break the chip that was created. Repeat the procedure until the hole is completely threaded.

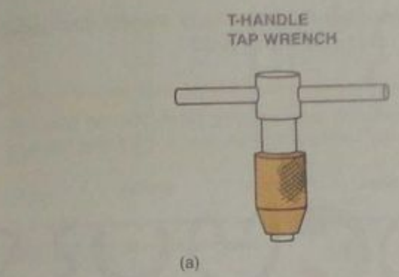


Figure 8–12 (a) A T-handle is used to hold and rotate small taps. (b) A tap wrench is used to hold and drive larger taps.



Figure 8–13 A die handle used to rotate a die while cutting threads on a metal rod.

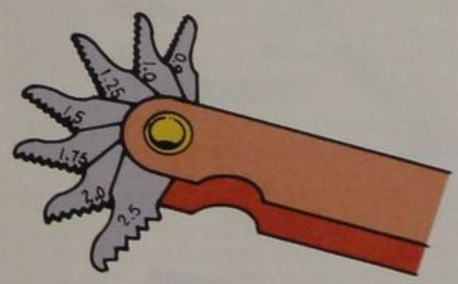


Figure 8–14 A typical thread pitch gauge.

Die Usage A die should be used on the specified diameter rod for the size of the thread. Install the die securely into the die handle. See Figure 8–13.

Lubricate the die and the rod and place the die onto the end of the rod to be threaded. Rotate the die handle one full turn clockwise, then reverse the direction and rotate the die handle about a half turn counterclockwise to break the chip that was created. Repeat the process until the threaded portion has been completed.

THREAD PITCH GAUGE

A thread pitch gauge is a hand tool that has the outline of various thread sizes machined on stamped blades. To determine the thread pitch size of a fastener, the technician matches the thread of the thread pitch gauge to the threads of the fastener. See Figure 8–14.

PREVIOUSLY ASKED QUESTION ???

What Is the Difference Between a Tap and a Thread Chaser?

A tap is a cutting tool and is designed to cut new threads. A thread chaser has more rounded threads and is designed to clean dirty threads without removing metal. Therefore, when cleaning threads, it is best to use a thread chaser rather than a tap to prevent the possibility of removing metal, which would affect the fit of the bolt being installed. See Figure 8–15.



Figure 8–15 A thread chaser is shown at the top compared to a tap on the bottom. A thread chaser is used to clean threads without removing metal.

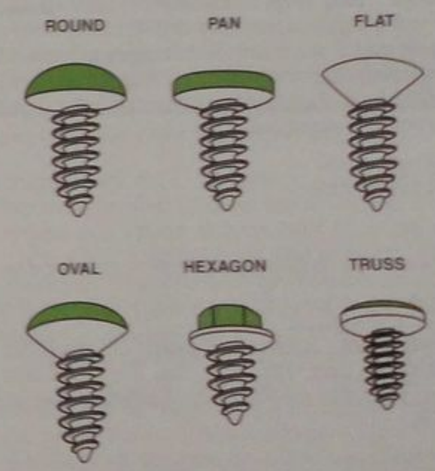


Figure 8–16 Sheet metal screws come with many head types.

SHEET METAL SCREWS

Sheet metal screws are fully threaded screws with a point for use in sheet metal. Also called **self-tapping screws,** they are used in many places on the vehicle, including fenders, trim, and door panels. See Figure 8–16.

These screws are used in unthreaded holes and the sharp threads cut threads as they are installed. This makes for a quick and easy installation when installing new parts, but the sheet metal screw can easily strip out the threads when used on the same part over and over, so care is needed.

When reinstalling self-tapping screws, first turn the screw lightly backwards until you feel the thread drop into the existing thread in the screw hole. Then, turn the screw in; if it threads in easily, continue to tighten the screw. If the screw seems to turn hard, stop and turn it backwards about another half turn to locate the existing thread and try again. This technique can help prevent stripped holes in sheet metal and plastic parts.

Sheet metal screws are sized according to their major thread diameter.

Size	Diameter Decimal (inch)	Diameter Nearest Fraction Inch
4	0.11	7/64
6	0.14	9/64
8	0.17	11/64
10	0.19	3/16
12	0.22	7/32
14	0.25	1/4

WASHERS

Washers are often used under cap screw heads and under nuts. See Figure 8–17.

Plain flat washers are used to provide an even clamping load around the fastener. Lock washers are added to prevent accidental loosening. In some accessories, the washers are locked onto the nut to provide easy assembly.

SNAP RINGS AND CLIPS

Snap Rings **Snap rings** are not threaded fasteners, but instead attach with a springlike action. Snap rings are constructed of spring steel and are used to attach parts without using a threaded fastener. There are several different types of snap rings and most require the use of a special pair of pliers, called snap ring pliers, to release or install. The types of snap rings include:

- Expanding (internal)
- Contracting (external)
- E-clip
- C-clip
- Holeless snap rings in both expanding and contracting styles

See Figure 8–18.

Door Panel Clips Interior door panels and other trim pieces are usually held in place with plastic clips. Due to the tapered and fluted shape, these clips are often called **Christmas tree clips.** See Figure 8–19.



Figure 8–17 Various types of nuts (top) and washers (bottom) serve different purposes and all are used to secure bolts or cap screws.

A special tool is often used to remove interior door panels without causing any harm. See Figure 8–20.

CAUTION: Use extreme care when removing panels that use plastic or nylon clips. It is very easy to damage the door panel or clip during removal.



Figure 8–18 Some different types of snap rings. An internal snap ring fits inside of a housing or bore, into a groove. An external snap ring fits into a groove on the outside of a shaft or axle. An E-Clip fits into a groove in the outside of a shaft. A C-Clip shown is used to retain a window regulator handle on its shaft.



Figure 8–19 A typical door panel retaining clip.



Figure 8–20 Plastic or metal trim tools are available to help the technician remove interior door panels and other trim without causing harm.

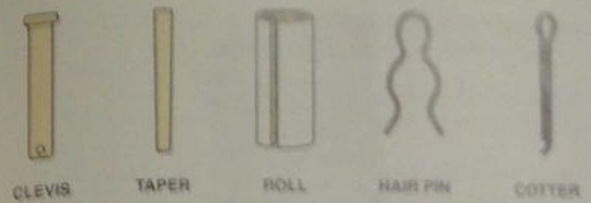


Figure 8–21 Pins come in various types.

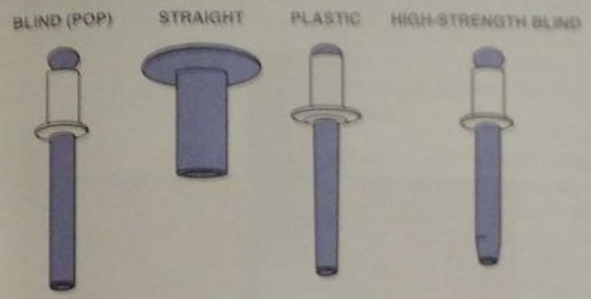


Figure 8–22 Various types of rivets.

Pins **Cotter pins,** also called a cotter key, are used to keep linkage or a threaded nut in place or to keep it retained. The word *cotter* is an Old English verb meaning "to close or fasten." There are many other types of pins used in vehicles, including clevis pins, roll pins, and hair pins. See Figure 8–21.

Pins are used to hold together shafts and linkages, such as shift linkages and cable linkages. The clevis pin is held in place with a cotter pin, while the taper and roll pins are driven in and held by friction. The hair pin snaps into a groove on a shaft.

Rivets Rivets are used in many locations to retain components, such as window mechanisms, that do not require routine removal and/or do not have access to the back side for a nut. A drill is usually used to remove a rivet and a rivet gun is needed to properly install a rivet. Some rivets are plastic and are used to hold some body trim pieces. The most common type of rivet is called a **pop rivet** because as the rivet tool applies a force to the shaft of the pop rivet, it causes the rivet to expand and tighten the two pieces together. When the shaft of the rivet, which looks like a nail, is pulled to its maximum, the shaft breaks, causing a "pop" sound.

Rivets may be used in areas of the vehicle where a semipermanent attachment is needed and in places where there is no access to the back side of the workpiece. They are installed using a rivet gun or by peening with a ball-peen hammer. See Figure 8–22.

Both types of blind rivets require the use of a rivet gun to install. The straight rivet is placed through the workpieces and then peened over with a ball-peen hammer or an air-operated tool. The plastic rivet is used with a rivet gun to install some body trim parts.

Locking Nuts Some nuts, called jam nuts, are used to keep bolts and screws from loosening. **Jam nuts** screw on top of a regular nut and jam against the regular nut to prevent loosening. A jam nut is so called because of its intended use, rather than a special design. Some jam nuts are thinner than a standard nut. Jam nuts are also called **pal nuts.** See Figure 8–23.

There are also self-locking nuts of various types. Some have threads that are bent inward to grip the threads of the bolt. Some

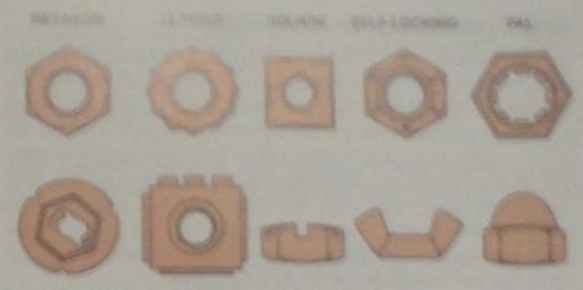


Figure 8–23 All of the nuts shown are used by themselves except for the pal nut, which is used to lock another nut to a threaded fastener so they will not be loosened by vibration.

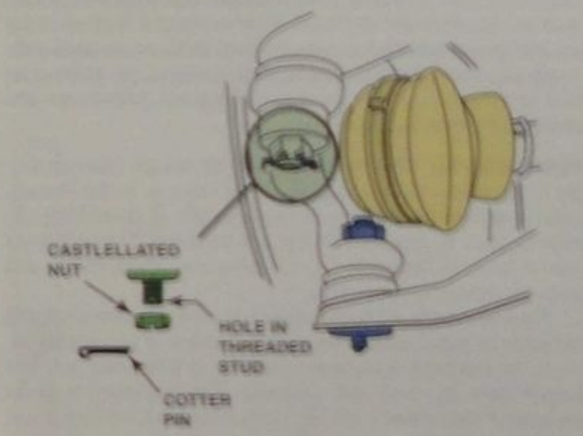


Figure 8–24 A castellated nut is locked in place with a cotter pin.

are oval-shaped at one end to fit tightly on a bolt. Fiber lock nuts have a fiber insert near the top of the nut or inside it; this type of nut is also made with a plastic or nylon insert. When the bolt turns through the nut, it cuts threads in the fiber or plastic. This puts a drag on the threads that prevents the bolt from loosening.

One of the oldest types of retaining nuts is the castle nut. It looks like a small castle, with slots for a cotter pin. A castellated nut is used on a bolt that has a hole for the cotter pin. See Figure 8–24.

Flat washers are placed underneath a nut to spread the load over a wide area and prevent gouging of the material. However, flat washers do not prevent a nut from loosening.

Lock washers are designed to prevent a nut from loosening. Spring-type lock washers resemble a loop out of a coil spring. As the nut or bolt is tightened, the washer is compressed. The tension of the compressed washer holds the fastener firmly against the threads to prevent it from loosening. Lock washers should not be used on soft metal such as aluminum. The sharp ends of the steel washers would gouge the aluminum badly, especially if they are removed and replaced often.

Another type of locking washer is the star washer. The teeth on a star washer can be external or internal, and they bite into the metal because they are twisted to expose their edges. Star washers are used often on sheet metal or body parts. They are seldom used on engines. The spring steel lock washer also uses the tension of the compressed washer to prevent the fastener from loosening. The waves in this washer make it look like a distorted flat washer.

HOW TO AVOID BROKEN FASTENERS

Try not to break, strip, or round off fasteners in the first place. There are several ways that you can minimize the number of fasteners you damage. First, never force fasteners loose during disassembly. Taking a few precautionary steps will often prevent damage. If a bolt or nut will not come loose with normal force, try tightening it in slightly and then backing it out. Sometimes turning the fastener the other way will break corrosion loose, and the fastener will then come out easily. Another method that works well is to rest a punch on the head of a stubborn bolt and strike it a sharp blow with a hammer. Often this method will break the corrosion loose.

Left-Handed Threads Although rare, left-handed fasteners are occasionally found on engine assemblies. These fasteners will loosen when you turn them clockwise, and tighten when you turn them counterclockwise. Left-handed fasteners are used to fasten parts to the ends of rotating assemblies that turn counterclockwise, such as crankshafts and camshafts. Most automobile engines do not use left-handed threads; however, they will be found on many older motorcycle engines. Some left-handed fasteners are marked for easy identification, others are not. Left-handed threads are also found inside some transaxles.

Penetrating Oil **Penetrating oil** is a lightweight lubricant similar to kerosene, which soaks into small crevices in the threads, called **capillary action.** The chemical action of penetrating oils helps to break up and dissolve rust and corrosion. The oil forms a layer of boundary lubrication on the threads to reduce friction and make the fastener easier to turn.

For best results, allow the oil time to soak in before removing the nuts and bolts. To increase the effectiveness of penetrating oil, tap on the bolt head or nut with a hammer, or alternately work the fastener back and forth with a wrench. This movement weakens the bond of the corrosion and lets more of the lubricant work down into the threads.

Proper Tightening Proper tightening of bolts and nuts is critical for proper clamping force, as well as to prevent breakage. All fasteners should be tightened using a torque wrench. A torque wrench allows the technician to exert a known amount of torque to the fasteners. However, rotating torque on a fastener does not mean clamping force because up to 80% of the torque used to rotate a bolt or nut is absorbed by friction by the threads. Therefore, for accurate tightening, two things must be performed:

- The threads must be clean and lubricated if service information specifies that they be lubricated.
- Always use a torque wrench to not only ensure proper clamping force, but also to ensure that all fasteners are tightened the same.

THREAD REPAIR INSERTS

Thread repair inserts are used to replace the original threaded hole when it has become damaged beyond use. The original threaded hole is enlarged and a threaded insert is installed to restore the threads to the original size.

Helical Inserts A **helical insert** looks like a small, stainless-steel spring. See Figure 8–25.

To install a helical insert, a hole must be drilled to a specified oversize, and then it is tapped with a special tap designed for the thread inserts. The insert is then screwed into the hole. See Figure 8–26.

The insert stays in the casting as a permanent repair and bolts can be removed and replaced without disturbing the insert. One advantage of a helical insert is that the original bolt can be used because the internal threads are the same size. When correctly installed,



Figure 8–25 Helical inserts look like small, coiled springs. The outside is a thread to hold the coil in the hole, and the inside is threaded to fit the desired fastener.

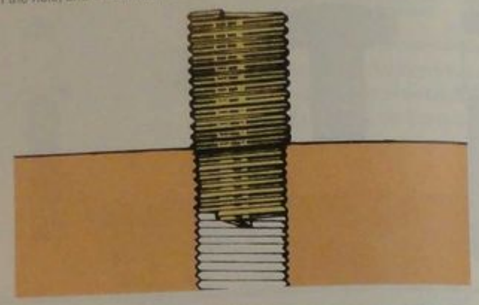


Figure 8–26 The insert provides new, stock-size threads inside an oversize hole so that the original fastener can be used.



Figure 8–27 Helicoil® kits, available in a wide variety of sizes, contain everything needed to repair a damaged hole back to its original size.

an insert is often stronger than the original threads, especially in aluminum castings. Some vehicle manufacturers such as BMW specify that the threads be renewed using an insert if the cylinder head has to be removed and reinstalled. Plus many high-performance engine rebuilders install inserts in blocks, manifolds, and cylinder heads as a precaution.

One of the best known of the helical fasteners is the **Helicoil®**, manufactured by Helicoil® Products. To install Helicoil® inserts, you will need to have a thread repair kit. The kit includes a drill bit, tap, installation mandrel, and inserts. Repair kits are available for a wide variety of diameters and pitch to fit both American Standard and metric threads. A simple kit contains the tooling for one specific thread size. Master kits that cover a range of sizes are also available. Installing an insert is similar to tapping new threads. A summary of the procedures includes:

1. Select the Helicoil® kit designed for the specific diameter and thread pitch of the hole to be repaired. See Figure 8–27.
2. Use the drill bit supplied with the kit. The drill size is also specified on the Helicoil® tap, to open up the hole to the necessary diameter and depth.
3. Tap the hole with the Helicoil® tap, being sure to lubricate the tap. Turn it in slowly and rotate counterclockwise occasionally to break the chip that is formed.
4. Thread an insert onto the installation mandrel until it seats firmly. Apply a light coating of the recommended thread locking compound to the external threads of the insert.
5. Use the mandrel to screw the insert into the tapped hole. Once started, spring tension prevents the insert from unscrewing. Stop when the top of the insert is 1/4 to 1/2 turn below the surface.
6. Remove the mandrel by unscrewing it from the insert, and then use a small punch or needle-nose pliers to break off the tang at the base of the insert. Never leave the tang in the bore. The finished thread is ready for use immediately.

Threaded Inserts **Threaded inserts** are tubular, case-hardened, solid steel wall pieces that are threaded inside and outside. The inner thread of the insert is sized to fit the original fastener of the hole to be repaired. The outer thread design will vary. These may be self-tapping threads that are installed in a blank hole, or machine threads that require the hole to be tapped. Threaded inserts return a damaged hole to original size by replacing part of the surrounding casting so drilling is required. Most inserts fit into three categories:

- Self-tapping
- Solid-bushing
- Key-locking

Self-Tapping Inserts The external threads of a self-tapping insert are designed to cut their own way into a casting. This eliminates the need of running a tap down the hole. To install a typical self-tapping insert, follow this procedure:

1. Drill out the damaged threads to open the hole to the proper size, using the specified size drill bit.
2. Select the proper insert and mandrel. As with Helicoils®, the drill bit, inserts, and mandrel are usually available as a kit.
3. Thread the insert onto the mandrel. Use a tap handle or wrench to drive the insert into the hole. Because the insert will cut its own path into the hole, it may require a considerable amount of force to drive the insert in.
4. Thread the insert in until the nut or flange at the bottom of the mandrel touches the surface of the workpiece. This is the depth stop to indicate the insert is seated.
5. Hold the nut or flange with a wrench, and turn the mandrel out of the insert. The threads are ready for immediate use.

Solid-Bushing Inserts The external threads of solid-bushing inserts are ground to a specific thread pitch, so you will have to run a tap into the hole. See Figure 8–28.

Some inserts use a machine thread so a standard tap can be used; others have a unique thread and you have to use a special tap. The thread inserts come with a matching installation kit. See Figure 8–29.

To install threaded inserts, follow this procedure:

1. Drill out the damaged threads to open the hole to the proper size. The drill bit supplied with the kit must be the one used because it is properly sized to the tap. See Figure 8–30.
2. Cut the recess in the top of the hole with the special tool, then clean the hole with a brush or compressed air.
3. Use the previously detailed tapping procedures to thread the hole. See Figure 8–31. Be sure to tap deep enough; the top of the insert must be flush with the casting surface.
4. Thread the insert onto the installation driver, using the driver to screw the insert into the hole. Some inserts require that a thread-locking compound be applied; others go in dry.
5. Remove the installation driver, and the new threads are ready for service with the original fastener.

Key-Locking Inserts Key-locking inserts are similar to solid-bushing inserts, but are held in place by small keys. After the insert

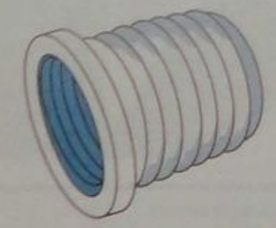


Figure 8–28 This solid-bushing insert is threaded on the outside, to grip the workpiece. The inner threads match the desired bolt size.

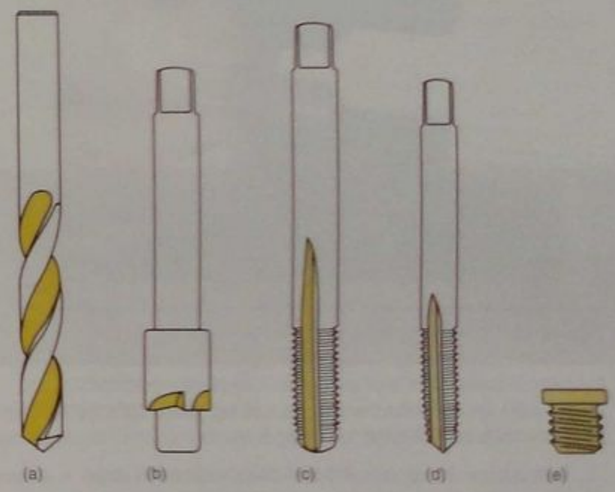


Figure 8–29 A Timesert® kit includes the drill (a), the recess cutter (b), a special tap (c), the installer (d), and the Timesert® threaded bushing (e).



Figure 8–30 Drill out the damaged threads with the correct bit.



Figure 8–31 Use a special tap for the insert.

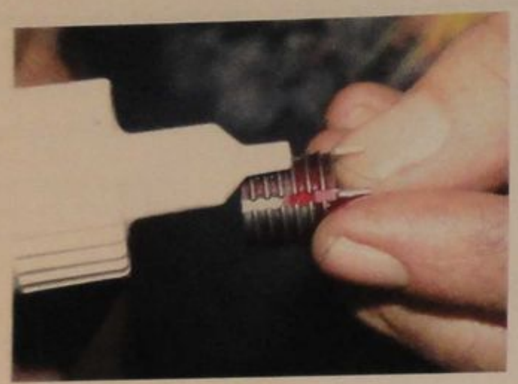


Figure 8–32 Put some thread-locking compound on the insert.

has been installed, the keys are driven into place—perpendicular to the threads—to keep the insert from turning out. A typical installation procedure includes the following steps:

1. Drill out the damaged thread with the specified drill size.
2. Tap the drilled hole with the specified tap.
3. After putting thread locking compound on the insert, use the mandrel to screw the insert into the tapped hole until it is slightly below the surface. See Figure 8–32. The keys act as a depth stop and prevent the insert from turning.
4. Drive the keys down using the driver supplied with the insert kit. Be sure the keys are flush with the top of the insert. See Figures 8–33 and 8–34.

SUMMARY

1. The most common type of fastener is a threaded one often referred to as a bolt. A nut or thread hole is used at the end of a bolt to fasten two parts together.
2. The size of threaded fasteners includes the diameter, length, and pitch of the threads, as well as the shape of the head of the bolt.
3. Metric bolts are labeled with an "M," and the diameter across the threads is in millimeters followed by the distance between the threads measured in millimeters, such as $M8 \times 1.5$.
4. Graded bolts are hardened and are capable of providing more holding force than nongraded bolts.
5. Many nuts are capable of remaining attached to the bolt regardless of vibration. These types of nuts are often called prevailing torque nuts.



Figure 8–33 Use the driver to drive the keys down flush with the surface of the workpiece.



Figure 8–34 The insert and insert locks should be below the surface of the workpiece.

6. Other commonly used fasteners in the automotive service industry include sheet metal screws, snap rings and clips, door panel clips, cotter pins, and rivets.
7. Threads can be repaired using a Helicoil® or threaded insert.

REVIEW QUESTIONS

1. What is the difference between a bolt and a stud?
2. How is the size of a metric bolt expressed?
3. What is meant by the grade of a threaded fastener?
4. How do prevailing torque nuts work?
5. How are threaded inserts installed?

CHAPTER QUIZ

1. The thread pitch of a bolt is measured in what units?
   a. Millimeters
   b. Threads per inch
   c. Fractions of an inch
   d. Both a and b can be correct
2. Technician A says that the diameter of a bolt is the same as the wrench size used to remove or install the fastener. Technician B says that the length is measured from the top of the head of the bolt to the end of the bolt. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. The grade of a fastener, such as a bolt, is a measure of its _____.
   a. Tensile strength
   b. Hardness
   c. Finish
   d. Color
4. Which of the following is a metric bolt?
   a. 5/16 – 18
   b. 1/2 - 20
   c. M12 × 1.5
   d. 8 mm
5. A bolt that is threaded into a casting is often called a _____.
   a. Stud
   b. Cap screw
   c. Block bolt
   d. Crest bolt
6. The marks (lines) on the heads of bolts indicate _____.
   a. Size
   b. Grade
   c. Tensile strength
   d. Both b and c
7. A bolt that requires a 1/2-inch wrench to rotate is usually what size when measured across the threads?
   a. 1/2-inch
   b. 5/16 inch
   c. 3/8 inch
   d. 7/16 inch
8. A screw that cuts mating threads when installed is called a _____ screw.
   a. Sheet metal
   b. Tapered
   c. Self-tapping
   d. Blunt end
9. All of the following are types of clips *except* _____.
   a. E-clip
   b. Cotter
   c. C-clip
   d. Internal
10. What type of fastener is commonly used to retain interior door panels?
    a. Christmas tree clips
    b. E-clips
    c. External clips
    d. Internal clips

CHAPTER 9

Hand Tools

OBJECTIVES: After studying Chapter 9, the reader will be able to: Describe what tool is the best to use for each job. • Discuss how to safely use hand tools. • Explain the difference between the brand name (trade name) and the proper name for tools. • Explain how to maintain hand tools.

KEY TERMS: adjustable wrench • aviation tin snips • beam-type torque wrench • box-end wrench • breaker bar (flex handle) • cheater bar • chisel • clicker-type torque wrench • close end • cold chisel • combination wrench • crowfoot socket • dead-blow hammer • diagonal (side-cut or dike) pliers • double-cut file • drive size • easy out • extension • files • fitting wrench • flare-nut wrench • flat-tip (straight blade) screwdriver • hacksaw • locking pliers • multi-groove adjustable pliers • needle-nose pliers • nut splitter • offset left aviation snip • offset right aviation snip • open-end wrench • punch • ratchet • removers • screwdriver • seal driver • seal puller • single-cut file • slip-joint pliers • snap-ring pliers • socket • socket adapter • straight cut aviation snip • stud removal tool • stud remover • tin snips • torque wrench • tube-nut wrench • universal joint • utility knife • VISE GRIPS® • water pump pliers • wrench

WRENCHES

Wrenches are the most used hand tool by service technicians. Most wrenches are constructed of forged alloy steel, usually chrome-vanadium steel. See Figure 9–1.

After the wrench is formed, the wrench is hardened, and then tempered to reduce brittleness, and then chrome plated. There are several types of wrenches.

Open-End Wrench An **open-end wrench** is usually used to loosen or tighten bolts or nuts that do not require a lot of torque. An open-end wrench can be easily placed on a bolt or nut with an angle of 15 degrees, which allows the wrench to be flipped over and used again to continue to rotate the fastener. The major disadvantage



Figure 9–1 A forged wrench after it has been forged but before the flashing, extra material around the wrench has been removed.

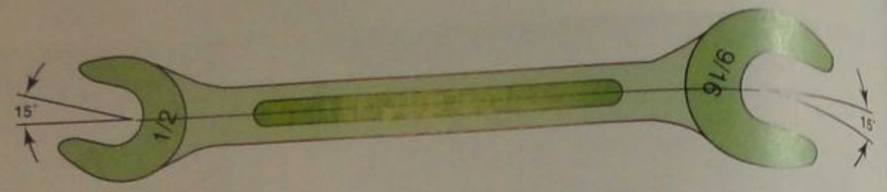


Figure 9–2 A typical open-end wrench. The size is different on each end and notice that the head is angled 15 degrees at each end.

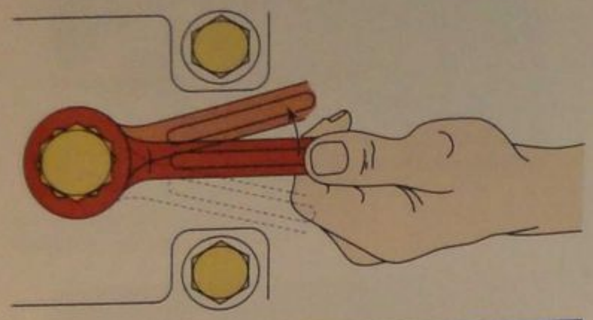


Figure 9–3 A typical box-end wrench is able to grip the bolt or nut at points completely around the fastener. Each end is a different size.

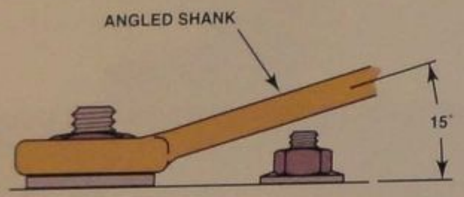


Figure 9–4 The end of a box-end wrench is angled 15 degrees to allow clearance for nearby objects or other fasteners.

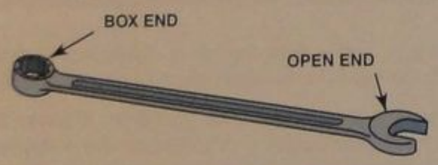


Figure 9–5 A combination wrench has an open end at one end and a box end at the other end.

of an open-end wrench is the lack of torque that can be applied due to the fact that the open jaws of the wrench only contact two flat surfaces of the fastener. An open-end wrench has two different sizes; one at each end. See Figure 9–2.

Box-End Wrench A **box-end wrench** is placed over the top of the fastener and grips the points of the fastener. A box-end wrench is angled 15 degrees to allow it to clear nearby objects. See Figure 9–3.

Therefore, a box-end wrench should be used to loosen or to tighten fasteners. A box-end wrench is also called a **close-end** wrench. A box-end wrench has two different sizes; one at each end. See Figure 9–4.

Most service technicians purchase **combination wrenches,** which have the open end at one end and the same size box end on the other end. See Figure 9–5.

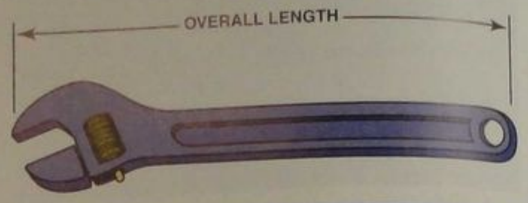


Figure 9–6 An adjustable wrench. Adjustable wrenches are sized by the overall length of the wrench and not by how far the jaws open. Common sizes of adjustable wrenches include 8, 10, and 12 inch.



Figure 9–7 The end of a typical line wrench, which shows that it is capable of grasping most of the head of the fitting.

A combination wrench allows the technician to loosen or tighten a fastener using the box end of the wrench, turn it around, and use the open end to increase the speed of rotating the fastener.

Adjustable Wrench An **adjustable wrench** is often used where the exact size wrench is not available or when a large nut, such as a wheel spindle nut, needs to be rotated but not tightened. An adjustable wrench should not be used to loosen or tighten fasteners because the torque applied to the wrench can cause the moveable jaws to loosen their grip on the fastener, causing it to become rounded. See Figure 9–6.

Line Wrenches Line wrenches are also called **flare-nut wrenches, fitting wrenches, or tube-nut wrenches** and are designed to grip almost all the way around a nut used to retain a fuel or refrigerant line, and yet, be able to be installed over the line. See Figure 9–7.

Safe Use of Wrenches Wrenches should be inspected before use to be sure they are not cracked, bent, or damaged. All wrenches should be cleaned after use before being returned to the toolbox. Always use the correct size of wrench for the fastener being loosened or tightened to help prevent the rounding of the flats of the fastener. When attempting to loosen a fastener, pull a wrench—do not push a wrench. If a wrench is pushed, your knuckles can be hurt when forced into another object if the fastener breaks loose.

RATCHETS, SOCKETS, AND EXTENSIONS

A **socket** fits over the fastener and grips the points and flats of the bolt or nut. The socket is rotated (driven) using either a long, a ratchet, a **breaker bar (flex handle)** or a **ratchet.** See Figures 9–8 and 9–9.

A ratchet turns the socket in only one direction and allows the rotating of the ratchet handle back and forth in a narrow space. Socket **extensions** and **universal joints** are also used with sockets to allow access to fasteners in restricted locations.

Sockets are available in various **drive sizes,** including 1/4-inch, 3/8-inch, and 1/2-inch sizes for most automotive use. See Figures 9–10 and 9–11.

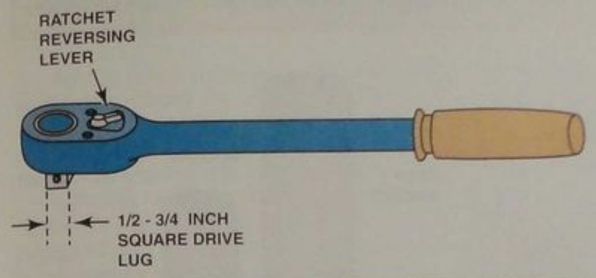


Figure 9–8 A typical ratchet used to rotate a socket. A ratchet makes a ratcheting noise when it is being rotated in the opposite direction from loosening or tightening. A knob or lever on the ratchet allows the user to switch directions.

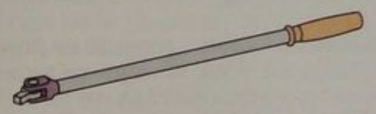


Figure 9–9 A typical flex handle used to rotate a socket, also called a breaker bar because it usually has a longer handle than a ratchet and therefore, can be used to apply more torque to a fastener than a ratchet.

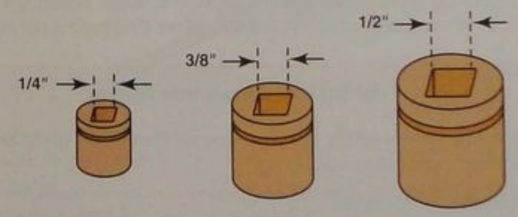


Figure 9–10 The most commonly used socket drive sizes include 1/4-inch, 3/8-inch, and 1/2-inch drive.

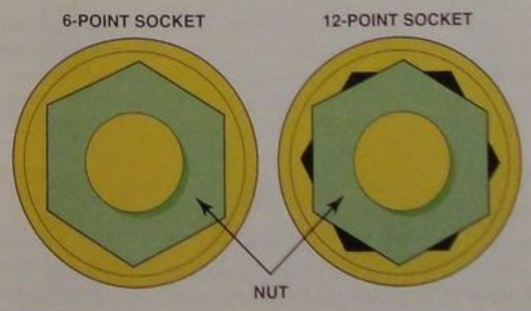


Figure 9–11 A six-point socket fits the head of the bolt or nut on all sides. A twelve-point socket can round off the head of a bolt or nut if a lot of force is applied.

Right to Tighten

It is sometimes confusing which way to rotate a wrench or screwdriver, especially when the head of the fastener is pointing away from you. To help visualize while looking at the fastener, say "righty tighty, lefty loosey."

Crowfoot Sockets A **crowfoot socket** is a socket that is an open-end or line wrench to allow access to fasteners that cannot be reached using a conventional wrench. See Figure 9–12.

Crowfoot sockets are available in the following categories:

- Fractional inch open-end wrench
- Metric open-end wrench
- Fractional line wrench
- Metric line wrench

Torque Wrenches **Torque wrenches** are socket turning handles that are designed to apply a known amount of force to the fastener. There are two basic types of torque wrenches including:

1. **Clicker type.** A **clicker-type torque wrench** is first set to the specified torque and then it "clicks" when the set torque value has been reached. When force is removed from the torque wrench handle, another click is heard. The setting on a clicker-type torque wrench should be set back to zero after use and checked for proper calibration regularly. See Figure 9–13.
2. A **beam-type torque wrench** is used to measure torque, but instead of presetting the value, the actual torque is displayed on



Figure 9–12 A crowfoot socket is designed to reach fasteners using a ratchet or breaker bar with an extension.



Figure 9–13 Using a torque wench to tighten connecting rod nuts on an engine.

the dial of the wrench as the fastener is being tightened. Beam-type torque wrenches are available in 1/4-inch, 3/8-inch, and 1/2-inch drives and both English and metric units. See Figure 9–14.



Figure 9–14 A beam-type torque wrench that displays the torque reading on the face of the dial. The beam display is read as the beam defects, which is in proportion to the amount of torque applied to the fastener.

TECH TIP ✓ Check Torque Wrench Calibration Regularly

Torque wrenches should be checked regularly. For example, Honda has a torque wrench calibration setup at each of their training centers. It is expected that a torque wrench be checked for accuracy before every use. Most experts recommend that torque wrenches be checked and adjusted as needed at least every year and more often if possible. See Figure 9–15.



Figure 9–15 Torque wrench calibration checker.

FREQUENTLY ASKED QUESTION ???

Is It Lb-Ft or Ft-Lb of Torque?

The unit for torque is expressed as a force times the distance (leverage) from the object. Therefore, the official unit for torque is lb-ft (pound-feet) or Newton-meters (a force times a distance). However, it is commonly expressed in ft-lbs and even some torque wrenches are labeled with this unit.

TECH TIP ✓ Double-Check the Specifications

Misreading torque specifications is easy to do but can have serious damaging results. Specifications for fasteners are commonly expressed in lb-ft. Many smaller fasteners are tightened to specifications expressed in lb-in.

1 lb-ft = 12 lb-in.

Therefore, if a fastener were to be accidentally tightened to 24 lb-ft instead of 24 lb-in., the actual torque applied to the fastener will be 288 lb-in. instead of the specified 24 lb-in.

This extra torque will likely break the fastener, but it could also warp or distort the part being tightened. Always double-check the torque specifications.

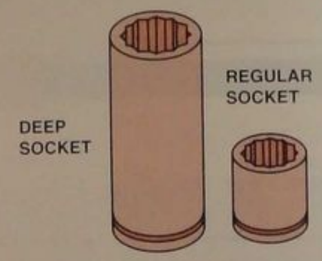


Figure 9–16 Deep sockets allow access to the nut that has a stud plus other locations needing great depth, such as spark plugs.

Safe Use of Sockets and Ratchets Always use the proper size socket that correctly fits the bolt or nut. All sockets and ratchets should be cleaned after use before being placed back into the toolbox. Sockets are available in short and deep well designs. See Figure 9–16.

Also select the appropriate drive size. For example, for small work, such as on the dash, select a 1/4-inch drive. For most general service work, use a 3/8-inch drive and for suspension and steering and other large fasteners, select a 1/2-inch drive. When loosening a fastener, always pull the ratchet toward you rather than push it outward.

TECH TIP ✓ Use Socket Adapters with Caution

Socket adapters are available and can be used for different drive size sockets on a ratchet. Combinations include:

- 1/4-inch drive—3/8-inch sockets
- 3/8-inch drive—1/4-inch sockets
- 3/8-inch drive—1/2-inch sockets
- 1/2-inch drive—3/8-inch sockets

Using a larger drive ratchet or breaker bar on a smaller size socket can cause the application of too much force to the socket, which could crack or shatter. Using a smaller size drive tool on a larger socket will usually not cause any harm, but would greatly reduce the amount of torque that can be applied to the bolt or nut.

TECH TIP ✓ Avoid Using "Cheater Bars"

Whenever a fastener is difficult to remove, some technicians will insert the handle of a ratchet or a breaker bar into a length of steel pipe. The extra length of the pipe allows the technician to exert more torque than can be applied using the drive handle alone. However, the extra torque can easily overload the socket and ratchet, causing them to break or shatter, which could cause personal injury.

SCREWDRIVERS

Many smaller fasteners are removed and installed by using a screwdriver. Screwdrivers are available in many sizes and tip shapes. The most commonly used screwdriver is called a **flat tip** or **straight blade.**

Flat-tip screwdrivers are sized by the width of the blade and this width should match the width of the slot in the screw. See Figure 9–17.

CAUTION: Do not use a screwdriver as a pry tool or as a chisel. Always use the proper tool for each application.

Another type of commonly used screwdriver is called a Phillips screwdriver, named for Henry F. Phillips, who invented the crosshead screw in 1934. Due to the shape of the crosshead screw and screwdriver, a Phillips screw can be driven with more torque than can be achieved with a slotted screw.

A Phillips head screwdriver is specified by the length of the handle and the size of the point at the tip. A #1 tip has a sharp point, a #2 tip is the most commonly used, and a #3 tip is blunt and is only used for larger sizes of Phillips head fasteners. For example, a #2 × 3-inch Phillips screwdriver would typically measure 6 inches from the tip of the blade to the end of the handle (3-inch-long handle and 3-inch-long blade) with a #2 tip.

Both straight blade and Phillips screwdrivers are available with a short blade and handle for access to fasteners with limited room. See Figure 9–18.

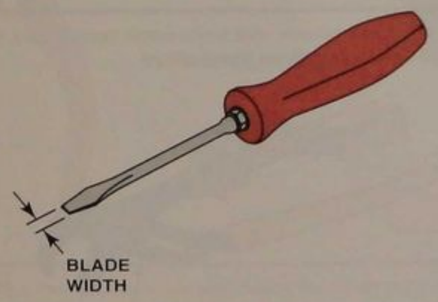


Figure 9–17 A flat-tip (straight blade) screwdriver. The width of the blade should match the width of the slot in the fastener being loosened or tightened.



Figure 9–18 Two stubby screwdrivers that are used to access screws that have limited space above. A straight blade is on top and a #2 Phillips screwdriver is on the bottom.

Offset Screwdrivers Offset screwdrivers are used in places where a conventional screwdriver cannot fit. An offset screwdriver is bent at the ends and is used similar to a wrench. Most offset screwdrivers have a straight blade at one end and a Phillips end at the opposite end. See Figure 9–19.

Impact Screwdriver An impact screwdriver is used to break loose or tighten a screw. A hammer is used to strike the end after the screwdriver holder is placed in the head of the screw and rotated in the desired direction. The force from the hammer blow does two things: it applies a force downward holding the tip of the screwdriver in the slot and then applies a twisting force to loosen (or tighten) the screw. See Figure 9–20.

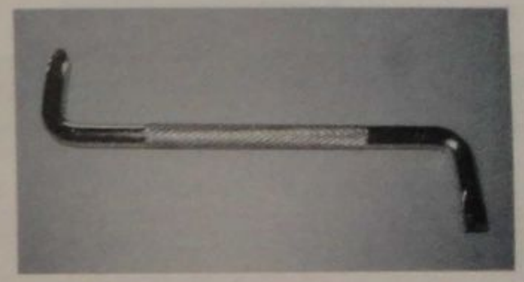


Figure 9–19 An offset screwdriver is used to install or remove fasteners that do not have enough space above to use a conventional screwdriver.



Figure 9–20 An impact screwdriver used to remove slotted or Phillips head fasteners that cannot be broken loose using a standard screwdriver.

FREQUENTLY ASKED QUESTION ???

What Is a Robertson Screwdriver?

A Canadian named P. L. Robertson invented the Robertson screw and screwdriver in 1908, which uses a square-shaped tip with a slight taper. The Robertson screwdriver uses color-coded handles because different size screws required different tip sizes. The color and sizes include:

- Orange (#00)—Number 1 and 2 screws
- Yellow (#0)—Number 3 and 4 screws
- Green (#1)—Number 5, 6, and 7 screws
- Red (#2)—Number 8, 9, and 10 screws
- Black (#3)—Number 12 and larger screws

The Robertson screws are rarely found in the United States but are common in Canada.

Safe Use of Screwdrivers Always use the proper type and size screwdriver that matches the fastener. Try to avoid pressing down on a screwdriver because if it slips, the screwdriver tip could go into your hand, causing serious personal injury. All screwdrivers should be cleaned after use. Do not use a screwdriver as a pry bar; always use the correct tool for the job.

HAMMERS AND MALLETS

Hammers Hammers and mallets are used to force objects together or apart. The shape of the back part of the hammer head (called the **peen**) usually determines the name. For example, a ball-peen hammer has a rounded end like a ball and it is used to straighten oil pans and valve covers, using the hammer head, and for shaping metal, using the ball peen. See Figure 9–21.

> **NOTE:** A claw hammer has a claw used to remove nails and is not used for automotive service.

A hammer is usually sized by the weight of the head of the hammer and the length of the handle. For example, a commonly used ball-peen hammer has an 8-ounce head with an 11-inch handle.

Mallets Mallets are a type of hammer with a large striking surface, which allows the technician to exert force over a larger area than a hammer, so as not to harm the part or component. Mallets are made from a variety of materials including rubber, plastic, or wood. See Figure 9–22.

A shot-filled plastic hammer is called a **dead-blow hammer.** The small lead balls (shot) inside a plastic head prevent the hammer from bouncing off of the object when struck. See Figure 9–23.

Safe Use of Hammers and Mallets All mallets and hammers should be cleaned after use and not exposed to extreme temperatures. Never use a hammer or mallet that is damaged in any way and always use caution to avoid doing damage to the components and the surrounding area. Always follow the hammer manufacturer's recommended procedures and practices.



Figure 9–21 A typical ball-peen hammer.



Figure 9–22 A rubber mallet used to deliver a force to an object without harming the surface.



Figure 9–23 A dead-blow hammer that was left outside in freezing weather. The plastic covering was damaged, which destroyed this hammer. The lead shot is encased in the metal housing and then covered.

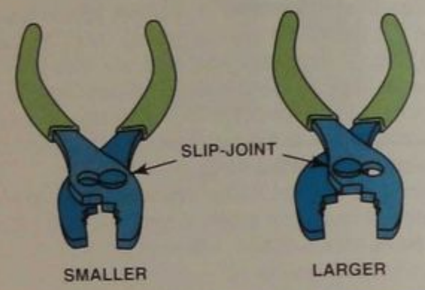


Figure 9–24 Typical slip-joint pliers, which are also common household pliers. The slip joint allows the jaws to be opened to two different settings.

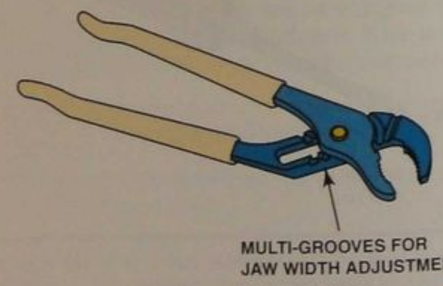


Figure 9–25 Multigroove adjustable pliers are known by many names, including the trade name "Channel Locks."

PLIERS

Slip-Joint Pliers Pliers are capable of holding, twisting, bending, and cutting objects and are an extremely useful classification of tools. The common household type of pliers is called the **slip-joint pliers.** There are two different positions where the junction of the handles meets to achieve a wide range of sizes of objects that can be gripped. See Figure 9–24.

MultiGroove Adjustable Pliers For gripping larger objects, a set of **multigroove adjustable pliers** is a commonly used tool of choice by many service technicians. Originally designed to remove the various size nuts holding rope seals used in water pumps, the name **water pump pliers** is also used. See Figure 9–25.

Linesman's Pliers Linesman's pliers are specifically designed for cutting, bending, and twisting wire. While commonly used by construction workers and electricians, linesman's pliers are very useful tools for the service technician who deals with wiring. The center parts of the jaws are designed to grasp round objects such as pipe or tubing without slipping. See Figure 9–26.

Diagonal Pliers **Diagonal pliers** are designed for cutting only. The cutting jaws are set at an angle to make it easier to cut wires. Diagonal pliers are also called **side cut** or **dike.** These pliers are constructed of hardened steel and they are used mostly for cutting wire. See Figure 9–27.

Needle-Nose Pliers **Needle-nose pliers** are designed to grip small objects or objects in tight locations. Needle-nose pliers have long, pointed jaws, which allow the tips to reach into narrow openings or groups of small objects. See Figure 9–28.

Most needle-nose pliers have a wire cutter located at the base of the jaws near the pivot. There are several variations of needle-nose pliers, including right angle jaws or slightly angled to allow access to certain cramped areas.

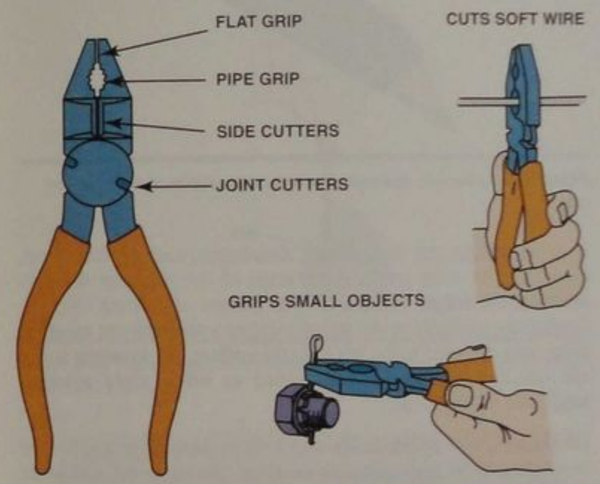


Figure 9–26 A linesman's pliers are very useful because they can help perform many automotive service jobs.

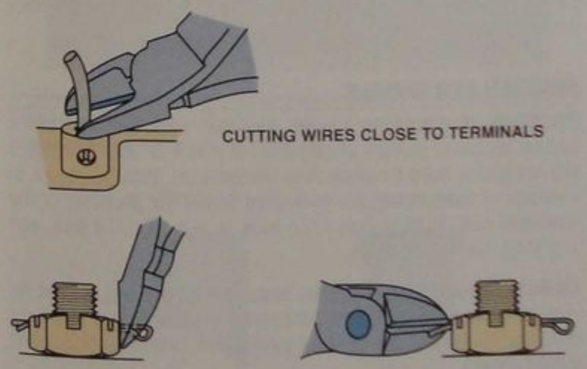


Figure 9–27 Diagonal-cut pliers are another common tool that has many names.

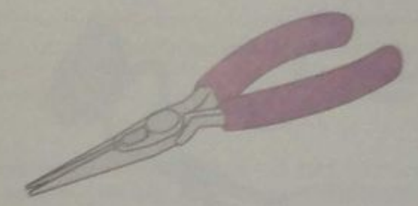


Figure 9–28 Needle-nose pliers are used where there is limited access to a wire or pin that needs to be installed or removed.

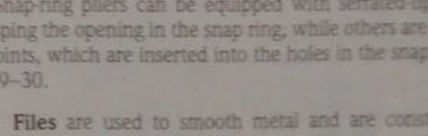


Figure 9–29 Locking pliers are best known by their trade name VISE GRIPS®.

Locking Pliers **Locking pliers** are adjustable pliers that can be locked to hold objects from moving. Most locking pliers also have wire cutters built into the jaws near the pivot point. Locking pliers come in a variety of styles and sizes and are commonly referred to by their trade name **VISE GRIPS®.** The size is the length of the pliers, not how far the jaws open. See Figure 9–29.

Safe Use of Pliers Pliers should not be used to remove any bolt or other fastener. Pliers should only be used when specified for use by the vehicle manufacturer.

TECH TIP ✓ **Brand Name versus Proper Term**

Technicians often use slang or brand names of tools rather than the proper term. This results in some confusion for new technicians. Some examples are given in the following table.

Brand Name	Proper Term	Slang Name
Crescent wrench	Adjustable wrench	Monkey wrench
Vise Grips	Locking pliers	
Channel Locks	Water pump pliers or multigroove adjustable pliers	Pump pliers
	Diagonal cutting pliers	Dikes or side cuts

Snap-Ring Pliers **Snap-ring pliers** are used to remove and install snap rings. Many snap-ring pliers are designed to be able to remove and install inward, as well as outward, expanding snap rings. Snap-ring pliers can be equipped with serrated-tipped jaws for grasping the opening in the snap ring, while others are equipped with points, which are inserted into the holes in the snap ring. See Figure 9–30.

Files **Files** are used to smooth metal and are constructed of hardened steel with diagonal rows of teeth. Files are available with a single row of teeth called a **single-cut file,** as well as two rows of teeth cut at an opposite angle called a **double-cut file.** Files are available in a variety of shapes and sizes from small flat files, half-round files, and triangular files. See Figure 9–31.



Figure 9–30 Snap-ring pliers are also called lock-ring pliers and are designed to remove internal and external snap rings (lock rings).

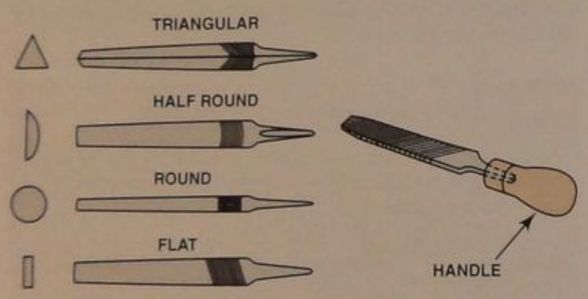


Figure 9–31 Files come in many different shapes and sizes. Never use a file without a handle.

Safe Use of Files Always use a file with a handle. Because files only cut when moved forward, a handle must be attached to prevent possible personal injury. After making a forward strike, lift the file and return the file to the starting position; avoid dragging the file backward.

TECH TIP ✓ **Use Chalk**

Often soft metal particles can become stuck in a file, especially when using it to file aluminum or other soft metals. Rub some chalk into the file before using it to prevent this from happening.

CUTTERS

Snips Service technicians are often asked to fabricate sheet metal brackets or heat shields and need to use one or more types of cutters available. The simplest is called **tin snips,** which are designed

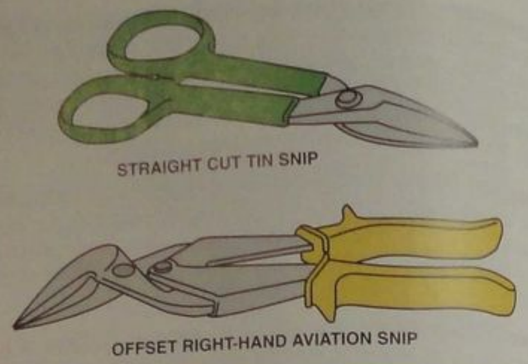


Figure 9–32 Tin snips are used to cut thin sheets of metal or carpet.

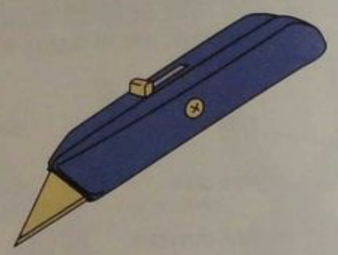


Figure 9–33 A utility knife uses replaceable blades and is used to cut carpet and other materials.

to make straight cuts in a variety of materials, such as sheet steel, aluminum, or even fabric. A variation of the tin snips is called **aviation tin snips.** There are three designs of aviation snips including one designed to cut straight (called a **straight cut aviation snip**), one designed to cut left (called an **offset left aviation snip**), and one designed to cut right (called an **offset right aviation snip**). See Figure 9–32.

Utility Knife A **utility knife** uses a replaceable blade and is used to cut a variety of materials such as carpet, plastic, wood, and paper products, such as cardboard. See Figure 9–33.

Safe Use of Cutters Whenever using cutters, always wear eye protection or a face shield to guard against the possibility of metal pieces being ejected during the cut. Always follow recommended procedures.

PUNCHES AND CHISELS

Punches A **punch** is a small diameter steel rod that has a smaller diameter ground at one end. A punch is used to drive a pin out that is used to retain two components. Punches come in a variety of sizes, which are measured across the diameter of the machined end. Sizes include 1/16 inch, 1/8 inch, 3/16 inch, and 1/4 inch. See Figure 9–34.

Chisels A **chisel** has a straight, sharp cutting end that is used for cutting off rivets or to separate two pieces of an assembly. The most common design of chisel used for automotive service work is called a **cold chisel.**

Safe Use of Punches and Chisels Always wear eye protection when using a punch or a chisel because the hardened steel is brittle and parts of the punch could fly off and cause serious personal injury. See the warning stamped on the side of this automotive punch in Figure 9–35.

Punches and chisels can also have the top rounded off, which is called "mushroomed." This material must be ground off to help avoid the possibility that the overhanging material is loosened and becomes airborne during use. See Figure 9–36.

REMOVERS

Removers are tools used to remove damaged fasteners. A remover tool is not normally needed during routine service unless the fastener is corroded or has been broken or damaged by a previous attempt to remove the bolt or nut.

To help prevent the need for a remover tool, all rusted and corroded fasteners should be sprayed with penetrating oil. Penetrating oil is a low viscosity oil that is designed to flow in between the threads of a fastener or other small separation between two parts. Commonly used penetrating oils include WD-40®, Kroil®, and CRC 5-56.

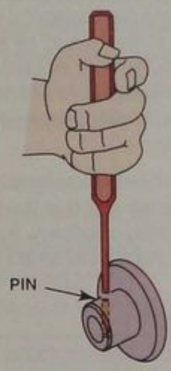


Figure 9–34 A punch used to drive pins from assembled components. This type of punch is also called a pin punch.



Figure 9–35 Warning stamped in the side of a punch warning that goggles should be worn when using this tool. Always follow safety warnings.

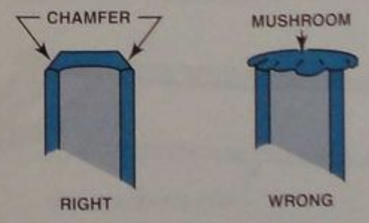


Figure 9–36 Use a grinder or a file to remove the mushroom material on the end of a punch or chisel.

CAUTION: Do not use penetrating oil as a lubricating oil because it is volatile and will evaporate soon after usage leaving little lubricant behind for protection.

Removers are a classification of tool used to remove stuck or broken fasteners. Over time, rust and corrosion can cause the threads of the fastener to be attached to the nut or the casting making it very difficult to remove. There are several special tools that can be used to remove damaged fasteners. Which one to use depends on the type of damage.

Damaged Heads If the bolt head or a nut becomes damaged or rounded, there are two special tools that can be used, including:

- **Stud remover.** A stud removal tool grips the part of the stub above the surface and uses a cam or wedge to grip the stud as it is being rotated by a ratchet or breaker bar. See Figure 9–37.
- **Nut splitter.** A **nut splitter** is used to remove the nut by splitting it from the bolt. A nut splitter is used by inserting the cutter against a flat of the nut and tightening the threaded bolt of the splitter. The nut will be split away from the bolt and can then be removed. See Figure 9–38.

CAUTION: Do not rotate the entire nut splitter or damage to the cutting wedge will occur.

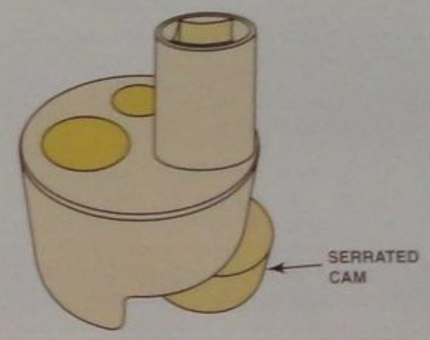


Figure 9–37 A stud remover uses an offset serrated wheel to grasp the stud so it will be rotated when a ratchet or breaker bar is used to rotate the assembly.

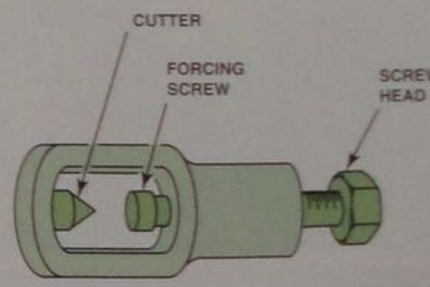


Figure 9–38 A nut splitter is used to split a nut that cannot be removed. After the nut has been split, a chisel is then used to remove the nut.

Broken Bolts, Studs, or Screws Often, bolts, studs, or screws break even with, or below the surface, making stud removal tools impossible to use. Bolt extractors are commonly called **"easy outs."** An easy out is constructed of hardened steel with flutes or edges ground into the side in an opposite direction of most threads. See Figure 9–39.

NOTE: Always select the largest extractor that can be used to help avoid the possibility of breaking the extractor while attempting to remove the bolt.

A hole is drilled into the center of a broken bolt. Then, the extractor (easy out) is inserted into the hole and rotated counterclockwise using a wrench. As the extractor rotates, the grooves grip tighter into the wall of the hole drilled in the broken bolt. As a result, most extractors are capable of removing most broken bolts.



Figure 9–39 A set of bolt extractors, commonly called easy outs.

TECH TIP ✓ **The Wax Trick**

Many times rusted fasteners can be removed by using heat to expand the metal and break the rust bond between the fastener and the nut or casting. Many technicians heat the fastener using a torch and then apply paraffin wax or a candle to the heated fastener. See Figure 9–40. The wax will melt and as the part cools, will draw the liquid wax down between the threads. After allowing the part to cool, attempt to remove the fastener. It will often be removed without any trouble.



Figure 9–40 Removing plugs or bolts is easier if the plug is first heated to cherry red color, using a torch, and then applying wax. During cooling, the wax flows in between the threads, making it easier to remove.

FREQUENTLY ASKED QUESTION ???

I Broke Off an Easy Out—Now What?

An extractor (easy out) is hardened steel and removing this and the broken bolt is now a job for a professional machine shop. The part, which could be as large as an engine block, needs to be removed from the vehicle and taken to a machine shop that is equipped to handle this type of job. One method involves using an electrical discharge machine (EDM). An EDM uses a high amperage electrical current to produce thousands of arcs between the electrode and the broken tool. The part is submerged in a nonconducting liquid and each tiny spark vaporizes a small piece of the broken tool.

HACKSAWS

A **hacksaw** is used to cut metals, such as steel, aluminum, brass, or copper. The cutting blade of a hacksaw is replaceable and the sharpness and number of teeth can be varied to meet the needs of the job. Use 14 or 18 teeth per inch (tpi) for cutting plaster or soft metals, such as aluminum and copper. Use 24 or 32 teeth per inch for steel or pipe. Hacksaw blades should be installed with the teeth pointing away from the handle. This means that a hacksaw cuts while the blade is pushed in the forward direction, and then pressure should be released as the blade is pulled rearward before repeating the cutting operation. See Figure 9–41.

Safe Use of Hacksaws Check that the hacksaw is equipped with the correct blade for the job and that the teeth are pointed away from the handle. When using a hacksaw, move the hacksaw slowly away from you, then lift slightly and return for another cut.

BASIC HAND TOOL LIST

Hand tools are used to turn fasteners (bolts, nuts, and screws). The following is a list of hand tools every automotive technician should possess. Specialty tools are not included.

Safety glasses
Tool chest
1/4-inch drive socket set (1/4 to 9/16 in. standard and deep sockets; 6 to 15 mm standard and deep sockets)
1/4-inch drive ratchet
1/4-inch drive 2-inch extension
1/4-inch drive 6-inch extension
1/4-inch drive handle
3/8-inch drive socket set (3/8 to 7/8 in. standard and deep sockets;10 to 19 mm standard and deep sockets)
3/8-inch drive Torx set (T40, T45, T50, and T55)
3/8-inch drive 13/16-inch plug socket
3/8-inch drive 5/8-inch plug socket

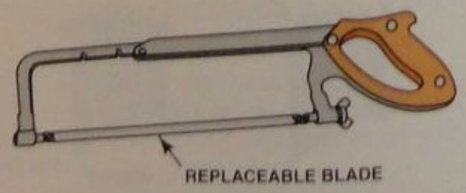


Figure 9–41 A typical hacksaw that is used to cut metal. If cutting sheet metal or thin objects, a blade with more teeth should be used.

3/8-inch drive ratchet
3/8-inch drive 1 1/2-inch extension
3/8-inch drive 3-inch extension
3/8-inch drive 6-inch extension
3/8-inch drive 18-inch extension
3/8-inch drive universal
1/2-inch drive socket set (1/2 to 1 in. standard and deep sockets)
1/2-inch drive ratchet
1/2-inch drive breaker bar
1/2-inch drive 5-inch extension
1/2-inch drive 10-inch extension
3/8-inch to 1/4-inch adapter
1/2-inch to 3/8-inch adapter
3/8-inch to 1/2-inch adapter
Crowfoot set (fractional inch)
Crowfoot set (metric)
3/8- through 1-inch combination wrench set
10 millimeters through 19 millimeters combination wrench set
1/16-inch through 1/4-inch hex wrench set
2 millimeters through 12 millimeters hex wrench set
3/8-inch hex socket
13 millimeters to 14 millimeters flare nut wrench
15 millimeters to 17 millimeters flare nut wrench
5/16-inch to 3/8-inch flare nut wrench
7/16-inch to 1/2-inch flare nut wrench
1/2-inch to 9/16-inch flare nut wrench
Diagonal pliers
Needle pliers
Adjustable-jaw pliers
Locking pliers
Snap-ring pliers
Stripping or crimping pliers
Ball-peen hammer
Rubber hammer
Dead-blow hammer
Five-piece standard screwdriver set
Four-piece Phillips screwdriver set
#15 Torx screwdriver
#20 Torx screwdriver
File
Center punch
Pin punches (assorted sizes)
Chisel
Utility knife
Valve core tool
Filter wrench (large filters)
Filter wrench (smaller filters)
Test light
Feeler gauge
Scraper
Magnet

TOOL SETS AND ACCESSORIES

A beginning service technician may wish to start with a small set of tools before spending a lot of money on an expensive, extensive tool box. See Figures 9–42 and 9–43.

TECH TIP ✓ **Hide Those from the Boss**

An apprentice technician started working for a dealership and put his tool box on a workbench. Another technician observed that, along with a complete set of good-quality tools, the box contained several adjustable wrenches. The more experienced technician said, "Hide those from the boss." If any adjustable wrench is used on a bolt or nut, the movable jaw often moves or loosens and starts to round the head of the fastener. If the head of the bolt or nut becomes rounded, it becomes that much more difficult to remove.

TECH TIP ✓ **Need to Borrow a Tool More Than Twice? Buy It!**

Most service technicians agree that it is okay for a beginning technician to borrow a tool occasionally. However, if a tool has to be borrowed more than twice, then be sure to purchase it as soon as possible. Also, whenever a tool is borrowed, be sure that you clean the tool and let the technician you borrowed the tool from know that you are returning the tool. These actions will help in any future dealings with other technicians.



Figure 9–42 A typical beginning technician tool set that includes the basic tools to get started.



Figure 9–43 A typical large tool box, showing just one of many drawers.

TECH TIP ✔ **The Valve Grinding Compound Trick**

Apply a small amount of valve grinding compound to a Phillips or Torx screw or bolt head. The gritty valve grinding compound "grips" the screwdriver or tool bit and prevents the tool from slipping up and out of the screw head. Valve grinding compound is available in a tube from most automotive parts stores.

SEAL DRIVERS AND PULLERS

Seal Pullers Grease seals are located on many automotive components, including brake rotors, transmission housings, and differentials. A **seal puller** is used to properly remove grease seals, as shown in Figure 9–44.

Seal Drivers A **seal driver** can be either plastic or metal, usually aluminum, and is used to seat the outer lip of a grease seal into the grease seal pocket. A seal is usually driven into position using a plastic mallet and a seal driver that is the same size as the outside diameter of the grease seal retainer. See Figure 9–45.

ELECTRICAL HAND TOOLS

Test Lights A test light is used to test for electricity. A typical automotive test light consists of a clear plastic screwdriver-like handle that contains a light bulb. A wire is attached to one terminal of the bulb, which the technician connects to a clean metal part of the vehicle. The other end of the bulb is attached to a point that can be used to test for electricity at a connector or wire. When there is power at the point and a good connection at the other end, the light bulb lights. See Figure 9–46.

Soldering Guns

- **Electric soldering gun.** This type of soldering gun is usually powered by 110-volt AC and often has two power settings expressed in watts. A typical electric soldering gun will produce from 85 to 300 watts of heat at the tip, which is more than adequate for soldering. See Figure 9–47.
- **Electric soldering pencil.** This type of soldering iron is less expensive and creates less heat than an electric soldering gun. A typical electric soldering pencil (iron) creates 30 to 60 watts of heat and is suitable for soldering smaller wires and connections.
- **Butane-powered soldering iron.** A butane-powered soldering iron is portable and very useful for automotive service work because an electrical cord is not needed. Most butane-powered soldering irons produce about 60 watts of heat, which is enough for most automotive soldering.



Figure 9–44 A seal puller being used to remove a seal from a rear axle.

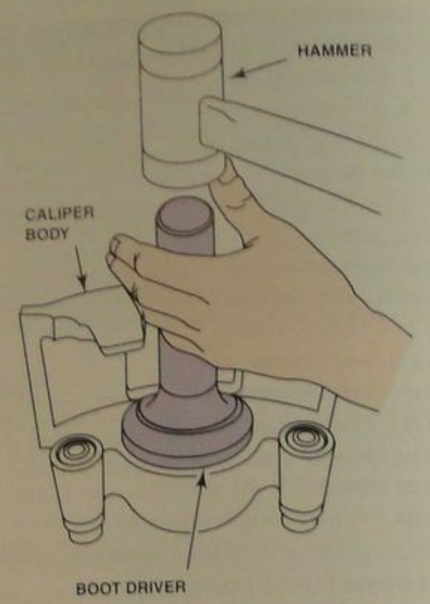


Figure 9–45 A seal driver or installer is usually plastic and is designed to seat the seal.



Figure 9–46 A typical 12-volt test light.

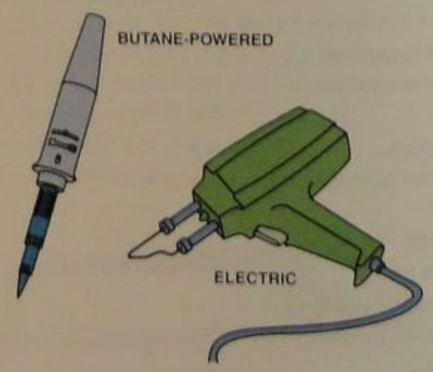


Figure 9–47 An electric soldering gun used to make electrical repairs. Soldering guns are sold by the wattage rating. The higher the wattage, the greater amount of heat created. Most solder guns used for automotive electrical work usually fall within the 60- to 160-watt range.

In addition to a soldering iron, most service technicians who do electrical-related work should have the following:

- Wire cutters
- Wire strippers
- Wire crimpers
- Heat gun

A digital meter is a necessary tool for any electrical diagnosis and troubleshooting. A digital multimeter, abbreviated DMM, is usually capable of measuring the following units of electricity:

- DC volts
- AC volts
- Ohms
- Amperes

TECH TIP ✔ **It Just Takes a Second**

Whenever removing any automotive component, it is wise to screw the bolts back into the holes a couple of threads by hand. This ensures that the right bolt will be used in its original location when the component or part is put back on the vehicle. Often, the same diameter of fastener is used on a component, but the length of the bolt may vary. Spending just a couple of seconds to put the bolts and nuts back where they belong when the part is removed can save a lot of time when the part is being reinstalled. Besides making certain that the right fastener is being installed in the right place, this method helps prevent bolts and nuts from getting lost or kicked away. How much time have you wasted looking for that lost bolt or nut?

SAFETY TIPS FOR USING HAND TOOLS

The following safety tips should be kept in mind whenever you are working with hand tools:

- Always *pull* a wrench toward you for best control and safety. Never push a wrench.
- Keep wrenches and all hand tools clean to help prevent rust and to allow for a better, firmer grip.
- Always use a 6-point socket or a box-end wrench to break loose a tight bolt or nut.
- Use a box-end wrench for torque and an open-end wrench for speed.
- Never use a pipe extension or other type of **"cheater bar"** on a wrench or ratchet handle. If more force is required, use a larger tool or use penetrating oil and/or heat on the frozen fastener. (If heat is used on a bolt or nut to remove it, always replace it with a new part.)
- Always use the proper tool for the job. If a specialized tool is required, use the proper tool and do not try to use another tool improperly.
- Never expose any tool to excessive heat. High temperatures can reduce the strength ("draw the temper") of metal tools.
- Never use a hammer on any wrench or socket handle unless you are using a special "staking face" wrench designed to be used with a hammer.
- Replace any tools that are damaged or worn.

HAND TOOL MAINTENANCE

Most hand tools are constructed of rust-resistant metals but they can still rust or corrode if not properly maintained. For best results and long tool life, the following steps should be taken:

- Clean each tool before placing it back into the tool box.
- Keep tools separated. Moisture on metal tools will start to rust more readily if the tools are in contact with another metal tool.
- Line the drawers of the tool box with a material that will prevent the tools from moving as the drawers are opened and closed. This helps to quickly locate the proper tool and size.
- Release the tension on all "clicker-type" torque wrenches.
- Keep the tool box secure.

TECH TIP ✔ **Use a Binder Clip**

A binder clip (size 1¼ inches wide) is used by wise technicians to help keep fender covers in place. See Figure 9–48. Binder clips are found at office supply stores.



Figure 9–48 A binder clip being used to keep a fender cover from falling.

SUMMARY

1. Wrenches are available in open end, box end, and combination open and box end.
2. An adjustable wrench should only be used where the proper size is not available.
3. Line wrenches are also called flare-nut wrenches, fitting wrenches, or tube-nut wrenches and are used to remove fuel or refrigerant lines.
4. Sockets are rotated by a ratchet or breaker bar, also called a flex handle.
5. Torque wrenches measure the amount of torque applied to a fastener.
6. Screwdriver types include straight blade (flat tip) and Phillips.
7. Hammers and mallets come in a variety of sizes and weights.
8. Pliers are a useful tool and are available in many different types, including slip joint, multigroove, lineman's, diagonal, needle nose, and locking pliers.
9. Other common hand tools include snap-ring pliers, files, cutters, punches, chisels, and hacksaws.

REVIEW QUESTIONS

1. Why are wrenches offset 15 degrees?
2. What are the other names for a line wrench?
3. What are the standard automotive drive sizes for sockets?
4. Which type of screwdriver requires the use of a hammer or mallet?
5. What is inside a dead-blow hammer?
6. What type of cutter is available in left and right cutters?

CHAPTER QUIZ

1. When working with hand tools, always _____.
   a. Push the wrench—don't pull toward you
   b. Pull a wrench—don't push a wrench
2. The proper term for Channel Locks is _____.
   a. Vise Grips
   b. Crescent wrench
   c. Locking pliers
   d. Multigroove adjustable pliers
3. The proper term for Vise Grips is _____.
   a. Locking pliers
   b. Slip-joint pliers
   c. Side cuts
   d. Multigroove adjustable pliers
4. Which tool listed is a brand name?
   a. Locking pliers
   b. Monkey wrench
   c. Side cutters
   d. Vise Grips
5. Two technicians are discussing torque wrenches. Technician A says that a torque wrench is capable of tightening a fastener with more torque than a conventional breaker bar or ratchet. Technician B says that a torque wrench should be calibrated regularly for the most accurate results. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. What type of screwdriver should be used if there is very limited space above the head of the fastener?
   a. Offset screwdriver
   b. Stubby screwdriver
   c. Impact screwdriver
   d. Robertson screwdriver
7. Where is the "peen" of the hammer?
   a. The striking face
   b. The handle
   c. The back part opposite the striking face
   d. The part that connects to the handle
8. What type of hammer is plastic coated, has a metal casing inside, and is filled with small lead balls?
   a. Dead-blow hammer
   b. Soft-blow hammer
   c. Sledge hammer
   d. Plastic hammer
9. Which type of pliers is capable of fitting over a large object?
   a. Slip-joint pliers
   b. Linesman's pliers
   c. Locking pliers
   d. Multigroove adjustable pliers
10. Which tool has a replaceable cutting edge?
    a. Side-cut pliers
    b. Tin snips
    c. Utility knife
    d. Aviation snips

CHAPTER 10 Power Tools and Shop Equipment

OBJECTIVES: After studying Chapter 10, the reader will be able to: Identify commonly used power tools. • Identify commonly used shop equipment. • Discuss the proper use of power tools and shop equipment. • Describe the safety procedures that should be followed when working with power tools and shop equipment.

KEY TERMS: air-blow gun • air compressor • air drill • air ratchet • bearing splitter • bench grinder • bench vise • die grinder • engine stand • hydraulic press • impact wrench • incandescent light • light emitting diode (LED) • portable crane • stone wheel • trouble light • wire brush wheel • work light

AIR COMPRESSOR

A shop air compressor is usually located in a separate room or an area away from the customer area of a shop. An **air compressor** is powered by a 220-V AC electric motor and includes a storage tank and the compressor itself, as well as the pressure switches, which are used to maintain a certain minimum level of air pressure in the system. The larger the storage tank, expressed in gallons, the longer an air tool can be operated in the shop without having the compressor start operating. See Figure 10–1.

Safe Use of Compressed Air Air under pressure can create dangerous situations. For example, an object, such as a small piece of dirt, could be forced out of an air hose blow gun with enough force to cause serious personal injury. All OSHA approved air nozzles have air vents drilled around the outside of the main discharge hole to help reduce the force of the air blast. Also, the air pressure used by an air nozzle (blow gun) must be kept to 30 PSI (207 kPa) or less. See Figure 10–2.

AIR AND ELECTRICALLY OPERATED TOOLS

Impact Wrench An **impact wrench,** either air (pneumatic) or electrically powered, is a tool that is used to remove and install fasteners. The air-operated 1/2-inch drive impact wrench is the most commonly used unit. See Figure 10–3.

The direction of rotation is controlled by a switch. See Figure 10–4.



Figure 10–1 A typical shop compressor. It is usually placed out of the way, yet accessible to provide for maintenance to the unit.



Figure 10–2 A typical air nozzle. Always use an air nozzle that is OSHA approved.



Figure 10–3 A typical 1/2-inch drive impact wrench.



Figure 10–4 This impact wrench features a variable torque setting using a rotary knob. The diameter of rotation can be changed by pressing the button at the bottom.



Figure 10–5 A typical battery-powered 3/8 inch drive impact wrench.

REAL WORLD FIX — **The Case of the Rusty Air Impact Wrenches**

In one busy shop, it was noticed by several technicians that water was being pumped through the air compressor lines and out of the vents of air impact wrenches whenever they were used. It is normal for moisture in the air to condense in the air storage tank of an air compressor. One of the routine service procedures is to drain the water from the air compressor. The water had been drained regularly from the air compressor at the rear of the shop, but the problem continued. Then someone remembered that there was a second air compressor mounted over the parts department. No one could remember ever draining the tank from that compressor. After that tank was drained, the problem of water in the lines was solved. The service manager assigned a person to drain the water from both compressors every day and to check the oil level. The oil in the compressor is changed every six months to help ensure long life of the expensive compressors.

Electrically powered impact wrenches commonly include:

- Battery-powered units. See Figure 10–5.
- 110-volt AC-powered units. This type of impact wrench is very useful, especially if compressed air is not readily available.

CAUTION: Always use impact sockets with impact wrenches, and be sure to wear eye protection in case the socket or fastener shatters. Impact sockets are thicker walled and constructed with premium alloy steel. They are hardened with a black oxide finish to help prevent corrosion and distinguish them from regular sockets. See Figure 10–6.



Figure 10–6 A black impact socket. Always use impact-type sockets whenever using an impact wrench to avoid the possibility of shattering the socket, which can cause personal injury.



Figure 10–7 An air ratchet is a very useful tool that allows fast removal and installation of fasteners, especially in areas that are difficult to reach or do not have room enough to move a hand ratchet wrench.

Air Ratchet An **air ratchet** is used to remove and install fasteners that would normally be removed or installed using a ratchet and a socket. An air ratchet is much faster, yet has an air hose attached, which reduces accessibility to certain places. See Figure 10–7.

Die Grinder A **die grinder** is a commonly used air-powered tool, which can also be used to sand or remove gaskets and rust. See Figure 10–8.

Air Drill An **air drill** is a drill that rotates faster than electric drills (up to 1800 RPM). Air drills are commonly used in auto body work when many holes need to be drilled for plug welding.

Air Blow Gun An **air blow gun** is used to clean equipment and other purposes where a stream of air would be needed. Automotive air blow guns should meet OSHA requirements and include passages



Figure 10–8 This typical die grinder surface preparation kit includes the air-operated die grinder, as well as a variety of sanding discs for smoothing surfaces or removing rust.

to allow air to escape outward at the nozzle, thereby relieving pressure if the nozzle were to become blocked.

Air-Operated Grease Gun An air-operated grease gun uses shop air to operate a plunger, which then applies a force to grease a grease cartridge. Most air-operated grease guns use a 1/4-inch air inlet and operate on 90 PSI of air pressure.

Battery-Powered Grease Gun Battery-powered grease guns are more expensive than air-operated grease guns but offer the convenience of not having an air hose attached, making use easier. Many use rechargeable 14- to 18-volt batteries and use standard grease cartridges.

TROUBLE LIGHTS

Incandescent **Incandescent lights** use a filament that produces light when electric current flows through the bulb. This was the standard **trouble light,** also called a **work light** for many years until safety issues caused most shops to switch to safer fluorescent or LED lights. If incandescent light bulbs are used, try to locate bulbs that are rated "rough service," which is designed to withstand shock and vibration more than conventional light bulbs.

WARNING: Do not use incandescent trouble lights around gasoline or other flammable liquids. The liquids can cause the bulb to break and the hot filament can ignite the flammable liquid.

Fluorescent A trouble light is an essential piece of shop equipment, and for safety, should be fluorescent rather than incandescent. Incandescent light bulbs can scatter or break if gasoline were to be splashed onto the bulb creating a serious fire hazard. Fluorescent light tubes are not as likely to be broken and are usually protected by a clear plastic enclosure. Trouble lights are usually attached to a retractor, which can hold 20 to 50 feet of electrical cord. See Figure 10–9.

LED Trouble Light **Light emitting diode (LED)** trouble lights are excellent to use because they are shock resistant, long lasting, and do not represent a fire hazard. Some trouble lights are battery powered and therefore can be used in places where an attached electrical cord could present problems.



Figure 10–9 A fluorescent trouble light operates cooler and is safer to use in the shop because it is protected against accidental breakage where gasoline or other flammable liquids would happen to come in contact with the light.



Figure 10–10 A typical pedestal grinder with a wire wheel on the left side and a stone wheel on the right side. Even though this machine is equipped with guards, safety glasses or a face shield should always be worn when using a grinder or wire wheel.

BENCH/PEDESTAL GRINDER

A grinder can be mounted on a workbench or on a stand-alone pedestal.

Bench- or Pedestal-Mounted Grinder These high-powered grinders can be equipped with a wire brush wheel and/or a stone wheel.

- A **wire brush wheel** is used to clean threads of bolts as well as to remove gaskets from sheet metal engine parts.
- A **stone wheel** is used to grind metal or to remove the mushroom from the top of punches or chisels. See Figure 10–10.

CAUTION: Always wear a face shield when using a wire wheel or a grinder. Also keep the part support ledge (table) close to the stone.

Most **bench grinders** are equipped with a grinding wheel (stone) on one side and a wire brush wheel on the other side. A bench grinder is a very useful piece of shop equipment and the wire wheel end can be used for the following:

- Cleaning threads of bolts
- Cleaning gaskets from sheet metal parts, such as steel valve covers

CAUTION: Only use a steel wire brush on steel or iron components. If a steel wire brush is used on aluminum or copper-based metal parts, it can remove metals from the part.

The grinding stone end of the bench grinder can be used for the following:

- Sharpening blades and drill bits
- Grinding off the heads of rivets or parts
- Sharpening sheet metal parts for custom fitting
- Cleaning threads using the wire brush wheel

BENCH VISE

A **bench vise** is used to hold components so that work can be performed on the unit. The size of a vise is determined by the length of the jaws. Two common sizes of vises are 4-inch and 6-inch models. The jaws of most vises are serrated and can cause damage to some components unless protected. Many types of protection can be used, including aluminum jaw covers or by simply placing wood between the vise jaws and the component being held. See Figure 10–11.

Safe Use of Vises The jaws of vises can cause damage to the part or component being held. Use pieces of wood or other soft material between the steel jaws and the workpiece to help avoid causing damage. Many vises are sold with optional aluminum jaw covers. When finished using a vise, be sure to close the jaws and place the handle straight up and down to help avoid personal injury to anyone walking near the vise.

HYDRAULIC PRESSES

Hydraulic presses are hand-operated hydraulic cylinders mounted to a stand and designed to press bearings on or off of shafts, as well as other components. To press off a bearing, a unit called a **bearing splitter** is often required to apply force to the inner race of a bearing. Hydraulic presses use a pressure gauge to show the pressure being applied. Always follow the operating instructions supplied by the manufacturer of the hydraulic press. See Figure 10–12.



Figure 10–11 A typical vise mounted to a workbench.



Figure 10–12 A hydraulic press is usually used to press bearings on and off on rear axles and transmissions.



Figure 10–13 A typical portable crane used to lift and move heavy assemblies, such as engines and transmissions.

TECH TIP ✓ **Cover Work While Pressing**

Whenever pressing on a bearing or other component, use an old brake drum over the shaft and the bearing. In the event the bearing shatters during the pressing operation, the brake drum will prevent the parts of the bearing from flying outward where they could cause serious personal injury.

PORTABLE CRANE AND CHAIN HOIST

A **portable crane** is used to remove and install engines and other heavy vehicle components. Most portable cranes use a hand-operated hydraulic cylinder to raise and lower a boom that is equipped with a nylon strap or steel chain. At the end of the strap or chain is a steel hook that is used to attach around a bracket or auxiliary lifting device. See Figure 10–13.

Safe Use of Portable Cranes Always be sure to attach the hook(s) of the portable crane to a secure location on the unit being lifted. The hook should also be attached to the center of the weight of the object so it can be lifted straight up without tilting.

CAUTION: Always keep feet and other body parts out from under with the engine or unit being lifted. Always work around a portable crane as if the chain or strap could break at any time.

ENGINE STANDS

An **engine stand** is designed to safely hold an engine and to allow it to be rotated. This allows the technician to easily remove, install, and perform service work to the engine. See Figure 10–14.

Most engine stands are constructed of steel and supported by four casters to allow easy movement. There are two basic places where an engine stand attaches to the engine depending on the size of the engine. For most engines and stands, the retaining bolts attach to the same location as the bell housing at the rear of the engine.

On larger engines, such as the 5.9 Cummins inline six-cylinder diesel engine, the engine mounts to the stand using the engine mounting holes in the block. See Figure 10–15.



Figure 10–14 Two engines on engine stands. The plastic bags over the engines help keep dirt from getting onto these engines and engine parts.

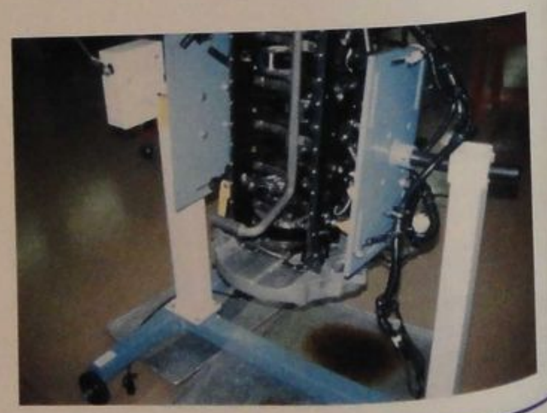


Figure 10–15 An engine stand that grasps the engine from the sides rather than the end.

Safe Operation of an Engine Stand When mounting an engine to an engine stand, be sure that the engine is being supported by a portable crane. Be sure the attaching bolts are grade 5 or 8 and the same thread size as the threaded holes in the block. Be sure that all attaching bolts are securely tightened before releasing the weight of the engine from the crane. Use caution when loosening the rotation retaining bolts because the engine could rotate rapidly, causing personal injury.

CARE AND MAINTENANCE OF SHOP EQUIPMENT

All shop equipment should be maintained in safe working order. Maintenance of shop equipment usually includes the following operations or procedures:

- Keep equipment clean. Dirt and grime can attract and hold moisture, which can lead to rust and corrosion. Oil or grease can attract dirt.
- Keep equipment lubricated. While many bearings are sealed and do not require lubrication, always check the instructions for the use of the equipment for suggested lubrication and other service procedures.

CAUTION: Always follow the instructions from the equipment manufacturer regarding proper use and care of the equipment.

PHOTO SEQUENCE Setup and Lighting a Torch



P10–1 Inspect the cart and make sure the bottles are chained properly before moving it to the work location.



P10–2 Start by attaching the appropriate work tip to the torch handle. The fitting should only be tightened hand tight. Make sure the valves on the torch handle are closed at this time.



P10–3 Each bottle has a regulator assembly with two gauges. The high pressure gauge shows bottle pressure, and the low pressure gauge indicates working pressure.



P10–4 Open the oxygen bottle valve fully open, and open the acetylene bottle valve 1/2 turn.



P10–5 Open the oxygen valve on the torch handle 1/4 turn in preparation for adjusting oxygen gas pressure.



P10–6 Turn the oxygen regulator valve clockwise and adjust oxygen gas pressure to 20 PSI. Close the oxygen valve on the torch handle.



P10–7 Open the acetylene valve on the torch handle 1/4 turn and adjust acetylene gas pressure to 7 PSI. Close the acetylene valve on the torch handle.



P10–8 Open the oxygen valve on the torch handle 1/4 turn and use an appropriate size tip cleaner to clean the tip orifice. Finish by closing the oxygen valve.



P10–9 Put on leather gloves and open the acetylene valve on the torch handle 1/4 turn. Use a flint striker to ignite the acetylene gas exiting the torch tip.

(continued)

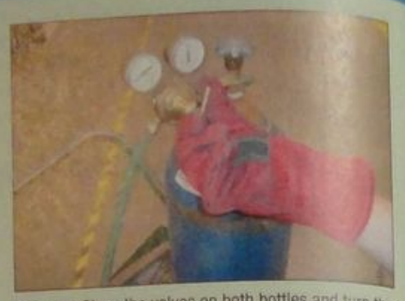
PHOTO SEQUENCE Setup and Lighting a Torch—continued



P10-10 Adjust the acetylene valve until the base of the flame just touches the torch tip. Slowly open the oxygen valve on the torch handle and adjust for a neutral flame (blue cone is well-defined).



P10-11 Once work is complete, extinguish the flame by quickly closing the acetylene valve on the torch handle. Be prepared to hear a loud "pop" when the flame goes out. Close the oxygen valve on the torch handle.



P10–12 Close the valves on both bottles and turn the regulator handles CCW until they no longer contact the internal springs. Open the gas valves briefly on the torch handle to release gas pressure from the hoses. Close the gas valves on the torch handle and put away the torch assembly.

Heating Metal



P10–13 Heating attachments include ordinary heating tips, middle and right and a "rosebud" (left). Ordinary heating tips work fine for most purposes, but occasionally the rosebud is utilized when a great deal of heat is needed.



P10–14 Note that while acetylene bottle pressures are relatively low, the oxygen bottle can be filled to over 2000 PSI. This can represent a serious hazard if precautions are not taken. Be absolutely certain that the bottles are chained properly to the cart before attempting to move it!



P10–15 Any time heating or cutting operations are being performed, be sure that any flammables have been removed from the immediate area. A fire blanket may be placed over floor drains or other objects to prevent fires. A fire extinguisher should be on hand in case of an emergency.



P10–16 Be sure to wear appropriate personal protective equipment during heating and cutting operations.



P10–17 Note that heating operations should be performed over steel or firebrick. Never heat or cut steel close to concrete, as it could cause the concrete to explode.



P10–18 When heating steel, move the torch in a circular pattern to prevent melting of the metal. Don't hold the torch too close to the work as this will cause a "snapping" or "backfire" that can extinguish the flame.

PHOTO SEQUENCE Cutting Metal



P10–19 Affix the cutting attachment to the torch handle. Note that the cutting attachment has a cutting handle and a separate oxygen valve.



P10–20 Fully open the oxygen valve on the torch handle. Oxygen flow will now be controlled with the valve on the cutting attachment.



P10–21 Oxygen gas pressure should be adjusted to 30 PSI whenever using the cutting attachment. Acetylene pressure is kept at 7 PSI.



P10–22 Open the acetylene valve on the torch handle 1/4 turn and light the torch. Adjust the flame until its base just touches the cutting tip. Slowly open the oxygen valve on the cutting attachment and adjust the flame until the blue cone is well-defined.



P10–23 Direct the flame onto a thin spot or sharp edge of the metal to be cut. This will build the heat quicker in order to get the cut started.



P10–24 When the metal glows red, depress the cutting handle and move the torch to advance the cut. You will need to move the torch faster when cutting thinner pieces of steel. On thicker pieces, point the cutting tip into the direction of the cut.

SUMMARY

1. Most shops are equipped with a large air compressor that supplies pressurized air to all stalls for use by the technician.
2. An air impact wrench is the most commonly used power tool in the shop. It is used mostly to remove fasteners. Caution should be exercised not to overtighten a fastener, using an air impact wrench.
3. Other air-operated tools include an air ratchet and a die grinder.
4. A bench or pedestal grinder usually has both a grinding stone and a wire brush wheel.
5. Trouble lights should be fluorescent or LED for maximum safety in the shop.
6. A hydraulic press is used to remove bearings from shafts and other similar operations.
7. A portable crane is used to remove and install engines or engine/transmission assemblies from vehicles.
8. Engine stands are designed to allow the technician to rotate the engine to get access to the various parts and components.

REVIEW QUESTIONS

1. List the tools used by service technicians that use compressed air?
2. Which trouble light design(s) is (are) the recommended type for maximum safety?
3. What safety precautions should be adhered to when working with a vise?
4. When using a blow gun, what precautions need to be taken?

CHAPTER QUIZ

1. When using compressed air and a blow gun, what is the maximum allowable air pressure?
   a. 10 PSI
   b. 20 PSI
   c. 30 PSI
   d. 40 PSI
2. Which air impact drive size is the most commonly used?
   a. 1/4 inch
   b. 3/8 inch
   c. 1/2 inch
   d. 3/4 inch
3. For safe use of compressed air using a blow gun, the pressure should not exceed _____.
   a. 10 PSI
   b. 20 PSI
   c. 30 PSI
   d. 40 PSI
4. What can be used to cover the jaws of a vise to help protect the object being held?
   a. Aluminum
   b. Wood
   c. Plastic
   d. All of the above

5. Technician A says that impact sockets have thicker walls than conventional sockets. Technician B says that impact sockets have a black oxide finish. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

6. Two technicians are discussing the use of a typical bench/pedestal mounted grinder. Technician A says that a wire brush wheel can be used to clean threads. Technician B says that the grinding stone can be used to clean threads. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. A hydraulic press is being used to separate a bearing from a shaft. What should be used to cover the bearing during the pressing operation?
   a. A shop cloth
   b. A brake drum
   c. A fender cover
   d. A paper towel

8. Which type of trouble light is recommended for use in the shop?
   a. Incandescent
   b. Fluorescent
   c. LED
   d. Either b or c

9. When mounting an engine to an engine stand, what grade of bolt should be used?
   a. 5 or 8
   b. 4 or 7
   c. 3 or 5
   d. 1 or 4

10. Proper care of shop equipment includes _____.
   a. Tuning up every 6months
   b. Keeping equipment clean
   c. Keeping equipment lubricated
   d. Both b and c

CHAPTER 11 Vehicle Lifting and Hoisting

OBJECTIVES: After studying Chapter 11, the reader will be able to: Identify vehicle hoisting and lifting equipment. • Discuss safety procedures related to hoisting or lifting a vehicle. • Describe the proper methods to follow to safely hoist a vehicle.

KEY TERMS: creeper • floor jack • jack stands • safety stands

FLOOR JACK

A **floor jack** is a hand-operated hydraulic device that is used to lift vehicles or components, such as engines, transmissions, and rear axle assemblies. Most floor jacks use four casters, which allow the jack to be easily moved around the shop. See Figure 11–1.

Safe Use of Floor Jacks Floor jacks are used to lift a vehicle or major vehicle component, but they are not designed to hold a load. Therefore **safety stands,** also called **jack stands** should always be used to support the vehicle. After the floor jack has lifted the vehicle, safety stands should be placed under the vehicle, and then, using the floor jack, lowered onto the safety stands. The floor jack can be lifted in position as another safety device but the load should be removed from the floor jack. If a load is retained on the floor jack, hydraulic fluid can leak past seals in the hydraulic cylinders, which would lower the vehicle, possibly causing personal injury. See Figure 11–2.

CREEPERS

When working underneath a vehicle, most service technicians use a **creeper,** which consists of a flat or concaved surface equipped with low-profile casters. A creeper allows the technician to maneuver under the vehicle easily.

Safe Use of Creepers Creepers can create a fall hazard if left on the floor. When a creeper is not being used, it should be picked up and placed vertically against a wall or tool box to help prevent accidental falls.

VEHICLE HOISTS

Vehicle hoists include older in-ground pneumatic/hydraulic (air pressure over hydraulic) and above-ground units. Most of the vehicle hoists used today use an electric motor to pressurize hydraulic fluid, which lifts the vehicle using hydraulic cylinders. Hoists are rated by the maximum weight that they can safely lift, such as 7,000 lbs to 12,000 lbs or more. Hoists can also have equal length arms or can be equipped with different length arms allowing the vehicle to be set so the doors can be opened and not hit the center support column. Many chassis and underbody service procedures require that the vehicle be hoisted or lifted off the ground. The simplest methods involve the use of drive-on ramps or a floor jack and safety (jack) stands, whereas in-ground or surface-mounted lifts provide greater access.

Setting the Pads Is a Critical Part of This Procedure All automobile and light-truck service manuals include recommended locations to be used when hoisting (lifting) a vehicle.



Figure 11–1 A hydraulic hand-operated floor jack.



Figure 11–2 Safety stands are being used to support the rear of this vehicle. Notice a creeper also.

Newer vehicles have a triangle decal on the driver's door indicating the recommended lift points. The recommended standards for the lift points and lifting procedures are found in SAE Standard JRP-2184. See Figure 11–3.

These recommendations typically include the following points:

1. The vehicle should be centered on the lift or hoist so as not to overload one side or put too much force either forward or rearward. See Figure 11–4.
2. The pads of the lift should be spread as far apart as possible to provide a stable platform.
3. Each pad should be placed under a portion of the vehicle that is strong and capable of supporting the weight of the vehicle.
   a. Pinch welds at the bottom edge of the body are generally considered to be strong.



Figure 11–3 Most newer vehicles have a triangle symbol indicating the recommended hoisting lift points.



(a)



(b)

Figure 11–4 (a) Tall safety stands can be used to provide additional support for a vehicle while on a hoist. (b) A block of wood should be used to avoid the possibility of doing damage to components supported by the stand.

CAUTION: Even though pinch weld seams are the recommended location for hoisting many vehicles with unitized bodies (unit body), care should be taken not to place the pad(s) too far forward or rearward. Incorrect placement of the vehicle on the lift could cause the vehicle to be imbalanced, and the vehicle could fall. This is exactly what happened to the vehicle in Figure 11–5.

b. Boxed areas of the body are the best places to position the pads on a vehicle without a frame. Be careful to note whether the arms of the lift might come into contact with other parts of the vehicle before the pad touches the intended location. Commonly damaged areas include the following:
   (1) Rocker panel moldings
   (2) Exhaust system (including catalytic converter)
   (3) Tires or body panels. See Figures 11–6 and 11–7.

4. The vehicle should be raised about a foot (30 centimeters [cm]) off the floor, then stopped and shaken to check for stability. If the vehicle seems to be stable when checked at a short distance from the floor, continue raising the vehicle and continue to view the vehicle until it has reached the desired height. The hoist should be lowered onto the mechanical locks, and then raised off of the locks before lowering.

CAUTION: Do not look away from the vehicle while it is being raised (or lowered) on a hoist. Often one side or one end of the hoist can stop or fail, resulting in the vehicle being slanted enough to slip or fall, creating physical damage not only to the vehicle and/or hoist but also to the technician or others who may be nearby.

HINT: Most hoists can be safely placed at any desired height as long as it is high enough for the safety latches to engage. For ease while working, the area in which you are working should be at chest level. When working on [illegible] it is not necessary to work on them down near the floor or over your head. Raise the hoist so that the components are at chest level.

5. Before lowering the hoist, the safety latch(es) must be released and the direction of the controls reversed. The speed downward is often adjusted to be as slow as possible for additional safety.



Figure 11–5 This vehicle fell from the hoist because the pads were not set correctly. No one was hurt, but the vehicle was a total loss.



(a)



(b)

Figure 11–6 (a) An assortment of hoist pad adapters that are often necessary to safely hoist many pickup trucks, vans, and sport utility vehicles. (b) A view from underneath a Chevrolet pickup truck showing how the pad extensions are used to attach the hoist lifting pad to contact the frame.

DRIVE-ON RAMPS

Ramps are an inexpensive way to raise the front or rear of a vehicle. See Figure 11–8. Ramps are easy to store, but they can be dangerous because they can "kick out" when driving the vehicle onto the ramps.

CAUTION: Professional repair shops do not use ramps because they are dangerous to use. Use only with extreme care.

SUMMARY

1. Whenever a vehicle is raised off the ground, it must be supported using safety stands.
2. Creepers should be stored vertically to prevent the possibility of stepping on it, which could cause a fall and personal injury.
3. Always adhere to the specified hoisting locations as found in service information.
4. Adapters or extensions are often needed when hoisting pickup trucks or vans.



(a)



(b)

Figure 11–7 (a) In this photo the pad arm is just contacting the rocker panel of the vehicle. (b) This photo shows what can occur if the technician places the pad too far inward underneath the vehicle. The arm of the hoist has dented in the rocket panel.

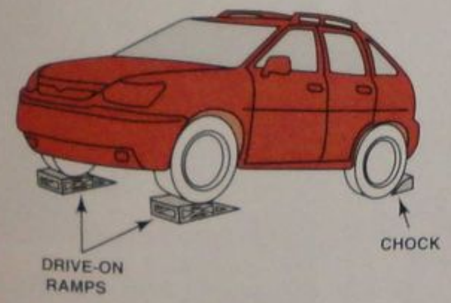


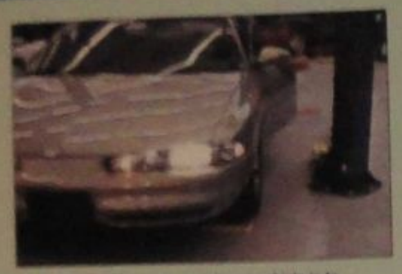
Figure 11–8 Drive-on-type ramps. The wheels on the ground level *must* be chocked (blocked) to prevent accidental movement down the ramp.

REVIEW QUESTIONS

1. Why must safety stands be used after lifting a vehicle with a floor jack?
2. What precautions should be adhered to when storing a creeper?
3. What precautions should be adhered to when hoisting a vehicle?

CHAPTER QUIZ

1. A safety stand is also called a _____.
   a. Jack
   b. Jack stand
   c. Bottle jack
   d. Safety stool
2. A creeper should be stored _____.
   a. Vertically
   b. Under a vehicle
   c. Flat on the floor
   d. Upside down on the floor
3. The SAE standard for hoist location is _____.
   a. J-1980
   b. SAE-2009
   c. JRP-2184
   d. J-14302
4. Tall safety stands would be used to _____.
   a. Support an engine while the vehicle is hoisted
   b. Lift a vehicle
   c. Lift a component such as an engine high off the ground
   d. Both b and c
5. Commonly damaged areas of a vehicle during hoisting include _____.
   a. Rocker panels
   b. Exhaust systems
   c. Tires or body panels
   d. All of the above
6. Pad extensions may be needed when hoisting what type of vehicle?
   a. Small cars
   b. Pickup trucks
   c. Vans
   d. Either b or c
7. Technician A says that a hoist can be stopped at any level as long as the safety latch engages. Technician B says that the vehicle should be hoisted to the top of the hoist travel for safety. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Before lowering the vehicle, what should the technician do?
   a. Be sure nothing is underneath the vehicle
   b. Raise the vehicle enough to release the safety latch
   c. Be sure no one will be walking under or near the vehicle
   d. All of the above
9. Technician A says that a creeper should be stored vertically. Technician B says that a creeper should be stored on its casters. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. When checking for proper pad placement, how high should the vehicle be raised?
   a. About 2 inches (5 cm)
   b. About 6 inches (15 cm)
   c. About one foot (30 cm)
   d. About 3 feet (91 cm)



P11–1 The first step in hoisting a vehicle is to properly align the vehicle in the center of the stall.



P11–2 Most vehicles will be correctly positioned when the left front tire is centered on the tire pad.



P11–3 Most pads at the end of the hoist arms can be rotated to allow for many different types of vehicle construction.



P11–4 The arms of the lifts can be retracted or extended to accommodate vehicles of many different lengths.



P11–5 Most lifts are equipped with short pad extensions that are often necessary to use to allow the pad to contact the frame of a vehicle without causing the arm of the lift to hit and damage parts of the body.



P11–6 Tall pad extensions can also be used to gain access to the frame of a vehicle. This position is needed to safely hoist many pickup trucks, vans, and sport utility vehicles.



P11–7 An additional extension may be necessary to hoist a truck or van equipped with running boards to give the necessary clearance.



P11–8 Position the front hoist pads under the recommended locations as specified in the owner's manual and for service information for the vehicle being serviced.



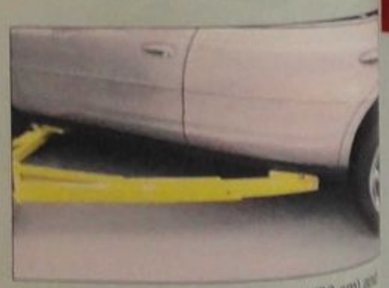
P11–9 Position the rear pads under the vehicle under the recommended locations.



P11–10 This photo shows an asymmetrical lift where the front arms are shorter than the rear arms. This design is best used for passenger cars and allows the driver to exit the vehicle easier because the door can be opened wide without it hitting the vertical support column.



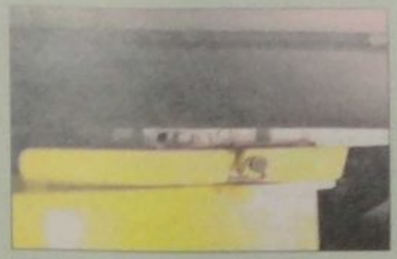
P11–11 After being sure all pads are correctly positioned, use the electromechanical controls to raise the vehicle.



P11–12 Raise the vehicle about one foot (30 cm) and stop to double-check that all pads contact the body or frame in the correct positions.



P11–13 With the vehicle raised about one foot off the ground, push down on the vehicle to check to see if it is stable on the pads. If the vehicle rocks, lower the vehicle and reset the pads. If the vehicle is stable, the vehicle can be raised to any desired working level. Be sure the safety is engaged before working on or under the vehicle.



P11–14 This photo shows the pads set flat and contacting the pinch welds of the body. This method spreads the load over the entire length of the pad and is less likely to dent or damage the pinch weld area.



P11–15 Where additional clearance is necessary for the arms to clear the rest of the body, the pads can be raised and placed under the pinch weld area as shown.



P11–16 When the service work is completed, the hoist should be raised slightly and the safety released before using the hydraulic lever to lower the vehicle.



P11–17 After lowering the vehicle, be sure all arms of the lift are moved out of the way before driving the vehicle out of the work stall.



P11–18 Carefully back the vehicle out of the stall. Notice that all of the lift arms have been neatly moved out of the way to provide clearance so that the tires will not contact the arms when the vehicle is driven out of the stall.

CHAPTER 12

Measuring Systems and Tools

OBJECTIVES: After studying Chapter 12, the reader will be able to: Describe how to read a ruler. • Explain how to use a micrometer and vernier dial caliper. • Describe how to use a telescopic gauge and a micrometer to measure cylinder and lifter bores. • Discuss how to measure valve guides using a small-hole gauge. • Calculate engine displacement and compression ratios.

KEY TERMS: barrel • feeler gauge • small-hole gauge • spindle • split-ball gauge • straightedge • thickness gauge • thimble

ENGLISH CUSTOMARY MEASURING SYSTEM

The English customary measuring system was established about A.D. 1100 in England during the reign of Henry I. The foot was determined to be 12 inches and was taken from the length of a typical foot. The yard (36 inches) was determined to be the length from King Henry's nose to the end of his outstretched hand. The mile came from Roman days and was originally defined as the distance traveled by a soldier in 1,000 paces or steps. Other English units, such as the pound (weight) and volume (gallon), evolved over the years from Roman and English measurements.

The Fahrenheit temperature scale was created by Gabriel Fahrenheit (1686–1736) and he used 100°F as the temperature of the human body, which he missed by 3.4 degrees (98.6°F is

considered now to be normal temperature). On the Fahrenheit scale, water freezes at 32°F and water boils at 212°F.

METRIC SYSTEM OF MEASURE

Most of the world uses the metric system of measure. The metric system was created in the late 1700s in France and used the physical world for the basis of the measurements. For example, the meter was defined as being 1/40,000,000 of the circumference of the earth (the distance around the earth at the poles). The Celsius temperature scale developed by Anders Celsius (1701–1744) used the freezing point of water as 0°C (32°F) and the boiling point of water as 100°C (212°F). Other units include a liter of water, which was then used as a standard of weight where 1 liter of water (about 1 quart) weighs 1 kilogram (1,000 grams). Units of measure are then divided or multiplied by 10, 100, and 1,000 to arrive at usable measurements. For example, a kilometer is 1,000 meters and is the most commonly used metric measurement for distance for travel. Other prefixes include:

m = milli = 1/1,000
k = kilo = 1,000
M = mega = 1,000,000

Linear Metric Measurements

1 kilometer = 0.62 miles
1 meter = 39.37 inches
1 centimeter (1/100 meter) = 0.39 inch
1 millimeter (1/1,000 meter) = 0.039 inch

Volume Measurement

1 cc (cubic centimeter) = 0.06 cubic inches
1 liter = 0.26 U.S. gallons (about 1 quart)

Weight Measurement

1 gram = 0.035 ounces
1 kilogram (1,000 grams) = 2.2 pounds

FREQUENTLY ASKED QUESTION ???

What Weighs a Gram?

To better understand the metric system measurements, it is often helpful to visualize a certain object and relate it to a metric unit of measure. For example, the following objects weigh about one gram:

- A dollar bill
- A small paper clip

Pressure Measurements

1 kilopascal (kPa) = 0.14 pounds per square inch (6.9 kPa = 1 PSI)
1 bar = 14.5 pounds per square inch

Derived Units All units of measure, except for the base units, are a combination of units that are referred to as derived units of measure. Some examples of derived units include:

Torque
Velocity
Density
Energy
Power

LINEAR MEASUREMENTS (TAPE MEASURE/RULE)

A tape measure or machinist rule divides inches into smaller units. Each smaller unit is drawn with a line shorter than the longer unit. The units of measure starting with the largest include:

1 inch
½ inch
¼ inch
⅛ inch
1/16 inch

Some rules show 1/32 of an inch. See Figure 12–1.

A metric scale is also included on many tape measures and machinists rules. See Figure 12–2.

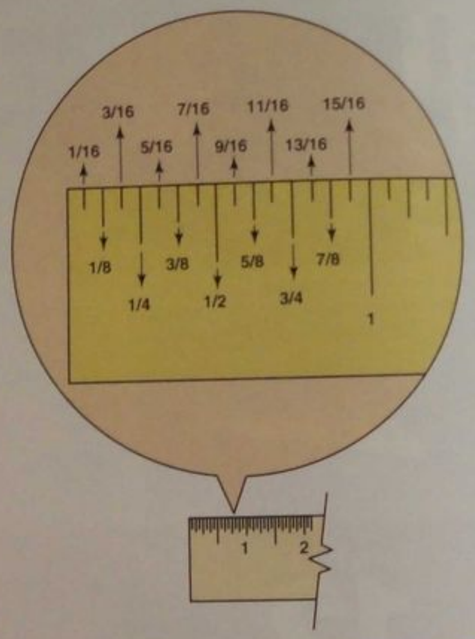


Figure 12–1 A rule showing that the larger the division, the longer the line.

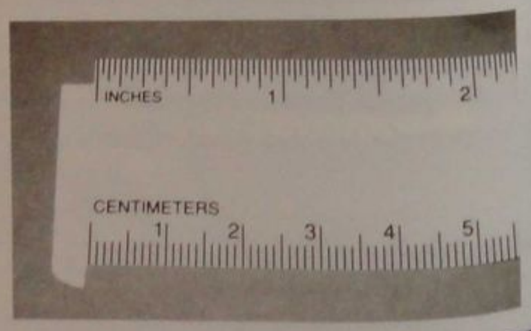


Figure 12–2 A plastic rule that has both inches and centimeters. Each line between the numbers on the centimeters represents one millimeter because there are 10 millimeters in 1 centimeter.

MICROMETER

A micrometer is the most used measuring instrument in engine service and repair. See Figure 12–3.

The **thimble** rotates over the **barrel** on a screw that has 40 threads per inch. Every revolution of the thimble moves the **spindle** 0.025 inch. The thimble is graduated into 25 equally spaced lines; therefore, each line represents 0.001 inch. Every micrometer should be checked for calibration on a regular basis. See Figures 12–4 through 12–6.

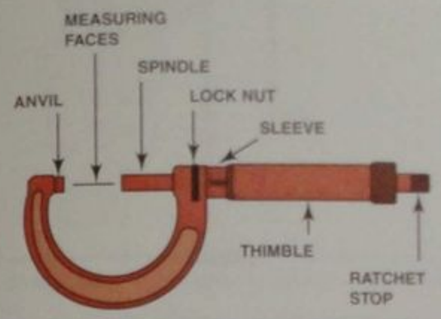


Figure 12–3 A typical micrometer showing the names of the parts.

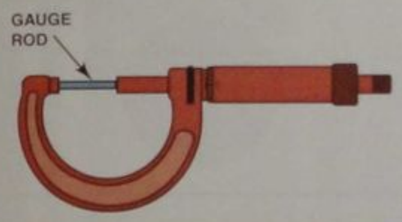


Figure 12–4 All micrometers should be checked and calibrated as needed using a gauge rod.

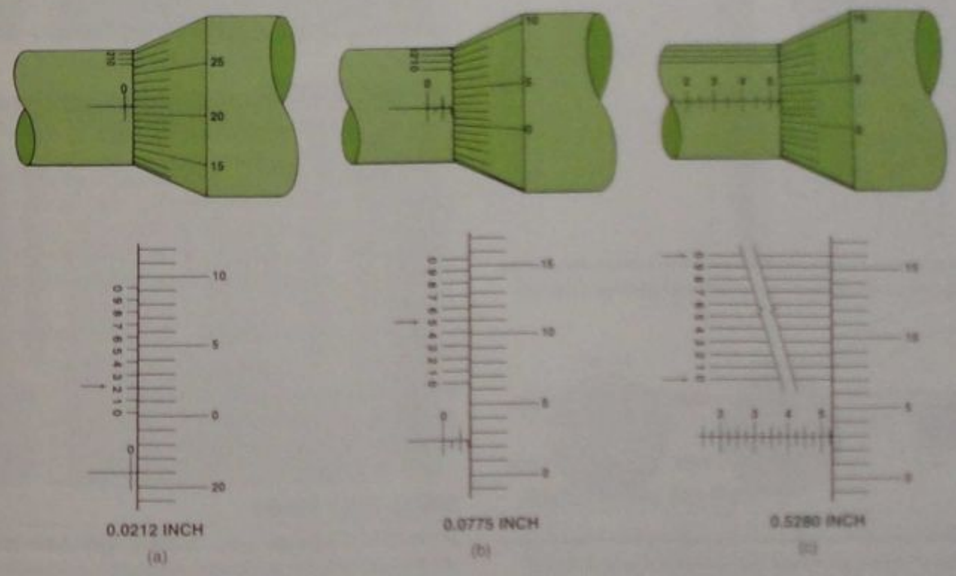


Figure 12–5 The three micrometer readings are (a) 0.0212 inch; (b) 0.0775 inch; (c) 0.5280 inch. These measurements used the vernier scale on the sleeve to arrive at the ten-thousandth measurement. The number that is aligned represents the digit in the ten-thousandth place.

Crankshaft Measurement Even though the connecting rod journals and the main bearing journals are usually different sizes, they both can and should be measured for out-of-round and taper. See Figure 12–7.

Out-of-Round A journal should be measured in at least two positions across the diameter and every 120 degrees around the journal, as shown in Figure 12–8, for an example of the six readings. Calculate the out-of-round measurement by subtracting the lowest reading from the highest reading for both A and B positions.

Position A: 2.0000 − 1.9995 = 0.0005 inch

Position B: 2.0000 − 1.9989 = 0.0011 inch

The maximum out-of-round measurement occurs in position B (0.0011 inch), which is the measurement that should be used to compare against factory specifications to determine if any machining will be necessary.

Taper To determine the taper of the journal, compare the readings in the same place between A and B positions and subtract the lower readings from the higher reading.

For example:

Position A		Position B	
2.0000	−	2.0000	= 0.0000
1.9999	−	1.9998	= 0.0001
1.9995	−	1.9989	= 0.0006

Use 0.0006 inch as the taper for the journal and compare with factory specifications.

Camshaft Measurement The journal of the camshaft(s) can also be measured using a micrometer and compared with factory specifications for taper and out-of-round. See Figure 12–9.

NOTE: On overhead valve (pushrod) engines, the camshaft journal diameter often decreases slightly toward the rear of the engine. Overhead camshaft engines usually have the same journal diameter.

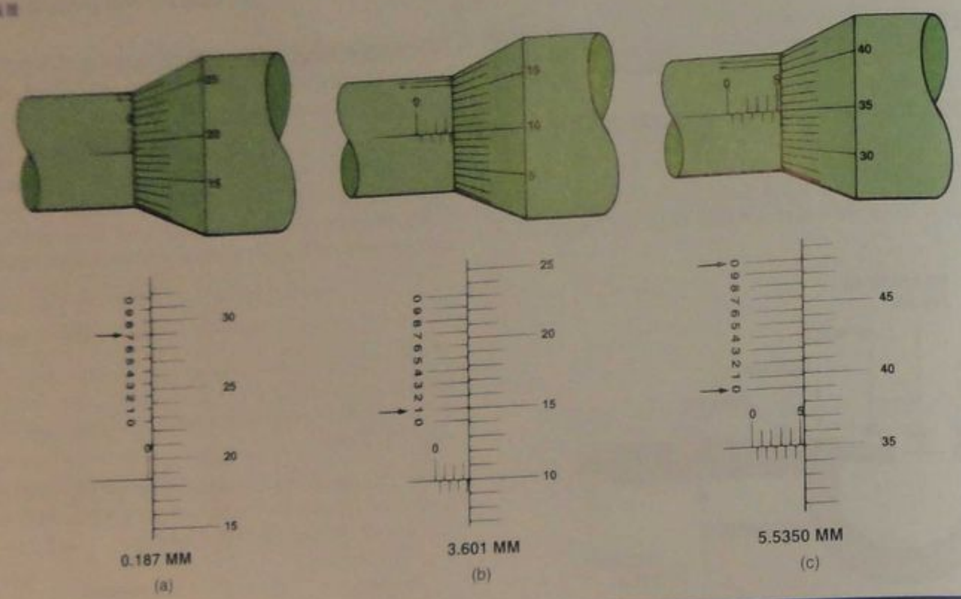


Figure 12–6 Metric micrometer readings that use the vernier scale on the sleeve to read to the nearest 0.001 millimeter.

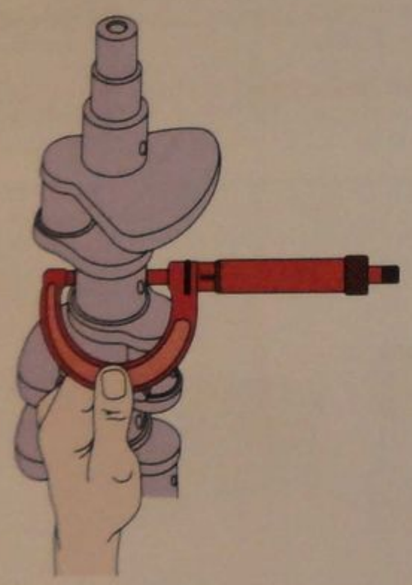


Figure 12–7 Using a micrometer to measure the connecting rod journal for out-of-round and taper.

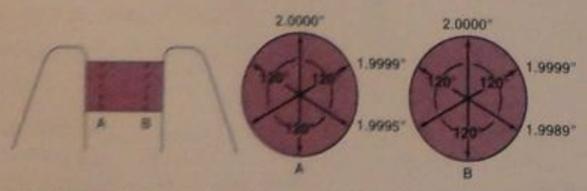


Figure 12–8 Crankshaft journal measurements. Each journal should be measured in at least six locations, but also in position A and position B and at 120-degree intervals around the journal.



Figure 12–9 Camshaft journals should be measured in three locations, 120 degrees apart, to check for out-of-round.

The lift can also be measured with a micrometer and compared with factory specifications, as shown in Figure 12–10.

TELESCOPIC GAUGE

A telescopic gauge is used with a micrometer to measure the inside diameter of a hole or bore.

The cylinder bore can be measured by inserting a telescopic gauge into the bore and rotating the handle lock to allow the arms of the gauge to contact the inside bore of the cylinder. Tighten the handle lock and remove the gauge from the cylinder. Use a micrometer to measure the telescopic gauge. See Figure 12–11.

A telescopic gauge can also be used to measure the following:

- Camshaft bearing. See Figure 12–12.
- Main bearing bore (housing bore) measurement
- Connecting rod bore measurement

SMALL-HOLE GAUGE

A **small-hole gauge** (also called a **split-ball gauge**) is used with a micrometer to measure the inside diameter of small holes such as a valve guide in a cylinder head. See Figures 12–13 and 12–14.

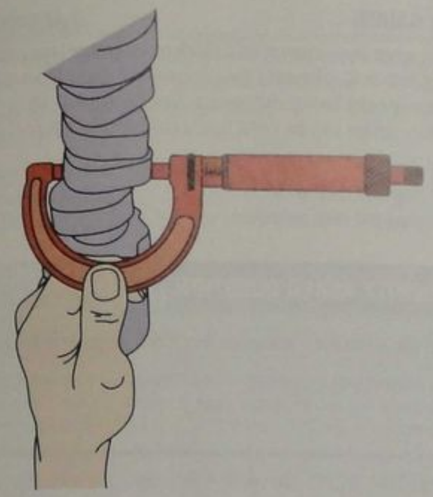
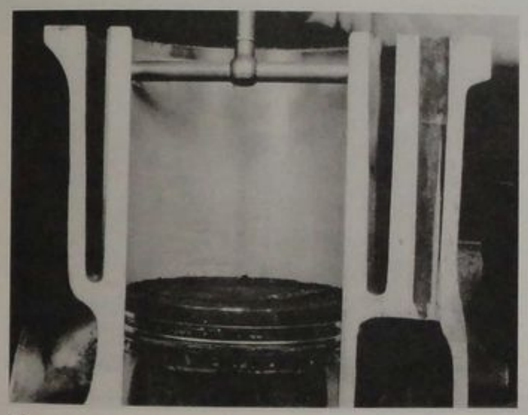
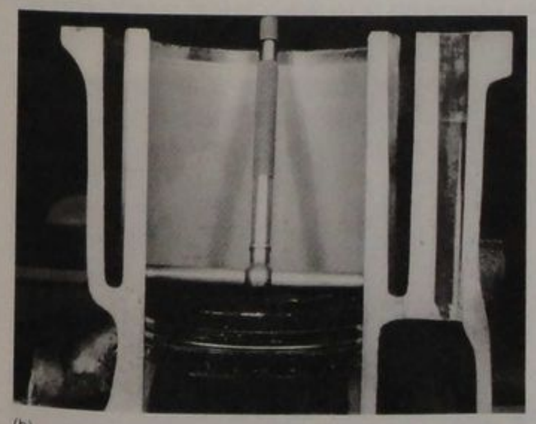


Figure 12–10 Checking a camshaft for wear by measuring the lobe height with a micrometer.

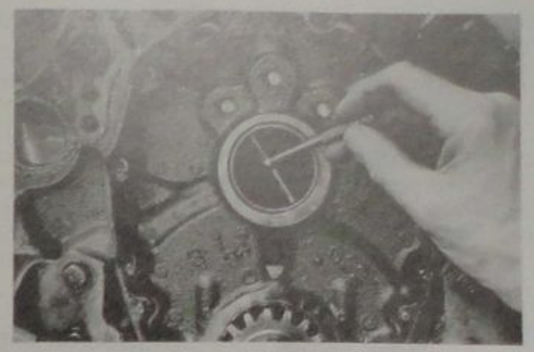


(a)

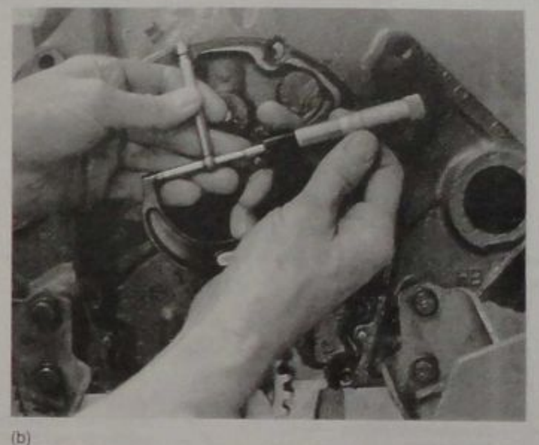


(b)

Figure 12–11 When the head is first removed, the cylinder taper and out-of-round should be checked below the ridge (a) and above the piston when it is at the bottom of the stroke (b).



(a)



(b)

Figure 12–12 (a) A telescopic gauge being used to measure the inside diameter (ID) of a camshaft bearing. (b) An outside micrometer used to measure the telescopic gauge.

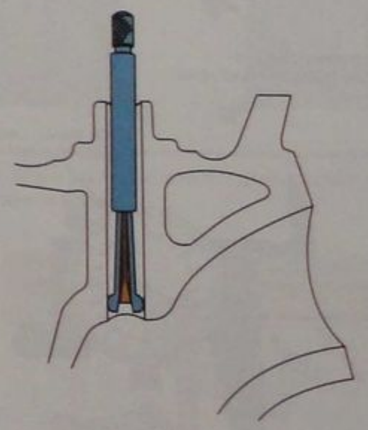


Figure 12–13 Cutaway of a valve guide with a hole gauge adjusted to the hole diameter.

VERNIER DIAL CALIPER

A vernier dial caliper is normally used to measure the outside diameter or length of a component such as a piston diameter or crankshaft and camshaft bearing journal diameter. See Figure 12–15.

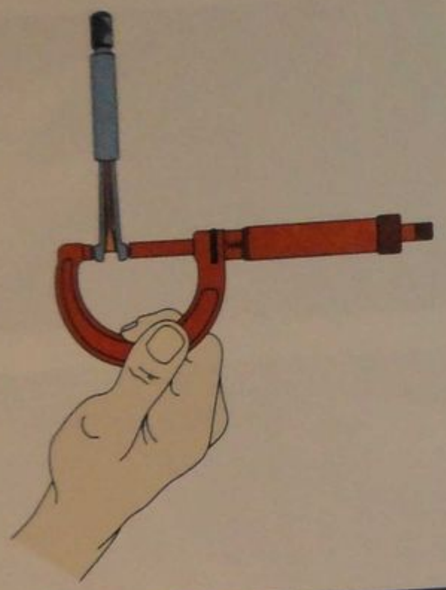


Figure 12–14 The outside of a hole gauge being measured with a micrometer.

FEELER GAUGE

A **feeler gauge** (also known as a **thickness gauge**) is an accurately manufactured strip of metal that is used to determine the gap or clearance between two components. See Figure 12–16.

A feeler gauge can be used to check the following:

- Piston ring gap. See Figure 12–17.
- Piston ring side clearance
- Connecting rod side clearance

FREQUENTLY ASKED QUESTION ???

What Is the Difference between the Word *Gage* and *Gauge*?

The word *gauge* means "measurement or dimension to a standard of reference." The word *gauge* can also be spelled *gage*. Therefore, in most cases, the words mean the same.

INTERESTING NOTE: One vehicle manufacturing representative told me that *gage* was used rather than *gauge* because even though it is the second acceptable spelling of the word, it is correct and it saved the company a lot of money in printing costs because the word *gage* has one less letter! One letter multiplied by millions of vehicles with gauges on the dash and the word *gauge* used in service manuals adds up to a big savings to the manufacturer.

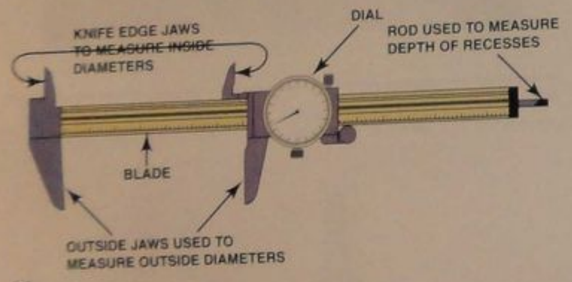


Figure 12–15 (a) A typical vernier dial caliper. This is a very useful measuring tool for automotive engine work because it is capable of measuring inside and outside measurements. (b) To read a vernier dial caliper, simply add the reading on the blade to the reading on the dial.

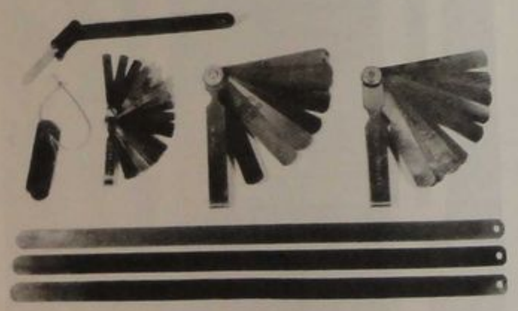


Figure 12–16 A group of feeler gauges (also known as thickness gauges), used to measure between two parts. The long gauges on the bottom are used to measure the piston-to-cylinder wall clearance.



Figure 12–17 A feeler gauge, also called a thickness gauge, is used to measure the small clearances such as the end gap of a piston ring.

STRAIGHTEDGE

A **straightedge** is a precision ground metal measuring gauge that is used to check the flatness of engine components when used with a feeler gauge. A straightedge is used to check the flatness of the following:

- Cylinder heads. See Figure 12–18.
- Cylinder block deck
- Straightness of the main bearing bores (saddles)

DIAL INDICATOR

A dial indicator is a precision measuring instrument used to measure crankshaft end play, crankshaft runout, and valve guide wear. A dial indicator can be mounted three ways, including:

- **Magnetic mount.** This is a very useful method because a dial indicator can be attached to any steel or cast iron part.
- **Clamp mount.** A clamp-mounted dial indicator is used in many places where a mount could be clamped.
- **Threaded rod.** Using a threaded rod allows the dial indicator to be securely mounted, such as shown in Figure 12–19.



Figure 12–18 A Straightedge is used with a feeler gauge to determine if a cylinder head is warped or twisted.

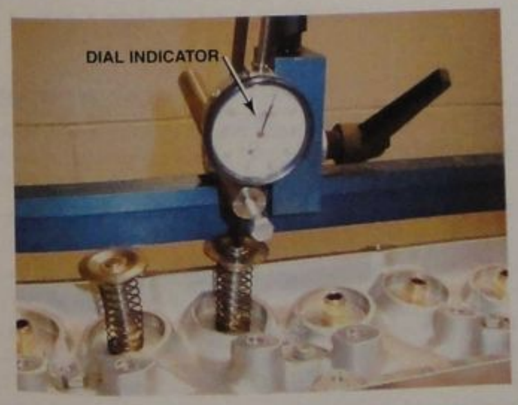


Figure 12–19 A dial indicator is used to measure valve lift during flow testing of a high performance cylinder head.

DIAL BORE GAUGE

A dial bore gauge is an expensive, but important, gauge used to measure cylinder taper and out-of-round as well as main bearing (block housing) bore for taper and out-of-round. See Figure 12–20. A dial bore gauge has to be adjusted to a dimension, such as the factory specifications. The reading on the dial bore gauge then indicates plus (+) or minus (−) readings from the predetermined dimension. This is why a dial bore is best used to measure taper and out-of-round because it shows the difference in cylinder or bore rather than an actual measurement.

DEPTH MICROMETER

A depth micrometer is similar to a conventional micrometer except that it is designed to measure the depth from a flat surface. See Figure 12–21.

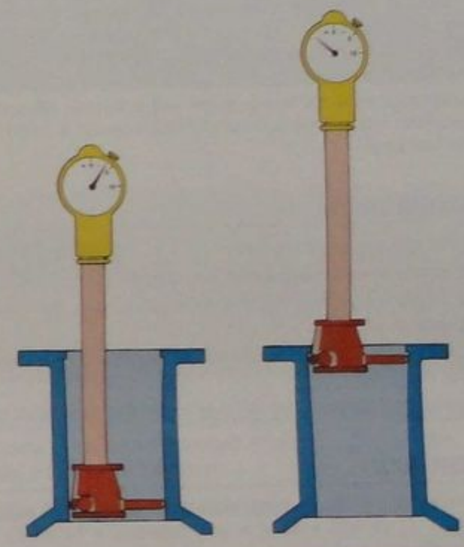


Figure 12–20 A dial bore gauge is used to measure cylinders and other engine parts for out-of-round and taper conditions.

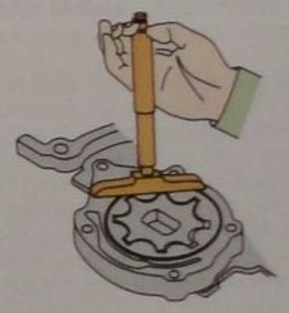


Figure 12–21 A depth micrometer being used to measure the height of the rotor of an oil pump from the surface of the housing.

SUMMARY

1. A tape measure or machinist rule can be used to measure linear distances.
2. A micrometer can measure 0.001 inch by using a thimble that has 40 threads per inch. Each rotation of the thimble moves the thimble 0.025 inch. The circumference of the thimble is graduated into 25 marks, each representing 0.001 inch.
3. A micrometer is used to check the diameter of a crankshaft journal as well as the taper and out-of-round.
4. A camshaft bearing and lobe can be measured using a micrometer.
5. A telescopic gauge is used with a micrometer to measure the inside of a hole or bore, such as the big end of a connecting rod or a cylinder bore.
6. A small-hole gauge (also called a split-ball gauge) is used with a micrometer to measure small holes such as the inside diameter of a valve guide in a cylinder head.
7. A vernier dial caliper is used to measure the outside diameter of components such as pistons or crankshaft bearing journals.
8. A feeler gauge (also called a thickness gauge) is used to measure the gap or clearance between two components such as piston ring gap, piston ring side clearance, and connecting rod side clearance. A feeler gauge is also used with a precision straightedge to measure the flatness of blocks and cylinder heads.
9. A dial indicator and dial bore gauge are used to measure differences in a component such as crankshaft end play (dial indicator) or cylinder taper (dial bore gauge).

REVIEW QUESTIONS

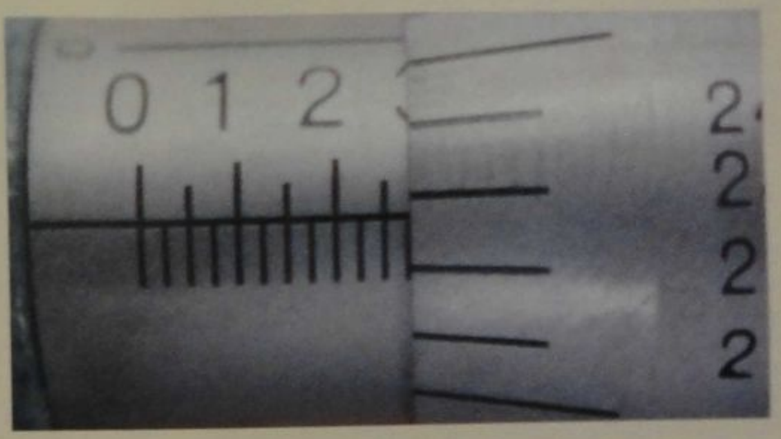
1. Explain how a micrometer is read.
2. Describe how to check a crankshaft journal for out-of-round and taper.
3. List engine components that can be measured with the help of a telescopic gauge.
4. List the gaps or clearances that can be measured using a feeler (thickness) gauge.
5. Explain why a dial bore gauge has to be set to a dimension before using.

CHAPTER QUIZ

1. The threaded movable part that rotates on a micrometer is called the _____.
   a. Barrel
   b. Thimble
   c. Spindle
   d. Anvil
2. To check a crankshaft journal for taper, the journal should be measured in at least how many locations?
   a. One
   b. Two
   c. Four
   d. Six
3. To check a crankshaft journal for out-of-round, the journal should be measured in at least how many locations?
   a. Two
   b. Four
   c. Six
   d. Eight
4. A telescopic gauge can be used to measure a cylinder bore if what other measuring device is used to measure the telescopic gauge?
   a. Micrometer
   b. Feeler gauge
   c. Straightedge
   d. Dial indicator
5. To directly measure the diameter of a valve guide in a cylinder head, use a micrometer and a _____.
   a. Telescopic gauge
   b. Feeler gauge
   c. Small-hole gauge
   d. Dial indicator
6. Which of the following *cannot* be measured using a feeler gauge?
   a. Valve guide clearance
   b. Piston ring gap
   c. Piston ring side clearance
   d. Connecting rod side clearance
7. Which of the following *cannot* be measured using a straightedge and a feeler gauge?
   a. Cylinder head flatness
   b. Block deck flatness
   c. Straightness of the main bearing bores
   d. Straightness of the cylinder bore
8. Which measuring gauge needs to be set up (adjusted) to a fixed dimension before use?
   a. Dial indicator
   b. Dial bore gauge
   c. Vernier dial gauge
   d. Micrometer
9. The freezing point of water is _____.
   a. 0°C
   b. 32°F
   c. 0°F
   d. Both a and b
10. Which metric unit of measure is used for volume measurement?
    a. Meter
    b. cc
    c. Centimeter
    d. Millimeter

SECTION IV Principles and Calculations

13 Scientific Principles and Materials
14 Math, Charts, and Calculations



CHAPTER 13

Scientific Principles and Materials

OBJECTIVES: After studying Chapter 13, the reader will be able to: Describe Newton's Laws of Motion. • Explain kinetic energy and why it is so important to brake design. • Discuss mechanical advantage and how it is used in a vehicle. • Explain the coefficient of friction. • Describe the difference between heat and temperature. • Describe the methods used to identify plastic, iron, steel, and aluminum.

KEY TERMS: acid material • alkaline • brake • brake horsepower (bhp) • BTU (British Thermal Unit) • caustic material • Celsius (centigrade) • conduction • conductor • convection • dynamometer (dyno or dyn) • energy • Fahrenheit • first-class lever • force • fulcrum • horsepower • hypothesis • inertia • insulator • kinetic energy • leverage • mass • mechanical advantage • Newton's laws of motion • pedal ratio • pH • potential energy • power • propagation • radiation • root cause • scientific method • second-class lever • third-class lever • torque • weight • work • wrought alloys

SCIENTIFIC METHOD

The **scientific method** is a series of steps taken to solve a problem. These steps help eliminate errors and to achieve an accurate result. A scientific method involves the following steps:

Step #1 Observe the conditions or problem and define or describe the problem.

Step #2 Formulate an explanation that could be the cause of the problem.

Step #3 Use the explanation (**hypothesis**) to test to see if it matches the existing problem. If not, then return to step 2 to formulate another explanation.

Step #4 After the explanation has proved to be a possible solution to a problem, additional tests should be performed to verify that the method works all of the time.

Using the Scientific Method While a service technician will not perform research, using a scientific approach to problem solving is very important.

This means that every fault should be investigated to determine the root cause rather than solving what at first is thought to be the problem or fault. The **root cause** is the true cause of a failure, which may not be noticed at first. Many service technicians ask themselves "why" when they discover a fault. Often this leads to another possible problem and then the technician should ask another "why." This scientific method of finding the root cause of an automotive problem is often called the "five whys." By the time the technician has asked "why" five times, the root cause is usually discovered.

Examples of the Five Whys As an example of using a scientific method approach to automotive faults, an owner may state

that the vehicle does not start and the battery appears to be dead. Therefore, applying the five whys (scientific approach) first ask why:

- First why—What caused the battery to become discharged? To answer this question requires observation and the creating of a hypothesis, such as "is the battery defective" or "did the customer leave the lights on?" This requires questioning the owner and testing the battery.
- Second why—Assume that the battery was in good condition but discharged. Now the technician should ask the second why, "Why did the battery become discharged?" This means that a battery ignition off drain test needs to be performed as well as testing of the charging system. Assume the battery drain test was okay, but that the charging system was not working okay.
- Third why—The charging system was found to be not working correctly. A visual inspection found that the generator (alternator) drive belt was not tight enough to properly operate the generator (alternator). The technician needs to ask the third why, "Why is the accessory drive belt still loose?"
- Fourth why—"Why was the accessory drive belt loose?" The cause could be a defective tensioner. If the tensioner itself was not a problem, then another "why" needs to be asked.
- Fifth why—If the accessory belt and belt tensioner were okay, then further investigation would be needed to find the root cause. For example, "is one of the tensioner retaining bolts loose, maybe from a previous repair?" This could be the root cause.

ENERGY PRINCIPLES

Energy is the ability or the capacity to do work. There are many forms of energy, but chemical, mechanical, and electrical energy are the most familiar kinds involved in the operation of an automobile. See Figure 13–1. Energy is called **kinetic energy** if the energy is in the form of a moving object. An example of kinetic energy is a moving vehicle. Energy is called **potential energy** if it is capable of being changed to useful energy, such as the potential energy stored in a battery or a vehicle at the top of a hill. In both of these cases, there is no energy being released but if the battery were connected to an electrical load, such as a light bulb, or the vehicle starts moving down the hill, the energy is being released.

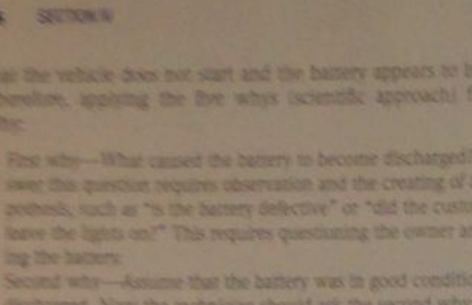


Figure 13–1 Energy, which is the ability to perform work, exists in many forms.

TORQUE

Torque is the term used to describe a rotating force that may or may not result in motion. Torque is measured as the amount of **force** multiplied by the length of the lever through which it acts. If a one-foot-long wrench is used to apply 10 pounds of force to the end of the wrench to turn a bolt, then you are exerting 10 pound-feet of torque. See Figure 13–2. The metric unit for torque is Newton-meters because Newton is the metric unit for force and the distance is expressed in meters.

1 pound-foot = 1.3558 Newton-meters

1 Newton-meter = 0.7376 pound-foot

WORK

Work is defined as actually accomplishing movement when force (torque) is applied to an object. A service technician can apply torque to a bolt in an attempt to loosen it, yet no work is done until the bolt actually moves. Work is calculated by multiplying the applied force (in pounds) by the distance the object moves (in feet). If you applied 100 pounds of force to move an object 10 feet, then you accomplished 1,000 foot-pounds of work (100 pounds × 10 feet = 1,000 foot pounds). See Figure 13–3.

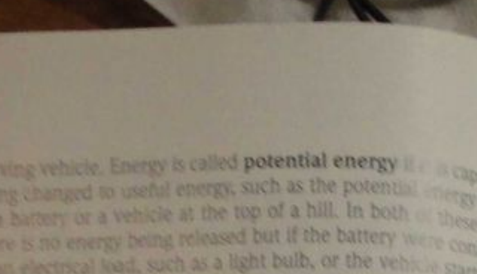


Figure 13–2 Torque is a twisting force equal to the distance from the pivot point times the force applied expressed in units called pound-feet (lb-ft) or Newton-meters (N-m).

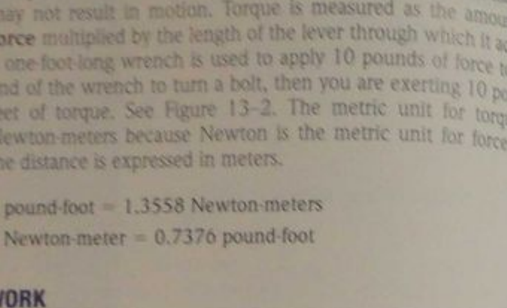


Figure 13–3 Work is calculated by multiplying force times distance. If you push 100 pounds 10 feet, you have done 1,000 foot-pounds of work.

Newton-Meters to Pound-Feet Conversion Chart
(1 N-m = 0.074 lb-ft)

N-m	Lb-ft	N-m	Lb-ft	N-m	Lb-ft	N-m	Lb-ft
1	0.74	26	19.2	51	37.7	76	56.2
2	1.5	27	20.0	52	38.5	77	57.0
3	2.2	28	20.7	53	39.2	78	57.7
4	3.0	29	21.5	54	40.0	79	58.5
5	3.7	30	22.2	55	40.7	80	59.2
6	4.4	31	22.9	56	41.4	81	59.9
7	5.2	32	23.7	57	42.2	82	60.7
8	5.9	33	24.4	58	42.9	83	61.4
9	6.7	34	25.2	59	43.7	84	62.2
10	7.4	35	25.9	60	44.4	85	62.9
11	8.1	36	26.6	61	45.1	86	63.6
12	8.9	37	27.4	62	45.9	87	64.4
13	9.6	38	28.1	63	46.6	88	65.1
14	10.4	39	28.9	64	47.4	89	65.9
15	11.1	40	29.6	65	48.1	90	66.6
16	11.8	41	30.3	66	48.8	91	67.3
17	12.6	42	31.1	67	49.6	92	68.1
18	13.3	43	31.8	68	50.3	93	68.8
19	14.1	44	32.6	69	51.0	94	69.6
20	14.8	45	33.3	70	51.8	95	70.3
21	15.5	46	34.0	71	52.5	96	71.0
22	16.3	47	34.8	72	53.3	97	71.8
23	17.0	48	35.5	73	54.0	98	72.5
24	17.8	49	36.3	74	54.8	99	73.3
25	18.5	50	37.0	75	55.5	100	74.0

Pound-Feet to Newton-Meters Conversion Chart
(1 lb-ft = 1.4 N-m)

Lb-ft	N-m	Lb-ft	N-m	Lb-ft	N-m	Lb-ft	N-m
1	1.4	26	35.4	51	71.4	76	106.4
2	2.8	27	37.8	52	72.8	77	107.8
3	4.2	28	39.2	53	74.2	78	109.2
4	5.6	29	40.6	54	75.6	79	110.6
5	7.0	30	42.0	55	77.0	80	112.0
6	8.4	31	43.4	56	78.4	81	113.4
7	9.8	32	44.8	57	79.8	82	114.8
8	11.2	33	46.2	58	81.2	83	116.2
9	12.6	34	47.6	59	82.6	84	117.6
10	14.0	35	49.0	60	84.0	85	119.0
11	15.4	36	50.4	61	85.4	86	120.4
12	16.8	37	51.8	62	86.8	87	121.8
13	18.2	38	53.2	63	88.2	88	123.2
14	19.6	39	54.6	64	89.6	89	124.6
15	21.0	40	56.0	65	91.0	90	126.0
16	22.4	41	57.4	66	92.4	91	127.4
17	23.8	42	58.8	67	93.8	92	128.8
18	25.2	43	60.2	68	95.2	93	130.2
19	26.6	44	61.6	69	96.6	94	131.6
20	28.0	45	63.0	70	98.0	95	133.0
21	29.4	46	64.4	71	99.4	96	134.4
22	30.8	47	65.8	72	100.8	97	135.8
23	32.2	48	67.2	73	102.2	98	137.2
24	33.6	49	68.6	74	103.6	99	138.6
25	35.0	50	70.0	75	105.0	100	140.0

FREQUENTLY ASKED QUESTION ???

What Is the Difference in Torque and Work?

The designations for torque and work are often confusing. Torque is expressed in pound-feet because it represents a force exerted a certain distance from the object and acts as a lever. Work, however, is expressed in foot-pounds because work is the movement over a certain distance (feet) multiplied by the force applied (pounds). Engines produce torque and service technicians exert torque represented by the unit pound-feet.

POWER

The term **power** means the rate of doing work. Power equals work divided by time. Work is achieved when a certain amount of mass (weight) is moved a certain distance by a force. If the object is moved in 10 seconds or 10 minutes does not make a difference in the amount of work accomplished, but it does affect the amount of power needed. Power is expressed in units of foot-pounds per minute.

HORSEPOWER

The power an engine produces is called horsepower (hp). One **horsepower** is the power required to move 550 pounds one foot in one second, or 33,000 pounds one foot in one minute (550 lb × 60 sec = 33,000 lb). This is expressed as 500 foot-pounds (ft-lb) per second or 33,000 foot-pounds per minute. See Figure 13–4.

The actual horsepower produced by an engine is measured with a **dynamometer.** A dynamometer (often abbreviated as **dyno** or **dyn**) places a load on the engine and measures the amount of twisting force the engine crankshaft places against the load. The load holds the engine speed, so it is called a **brake.** The horsepower derived from a dynamometer is called **brake horsepower (bhp).** The dynamometer actually measures the torque output of the engine. Torque is a rotating force that may or may not cause movement. The horsepower is calculated from the torque readings at various engine speeds (in revolutions per minute or RPM).

Horsepower is torque times RPM divided by 5252.

$$\text{Horsepower} = \frac{\text{Torque} \times \text{RPM}}{5252}$$

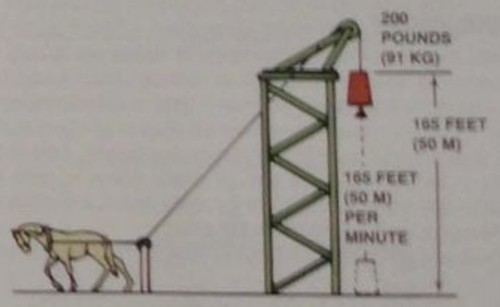


Figure 13–4 One horsepower is equal to 33,000 foot-pounds (200 lbs × 165 ft) of work per minute.

Torque is what the driver "feels" as the vehicle is being accelerated. A small engine operating at a high RPM may have the same horsepower as a large engine operating at a low RPM.

NOTE: As can be seen by the formula for horsepower, the higher the engine speed for a given amount of torque, the greater the horsepower.

NEWTON'S LAWS OF MOTION

Sir Isaac Newton (1643–1727) was an English physicist and mathematician who developed many theories of science, including three laws of motion.

1. **Newton's** first **law of motion** states that an object at rest tends to stay at rest and an object in motion tends to stay in motion unless acted on by an outside force. For example, it requires a large force to get a vehicle that is stopped into motion. It also requires that a force be applied to slow and stop a vehicle that is in motion.
2. Newton's second law of motion states that the force needed to move an object is proportional to the mass of the object multiplied by the acceleration rate of the object. This means that it requires a great deal more force to accelerate a heavy sport utility vehicle (SUV) than a small economy vehicle. The rate of acceleration also depends on the amount of force that is applied.
3. Newton's third law of motion states that for every action, there is an opposite and equal reaction. For example, when the air-fuel mixture is ignited in an engine, the force is exerted on the piston, which is forced downward, which causes the crankshaft of the engine to rotate. The opposite action is applied to the cylinder head of the engine and applies the same force although this part is designed not to move.

KINETIC ENERGY

Kinetic energy is a fundamental form of mechanical energy. It is the energy of mass in motion. Every moving object possesses kinetic energy, and the amount of that energy is determined by the object's mass and speed. The greater the mass of an object and the faster it moves, the more kinetic energy it possesses. Even at low speeds, a moving vehicle has enough kinetic energy to cause serious injury and damage. The job of the brake system is to dispose of that energy in a safe and controlled manner.

Engineers calculate kinetic energy using the following formula:

$$\frac{mv^2}{29.9} = E_k$$

where:

- m = mass or weight of the vehicle in pounds
- v = velocity of the vehicle in miles per hour
- E_k = kinetic energy in foot-pounds (ft-lb)

Another way to express this equation is as follows.

$$\frac{\text{weight} \times \text{speed}^2}{29.9} = \text{kinetic energy}$$

If a 3,000-pound vehicle traveling at 30 mph is compared to a 6,000-pound vehicle also traveling at 30 mph as shown in Figure 13–5, the equations for computing their respective kinetic energies look like this:

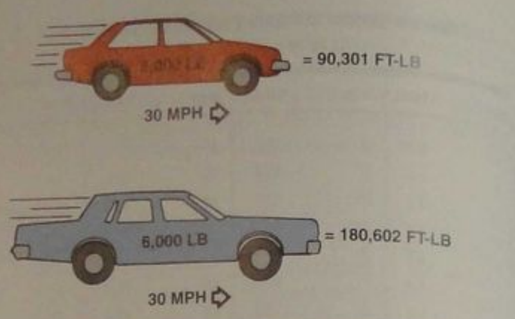


Figure 13–5 Kinetic energy increases in direct proportion to the weight of the vehicle.

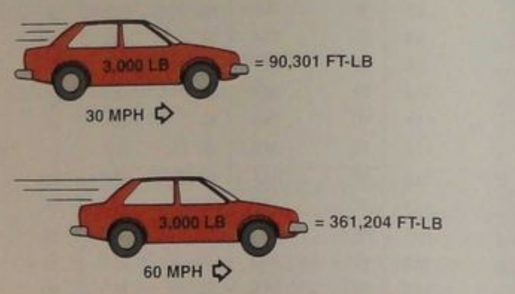


Figure 13–6 Kinetic energy increases as the square of any increase in vehicle speed.

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{6{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 180{,}602 \text{ ft-lb}$$

The results show that when the weight of a vehicle is doubled from 3,000 to 6,000 pounds, its kinetic energy is also doubled from 90,301 foot-pounds to 180,602 foot-pounds. In mathematical terms, kinetic energy increases *proportionally* as weight increases. In other words, if the weight of a moving object doubles, its kinetic energy also doubles. If the weight quadruples, the kinetic energy becomes four times as great.

If a 3,000-pound vehicle traveling at 30 mph is compared to the same vehicle traveling at 60 mph (Figure 13–6), the equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{3{,}000 \text{ lb} \times 60^2 \text{ mph}}{29.9} = 361{,}204 \text{ ft-lb}$$

The results show that the vehicle traveling at 30 mph has over 90,000 foot-pounds of kinetic energy, but at 60 mph the figure increases to over 350,000 foot-pounds. In fact, at twice the speed, the vehicle has exactly four times as much kinetic energy. If the speed were doubled again to 120 mph, the amount of kinetic energy would grow to almost 1,500,000 foot-pounds! In mathematical terms, kinetic energy increases as the *square of its speed.* In other words, if the speed of a moving object doubles (2), the kinetic energy becomes four times as great ($2^2 = 4$). And if the speed quadruples (4), say from 15 to 60 mph, the kinetic energy becomes 16 times as great ($4^2 = 16$). This is the reason speed has such an impact on kinetic energy.

FREQUENTLY ASKED QUESTION ???

What Is the Difference Between Mass and Weight?

Mass is the amount of matter in an object. One of the properties of mass is inertia. Inertia is the resistance to being put in motion and the tendency to remain in motion once it is set in motion.

The **weight** of an object is the force of gravity on the object and may be defined as the mass times the acceleration of gravity.

Therefore, mass means the property of an object and weight is a force.

Kinetic Energy and Brake Design The relationships between weight, speed, and kinetic energy have significant practical consequences for the brake system engineer. If vehicle A weighs twice as much as vehicle B, it needs a brake system that is twice as powerful. But if vehicle C has twice the speed potential of vehicle D, it needs brakes that are, not twice, but four times more powerful.

INERTIA

Although brake engineers take both weight and speed capability into account when designing a brake system, these are not the only factors involved. Another physical property, inertia, also affects the braking process and the selection of brake components. **Inertia** is defined by Isaac Newton's first law of motion, which states that a body at rest tends to remain at rest, and a body in motion tends to remain in motion in a straight line unless acted upon by an outside force.

TECH TIP ✔ Brakes Cannot Overcome the Laws of Physics

No vehicle can stop on a dime. The energy required to slow or stop a vehicle must be absorbed by the braking system. All drivers should be aware of this fact and drive at a reasonable speed for the road and traffic conditions.

MECHANICAL PRINCIPLES

The primary mechanical principle used to increase application force in every brake system is **leverage.** In the science of mechanics, a lever is a simple machine that consists of a rigid object, typically a metal bar that pivots about a fixed point called a **fulcrum.** There are three basic types of levers, but the job of all three is to change a quantity of energy into a more useful form.

A **first-class lever** increases the force applied to it and also changes the direction of the force. See Figure 13–7.

With a first-class lever, the weight is placed at one end while the lifting force is applied to the other. The fulcrum is positioned at some point in between. If the fulcrum is placed twice as far from the long end of the lever as from the short end, a 10-pound weight on the short end can be lifted by only a 5-pound force at the long end. However, the short end of the lever will travel only half as far as the long end. Moving the fulcrum closer to the weight will further reduce the force required to lift it, but it will also decrease the distance the weight is moved.

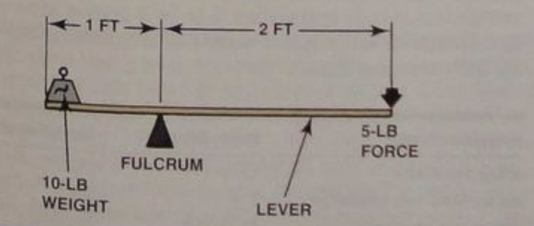


Figure 13–7 A first-class lever increases force and changes the direction of the force.

A **second-class lever** increases the force applied to it and passes it along in the same direction. See Figure 13–8.

With a second-class lever, the fulcrum is located at one end while the lifting force is applied at the other. The weight is positioned at some point in between. If a 10-pound weight is placed at the center of the lever, it can be lifted by only a 5-pound force at the end of the lever. However, the weight will only travel half the distance the end of the lever does. As the weight is moved closer to the fulcrum, the force required to lift it, and the distance it travels, are both reduced.

A **third-class lever** actually reduces the force applied to it, but the resulting force moves farther and faster. See Figure 13–9.

With a third-class lever, the fulcrum is located at one end and the weight is placed at the other. The lifting force is applied at some point in between. If a 10-pound weight is placed at the end of the lever, it can be lifted by a 20-pound force applied at the middle of the lever. Although the force required to move the weight has doubled, the weight is moved twice as far and twice as fast as the point on the lever where the force was applied. The closer to the fulcrum the lifting force is applied, the greater the force required by the weight and the farther and faster the weight will move.

The levers in brake systems are used to increase force, so they are either first- or second-class. Second-class levers are the most common, and the service brake pedal is a good example. In a typical suspended brake pedal, the pedal arm is the lever, the pivot point is the fulcrum, and the force is applied at the foot pedal pad. See Figure 13–10. The force applied to the master cylinder by the pedal pushrod attached to the pivot is much greater than the force applied at the pedal pad, but the pushrod does not travel nearly as far.

Leverage creates a **mechanical advantage** that, at the brake pedal, is called the **pedal ratio.** For example, a pedal ratio of 5 to 1 is common for manual brakes, which means that a force of 10 pounds at the brake pedal will result in a force of 50 pounds at

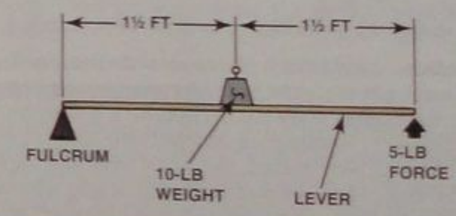


Figure 13–8 A second-class lever increases force in the same direction as it is applied.

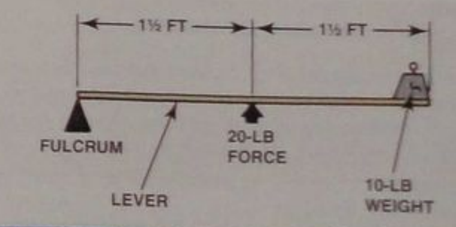


Figure 13–9 A third-class lever reduces force but increases the speed and travel of the resulting work.

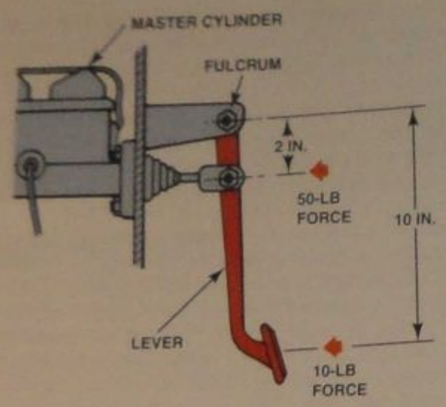


Figure 13–10 This brake pedal assembly provides a 5:1 mechanical advantage because a 10-lb force input results in a 50-lb force into the master cylinder.

the pedal pushrod. In practice, leverage is used at many points in both the service and parking brake systems to increase braking force while making it easier for the driver to control the amount of force applied.

HEAT AND TEMPERATURE

Heat and temperature are related but are not the same. Temperature is the intensity of the heat source, whereas heat is the quantity of heat. For example, the heat from a match and a large fire may measure the same temperature, but the amount of heat generated by the fire is far greater than the amount of heat generated by a single match.

Heat Heat is measured in units called **British Thermal Units,** abbreviated **BTUs.** One BTU is the amount of heat needed to raise the temperature of one pound of water one degree Fahrenheit. For example, room heaters and air conditioners are rated in how many BTUs per hour can be added (heater) or removed (air conditioner) from a space in one hour.

Heat energy can be transferred by three ways, including:

- **Conduction**—Conduction is the process of the heat traveling from a hotter part to a colder part of the same object or by direct contact. For example, if one end of a steel bar is heated, then the heat will travel by conduction toward the colder areas of the bar. Also, if the metal were touched, heat would travel from the steel bar to the finger. Metals are good conductors of heat, whereas plastic, rubber, and ceramics are poor conductors of heat and are called **insulators.**

TECH TIP ✔ **Conductors and Insulators**

If a material is a good conductor of heat, it is also a good conductor of electricity. Most **conductors** are metals, such as steel, copper, aluminum, and brass. Most insulators are nonmetals, such as plastic and rubber. Therefore, if a material does not conduct heat, it usually will not conduct electricity.

- **Convection**—Convection is the transfer of heat through a liquid or a gas, which causes it to rise while the cooler liquid or gas falls within a container. A hot air balloon is an example where hot gas in the balloon causes it to rise above the surrounding cooler air.
- **Radiation**—Radiation is a method of energy transfer where heat is transmitted through the air. Heat from the sun is transmitted through the atmosphere where it heats the ground. Heat can be felt above a hot stove.



Figure 13–11 A typical outdoor thermometer which is used to measure temperature, not heat.

Temperature Temperature is the measurement of the ability to give up or absorb heat from another body. Heat always flows from a warmer object to a colder object. See Figure 13–11.

FREQUENTLY ASKED QUESTION ???

How Does a Coat Keep You Warm?

A coat is worn in cold weather to keep warm. Does it keep the cold out or the heat in? Actually, both, but because heat travels from a warm object (human body) to a colder object (outside cold air), the primary purpose of a coat is to keep the body heat from escaping into the cold air.

Temperature is measured using two scales: **Celsius** (also called **centigrade**) and **Fahrenheit.** The Celsius scale was devised by taking the freezing point and the boiling point of water and dividing it into 100 equal parts.

The Fahrenheit scale was developed by Gabriel Fahrenheit (1686–1736), a German physicist who proposed the scale in 1724. He wanted to avoid using negative numbers, so the scale used had zero degrees representing the coldest outside air temperature he had ever measured and used his own body temperature to represent 100 degrees. Later, more accurate measurements indicate that average human body temperature to be 98.6 degrees so he was off by 1.4 degrees. Also, negative outside air temperatures can occur. See the comparison chart.

Temperature Symbol	Degree Celsius °C	Degree Fahrenheit °F
Boiling point of water	100.0	212.0
Average human body temperature	37.0	98.6
Average room temperature	20.0 to 25.0	68.0 to 77.0
Melting point of ice	0.0	32.0

TECH TIP ✔ **Quick and Easy Temperature Conversion**

Many service information and scan tool data are expressed in degrees Celsius, which is often confusing to those used to temperature expressed in Fahrenheit degrees. A quick and easy way to get an *approximate* conversion is to take the degrees in Celsius, double it, and add 25.

For example,

Celsius × 2 + 25 = approximate Fahrenheit degrees

0°C × 2 = 0 + 25 = 25°F (actual = 32°F)
10°C × 2 = 20 + 25 = 45°F (actual = 50°F)
15°C × 2 = 30 + 25 = 55°F (actual = 59°F)
20°C × 2 = 40 + 25 = 65°F (actual = 68°F)
25°C × 2 = 50 + 25 = 75°F (actual = 77°F)
30°C × 2 = 60 + 25 = 85°F (actual = 86°F)
35°C × 2 = 70 + 25 = 95°F (actual = 95°F)
40°C × 2 = 80 + 25 = 105°F (actual = 104°F)
45°C × 2 = 90 + 25 = 115°F (actual = 113°F)
50°C × 2 = 100 + 25 = 125°F (actual = 122°F)

FREQUENTLY ASKED QUESTION ???

What Is Thermodynamics?

Thermodynamics is the study of the relationship among temperature, pressure, and volume changes. The laws of thermodynamics help engineers design and develop engines with higher efficiency. Thermodynamics is therefore used in the design of the cooling system, as well as in the engine, because the more heat created by the burning of fuel in the engine, the more power the engine can develop using the same or less amount of fuel.

ACIDS AND BASES

Acids Acids are substances that can corrode metals and some can cause severe burns to the skin. Common household acids that are not harmful and taste sour include vinegar and lemon juice (citric acid). Stronger acids include:

- Hydrochloric acid
- Nitric acid
- Battery acid

Bases A base is a substance that can also burn the skin if strong enough and is also referred to as **alkaline.** Common household bases are generally not harmful unless eaten and have a bitter taste, including baking soda, soap, and antacid, such as Milk of Magnesia®. Stronger bases, which can burn the skin include:

- Lye (sodium hydroxide)
- Bleach
- Drain cleaner

pH Scale Most chemical cleaners used for cleaning carbon-type deposits are a strong soap, or **caustic material.** A value called **pH,** measured on a scale from 1 to 14, is used to indicate the amount of chemical activity. The term *pH* is from the French word *pouvoir hydrogine,* meaning "hydrogen power." Pure water is neutral. On the pH scale, water is pH 7. Caustic materials have pH numbers from 8 through 14. The higher the number, the stronger the caustic action will be. **Acid materials** have pH numbers from 6 through 1. The lower the number, the stronger the acid action will be. Caustic materials and acid materials neutralize each other, such as when baking soda is added to clean the outside of the battery (an acid surface). The caustic baking soda neutralizes any sulfuric acid that has been spilled or splashed on the outside of the battery.

CAUTION: Whenever working with chemicals, eye protection must be used.

FREQUENTLY ASKED QUESTION ???

Can Water and Acid Be Mixed Together?

Acids have a very strong affinity for water and as a result, if water is poured into acid, the resulting reaction would be extremely violent and acid would be forced outward in all directions. Always pour acid into water, never water into acid.

Technicians seldom need to work with acids because even battery electrolytes from the water and acid are premixed to help prevent the possibility of a technician creating a harmful reaction.

GAS LAWS

Gas laws are a set of characteristics that describe how gases act and the relationship between their temperature, pressure, and volume. Gas laws have application in most systems of the vehicle, including tires, air-conditioning systems, and anywhere else gases are present.

Boyle's Law Boyle's law was first written in 1662 by Robert Boyle (1627–1691) and describes the relationship between volume and pressure of a gas in a closed container. Boyle's law states that the volume of a gas varies inversely (opposite) with the pressure exerted against it in a closed container. Therefore, if a closed container is compressed, the volume of the gas inside is reduced but the pressure is increased.

Charles's Law Charles's Law was first formulated about 1787 by a French scientist, Jacque Charles (1746–1823). According to Charles's law when the temperature of a gas increases, the volume increases. When the temperature of a gas decreases, the volume decreases.

SOUND AND ACOUSTICS

Sound is the movement of air which the ear interprets as sound. Sound travels through the air, which is called **propagation.** Propagation of sound is normally thought to be only transmitted through air, but liquids can also transmit sound waves. Sound has two properties:

- **Frequency.** This is also called the pitch of the sound and is measured in Hertz or cycles per second. Normal hearing frequency ranges from as low as 20 Hertz to 20,000 Hertz. Very low frequencies, such as the heart beat, of one or two Hertz cannot be heard. High frequencies over 20,000 Hertz also cannot be detected by humans.
- **Intensity.** The intensity of sound, which is also called loudness, is measured in decibels (dB) named for Alexander Graham Bell (1847–1922), the inventor of the telephone. Relative intensity (loudness), using the decibel scale, includes the following examples:
  - Whisper 10–20 dB
  - Normal conversation 60 dB
  - Thunder 110 dB
  - Threshold of pain 120 dB

Acoustics Acoustics is the study of sound and how it is generated and transmitted. Acoustic engineers are employed by vehicle manufacturers to help reduce noise and designing methods to reduce or stop the noise from being transmitted into the passenger compartment. For example, according to acoustic engineers, about 80% of the noise created by the movement of the tires on the road is transmitted through the chassis and body of the vehicle. Only about 20% of the sound is transferred to the passenger compartment through the air.

TECH TIP **Wear Hearing Protection**

According to audiologists (hearing and speech doctors), a person should wear ear protection if the level of sound requires that your voice be raised in order to be heard. Any level that exceeds 90 dB requires the use of ear protection to avoid hearing loss. This means that ear protection should be worn when using a power mower or using an air tool, such as an air impact wrench or air ratchet.

PLASTICS

There are two basic types of plastic.

Thermoset Plastic This type of plastic is changed chemically when cured and shaped and cannot be reheated or reformed. Rubber is an example of a thermoset plastic material that cannot be remelted and reformed after curing. Other examples of thermoset plastics include:

- Bakelite (phenol formaldehyde resin)
- Polyester resin
- Epoxy resin

Thermoplastic This type of plastic is flexible at room temperature. Thermoplastic can be recycled by grinding it into pieces and remolding it into another shape. Examples of thermoplastics include:

- Polyethylene (PE)
- Polyvinyl chloride (PVC)
- Polystyrene (PS)
- ABS (acrylonitrile butadiene styrene)
- PA nylon (polyamides)

Plastic Identification While it is not important for the average service technician to determine what kind of plastic is being used for what application, it is important to know when restoring a part or refinishing a plastic part. For example, interior plastic parts can be made from the following plastic material:

- Polypropylene plastic (PP)
- Polyethylene (PE) (see Figure 13–12)
- ABS plastic
- ABS/PVC plastic
- Vinyl (PVC) plastic

Most large plastic pieces are labeled on the inside with letters, such as PP or PE. However, if no marking is visible, it is still possible to identify the type of plastic using a simple basic test. A painter will need to know the type of plastic if refinishing these parts. Often replacement plastic parts are available in only one color and must be painted to match the original when being replaced. A burn test is used to test if the plastic part is polypropylene or ABS plastic by performing the following steps:

Step #1 Remove a small piece from a hidden back side of the plastic part being tested.

Step #2 Hold the small piece of plastic with tweezers and ignite the plastic.

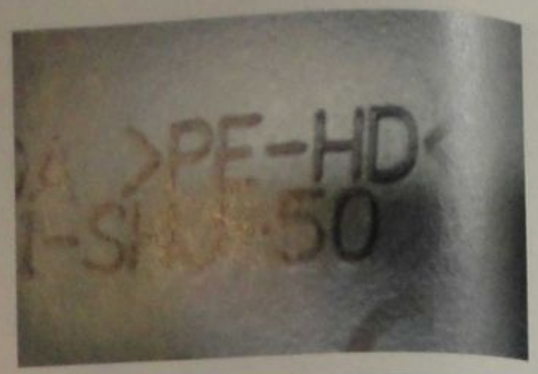


Figure 13–12 This interior plastic part is labeled PE-HD, which means polyethylene-high density.

Step #3 Observe the burning of the plastic:

- No visible smoke means that the plastic is polypropylene.
- Visible black smoke means that the plastic is ABS.

Step #4 To determine if a part to be painted is polyvinyl chloride, a copper wire test needs to be performed by heating a copper wire and then touching the heated wire to a hidden back side surface of the part being tested. After melting some plastic onto the copper wire, return the wire to the flame and observe the color of the flame. If the color of the flame is green/blue or turquoise, then the plastic is polyvinyl chloride (vinyl).

After the type of plastic has been identified, then check with service information and paint literature to determine the proper paint and preparations needed to refinish the plastic part.

IRON AND STEEL

Iron is a chemical element with a symbol of Fe. It is one of the most commonly available elements on earth and is refined from iron ore. Steel is made from iron after further refining. The main difference between iron and steel is the amount of carbon. The amount of carbon is critical to the strength and characteristics of iron and steel.

Cast Iron Cast iron contains 2% to 4% carbon and this carbon is usually in the shape of flakes of graphite 0.001 to 0.004 inches long. Cast iron is used in many automotive applications, including engine blocks, rear axle assemblies, and some suspension components.

Ductile Cast Iron In ductile iron, the carbon in the alloy with silicon are small ball-shapes called spherloidols. Ductile iron is also called malleable iron and is used to make crankshafts.

Gray Cast Iron Gray cast iron is cast iron that has another element, silicon, in the alloy giving the metal a gray color. Gray cast iron is used for engine blocks.

NOTE: Cast iron contains graphite, which acts as a lubricant when being machined. As a result, cooling oil or water is not needed when making cast iron brake rotors or brake drums.

SAE STEEL DESIGNATIONS

Steels are designed by a system established by the Society of Automotive Engineers and includes numbers to indicate the main element used in the alloy, plus the "points of carbon." One part of carbon is 0.01%. In other words, 100 points of carbon is equal to 1%. The percentage of carbon in steel has a huge effect on the strength and characteristics of the steel. For example:

- **Mild (low carbon) steel** has less than 20 points of carbon (0.02%). Mild steel is soft and easily formed but is not very strong. Common usage of low carbon steel is in tables and chairs and vehicle body parts where strength is not an issue.
- **Medium carbon steel** usually has between 25 and 50 points of carbon (0.25% and 0.50%). This type of steel can be heat treated to create steel that is ductile (flexible) and yet has good strength. This type of steel is usually used in forgings and machined components.
- **High carbon steel** usually has between 60 and 100 points (0.60% and 1.00%) of carbon and is very strong. It is commonly used in vehicle springs and can be hardened.

CAUTION: Both medium carbon and high carbon steel can be hardened by heating and then cooling, using water or oil to rapidly cool the metal. Therefore, if heating any metal, always allow it to cool slowly to avoid changing the hardness of the steel.

The SAE numbering designation usually includes four numbers:

- The first two numbers indicate the type of alloy which could include several alloy elements.
- The last two numbers designate the points of carbon.

1xxx = plain carbon steels
2xxx = nickel steels
3xxx = nickel-chromium steels
4xxx = molybdenum steels
5xxx = chromium steels
6xxx = chromium-vanadium steels
7xxx = tungsten-chromium steels
9xxx = silicon-manganese steels

A commonly used alloy for forged crankshafts is SAE 4340. The analysis of this designation is: 4340 = An alloy that contains 1.82% nickel, 0.5% to 0.8% chromium, and 0.25% molybdenum with 40 points of carbon.

ALUMINUM AND ALUMINUM ALLOYS

Aluminum is a lightweight metal that is used in many automotive applications, including suspension components, engine blocks, and cylinder heads. Aluminum is almost always combined with small quantities of other metals to form an alloy, using copper, manganese, zinc, or silicon. Aluminum and aluminum alloys that are mechanical shaped are called **wrought alloys** and are labeled according to the International Alloy Designation system. The system uses a four-digit number, which identifies the alloying elements, followed by a dash (-) and then a letter identifying the type of heat treatment. This is followed by a number identifying the specific hardness or temper of the finished alloy. A typical example would be 6061-T6. The 6061 is a 6000 series alloy with magnesium and silicon. The "61" further identifies other elements and their percentages. The numbering system for cast aluminum alloy is similar but is designed by standards of the Aluminum Association (AA).

SUMMARY

1. Energy is the ability to do work. A vehicle in motion represents kinetic energy which must be absorbed by the braking system during a stop.
2. Torque is a twisting force that may or may not result in motion.
3. Work is created when a force is applied to an object.
4. Power is the rate of doing work.
5. Horsepower is the power it takes to move 550 pounds, one foot in one second or torque × RPM ÷ 5252.
6. Kinetic energy is the energy of mass in motion.
7. Mechanical principles include levers, pulleys, and screws.
8. Heat is measured in BTUs and temperature is measured in degrees.
9. The pH of water is 7 with acids being lower than 7 and caustic chemicals higher than 7.

REVIEW QUESTIONS

1. What is kinetic energy?
2. How is mechanical advantage used in the braking system?
3. What is the difference between torque and power?
4. How can a burn test help identify the type of plastic used?
5. What is the pH of acids and bases?

CHAPTER QUIZ

1. All of the following are correct statements about braking *except*:
   a. Kinetic energy must be absorbed by the braking system.
   b. Kinetic energy of a vehicle doubles when the speed doubles.
   c. The heavier the vehicle, the greater the kinetic energy when moving.
   d. If the vehicle weight is doubled, the kinetic energy of a moving vehicle is doubled.
2. The brake pedal assembly uses a mechanical lever to _____.
   a. Increase the driver's force on the brake pedal applied to the master cylinder.
   b. Decrease the distance the brake pedal needs to be depressed by the driver.
   c. Decrease the driver's force on the brake pedal applied to the master cylinder.
   d. Allow for clearance between the brake pedal and the floor when the brakes are applied.
3. Technician A says that work is being performed if a force is being applied, yet the object does not move. Technician B says that torque is a twisting force that may or may not result in motion. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Two technicians are discussing engine horsepower and torque figures. Technician A says that torque is measured on a dynamometer. Technician B says that horsepower is measured on a dynamometer. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. An example of a lever and mechanical advantage used on a vehicle is the _____.
   a. Radio volume control
   b. Brake pedal
   c. Fuel tank
   d. Battery
6. Two technicians are discussing temperature and heat. Technician A says that temperature is the intensity of the heat source. Technician B says that heat is the amount of heat. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. Heat can move or travel by _____
   a. Conduction
   b. Convection
   c. Radiation
   d. All of the above

8. Technician A says that zero degrees Celsius is the freezing temperature of water. Technician B says that 100 degrees Celsius is the boiling temperature of water. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. Technician A says that pure (distilled) water has a pH of 7. Technician B says that the pH of acids is less than 7. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Technician A says that the kinetic energy of a vehicle is proportional to its weight. Technician B says that the kinetic energy of a moving vehicle is directly proportional to its speed. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

CHAPTER 14

Math, Charts, and Calculations

OBJECTIVES: After studying Chapter 14, the reader will be able to: Add and subtract decimal numbers. • Read a chart and graph. • Calculate percentages.

KEY TERMS: chart • decimal point • diagram • direct drive • drive gear • driven gear • fractions • gear reduction • graph • overdrive • percentage • scientific notation • variable

DECIMALS

Decimals are commonly used by service technicians. The placement of the decimal point indicates the value of the number. The naming of decimals includes tenths, hundredths, thousandths, and higher. Decimals are used to represent fractions of a unit by using a dot called a **decimal point** to indicate that the number is a decimal.

Tenths A decimal with one number to the right of the decimal point indicates an accuracy of 1/10 or 0.1. For example, 0.7 is the same as 7/10 and is pronounced "seven tenths" or "zero point seven." A decimal can also include numbers larger than zero, but has a resolution or accuracy measured in tenths, such as in 14.7.

Hundredth Decimals with two numbers to the right of the decimal point indicate an accuracy to 1/100 or 0.01. For example, 0.47 is pronounced "forty-seven hundredth" or "zero point four seven."

Thousandth A decimal with three numbers to the right of the decimal point indicates an accuracy to 1/1000 or 0.001. For example, 0.867 is pronounced "eight hundred sixty-seven thousandth" or "zero point eight six seven."

Adding and Subtracting Decimals When adding or subtracting decimals, the decimal point has to be aligned. This ensures that the numbers are placed into the correct position of tenth, hundredth, and thousandth. For example:

$$\begin{array}{r} 0.147 \\ +\ 0.02 \\ \hline 0.167 \end{array}$$

Notice that the top number is expressed in thousandths and the lower number is expressed in hundredths. The final figure is also shown in thousandths.

> **NOTE:** If these numbers were measurements, the first result cannot be more accurate than the least accurate measurement. This means that the final result should be expressed in hundredths instead of thousandths.

When subtracting or multiplying decimals, keep the decimal points aligned or use a calculator making certain to include the decimal point.

PERCENTAGE

Percentage is the relationship of a value or number out of 100. Using money as an example, three quarters (25 cents each) equals 75 cents ($0.75) or 75% of a dollar ($1.00). Many examples are not that easy, for example, 70 is what percentage of 120? To determine the percentage, divide the first number (70) by the second number (120).

$$70 \div 120 = 0.58$$

To convert this number to a percentage, multiply the number by 100 or move the decimal point two places to the right (58) and then add a percentage symbol to indicate that the number is a percentage (58%).

SCIENTIFIC NOTATION

Very large and very small decimal numbers are frequently expressed using scientific notation. **Scientific notation** is written as a number multiplied by the number of zeros to the right or left of the decimal point. For example, 68,000 could be written as 6.8×10^4, indicating that the number shown has 3 zeros plus the 8 to the right of the decimal point. Small numbers, such as 0.00068, would use a negative sign beside the number over the 10 to represent that the decimal point needs to be moved toward the left (6.8×10^{-4}).

ADDING AND SUBTRACTING

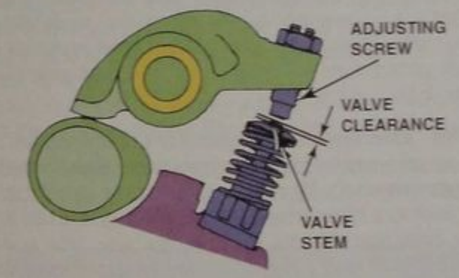
Technicians are often required to add or subtract measurements when working on vehicles. For example, adding and subtracting is needed to select shims (thin pieces of steel) for adjusting valve clearance or differential preload measurements.

For example, if the valve clearance specification is 0.012 in. and the clearance is actually 0.016 in., and the shim that is in place between the camshaft lobe and the valve bucket is 0.080 in. thick, what size (thickness) of shim needs to be installed to achieve the correct valve clearance?

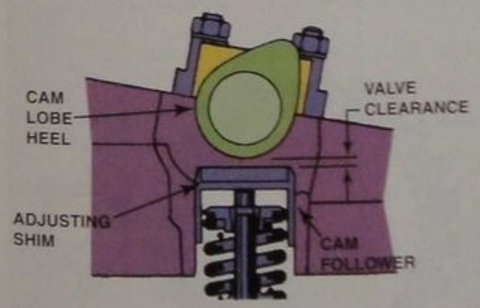
Solution: The shim thickness of 0.080 in. results in a valve clearance of 0.016 in. The specification requires that the shim needs to be thicker to reduce the valve clearance. See Figure 14–1.

To determine the thickness of a shim, the amount of clearance needed to be corrected needs to be calculated. The original clearance is 0.016 in. and the specification is 0.012 in. The difference is determined by subtracting the actual clearance from the specified clearance:

$$0.016 - 0.012 = 0.004 \text{ in.}$$



(a)



(b)

Figure 14–1 Valve clearance allows the metal parts to expand and maintain proper operation, both when the engine is cold or at normal operating temperature. (a) Adjustment is achieved by turning the adjusting screw. (b) Adjustment is achieved by changing the thickness of the adjusting shim.

The result (0.004 in.) then needs to be added to the thickness of the existing shim to determine the thickness of the replacement shim needed to achieve the correct valve clearance.

$$\begin{array}{rr} \text{Existing shim thickness} = & 0.080 \text{ in.} \\ \text{Additional thickness needed} = + & \underline{0.004 \text{ in.}} \\ \text{Thickness of new shim} = & 0.084 \text{ in.} \end{array}$$

FRACTIONS

Fractions, such as 1/2, 1/4, or 5/8 are commonly found in specifications for hose inside diameter measurements. A tape measure or machinists rule can be used to measure the fitting or the original part. Sometimes, fractions need to be converted to decimal units if the replacement parts are offered by that measurement method. When comparing fractions to decimal units, think about the number of cents in a dollar.

1/2 dollar = 50 cents
Quarter = 25 cents
1/10 (dime) = 10 cents
1/20 (nickel) = 5 cents

Other fractions, such as 3/8, 5/8, and 5/16 are harder to determine. If a chart is not available, divide the bottom number, called the denominator into the top number, called the numerator.

3/8 = 3.0 divided by 8 = 0.375
5/8 = 5.0 divided by 8 = 0.625
5/16 = 5.0 divided by 16 = 0.3125

MULTIPLYING AND DIVIDING

Multiplying by a service technician is usually done to determine gear ratios and to determine the total of many of the same items. For example, the final overall gear ratio is determined by multiplying the transmission gear ratio by the final drive ratio and is covered later in this chapter.

Dividing is commonly done when calculating total resistance of many resistances connected in parallel. In this situation, the value of the resistance is divided by the number of equal resistances. For example, if four bulbs with a resistance of 0.4 ohm were connected in parallel, the total resistance would be just 0.1 ohm ($0.4 \div 4 = 0.1$).

MATHEMATICAL FORMULAS

A formula uses letters to represent values or measurements and indicates how these numbers are to be multiplied, divided, added, or subtracted. To use a formula, the technician needs to replace the letters with the actual number and perform the indicated math functions.

For example, a formula used to determine engine speed in revolutions per minute (RPM) and is represented by the following formula:

$$\text{RPM} = \frac{\text{mph} \times \text{gear ratio} \times 336}{\text{tire diameter (inches)}}$$

This formula is used to determine the speed of the engine compared to the gear ratio and tire size. Sometimes, wheel and tire sizes are changed and knowing this is helpful.

To calculate the engine speed, the actual information needs to be placed into the formula.

Mph = 70 mph
Gear ratio = 2.41:1
Tire diameter = 26 inches

Replacing the terms with the actual numbers results in the following:

$$\text{RPM} = \frac{70 \times 2.41 \times 336}{26} = \frac{5668}{26} = 2180 \text{ RPM}$$

FUEL ECONOMY CALCULATOR

To calculate fuel economy in miles per gallons, two factors must be known:

1. How far was the vehicle driven.
2. How many gallons of fuel were needed.

This calculation requires that the fuel tank be filled two times; first at the start of the test and then at the end of the test distance. For example:

Step #1 Fill the tank until the nozzle clicks off.

> **NOTE:** Try to use the same station and pump, if possible, to achieve the most accurate results.

Step #2 Drive a reasonable distance. For the example, we drove 220 miles.

Step #3 Fill the fuel tank and record the number of gallons used. For this example, exactly 10.0 gallons.

Step #4 Calculate fuel economy: MPG = Miles driven divided by the number of gallons used.

MPG = 220 divided by 10.0 = 22.0 miles per gallon

FREQUENTLY ASKED QUESTION ???

How Is Metric Fuel Economy Measured?

In the United States fuel economy is expressed in miles per gallon. Outside of the United States, fuel economy is measured in the number of liters of fuel needed to travel 100 kilometers (62 miles), abbreviated L/100 km. This means that as the number increases, the fuel economy decreases. For example:

MPG	L/100 km
5	47.0
10	23.5
15	15.7
20	11.8
25	9.4
30	7.8
35	6.7
40	5.9
45	5.2
50	4.7

In the metric system, the fuel is measured; in the United States, the miles are measured.

GEAR RATIOS

When one gear turns another, the speed that the two gears turn in relation to each other is the gear ratio. Gear ratio is expressed as the number of rotations the **drive gear** must make in order to rotate the **driven gear** through one revolution. To obtain a gear ratio, simply divide the number of teeth on the driven gear by the number of teeth on the drive gear. Gear ratios, which are expressed relative to the number one, fall into three categories:

- Direct drive
- Gear reduction
- Overdrive

Direct Drive If two meshed gears are the same size and have the same number of teeth, they will turn at the same speed. Since the drive gear turns once for each revolution of the driven gear, the gear ratio is 1:1; this is called a **direct drive.** When a transmission is in direct drive, the engine and transmission turn at the same speed.

Gear Reduction If one gear drives a second gear that has three times the number of teeth, the smaller drive gear must travel three complete revolutions in order to drive the larger gear through one rotation. See Figure 14–2. Divide the number of teeth on the driven gear by the number of teeth on the drive gear and you get a 3:1 gear ratio (pronounced three to one). This type of gear arrangement, where driven gear speed is slower than drive gear speed, provides **gear reduction.** Gear reduction may also be called underdrive as drive speed is less than, or under, driven speed. Both terms mean the same thing and use is a matter of preference.

Gear reduction is used for the lower gears in a transmission. First gear in a transmission is called "low" gear because output speed, not gear ratio, is low. Low gears have numerically high gear ratios. That is, a 3:1 gear ratio is a lower gear than those with a 2:1 or 1:1 gear ratio. These three ratios taken in order represent a typical upshift pattern from low gear (3:1), to second gear (2:1), to drive gear (1:1).

Overdrive **Overdrive** is the opposite of a gear reduction condition and occurs when a driven gear turns faster than its drive gear. For the gears shown in Figure 14–3, the driven gear turns three times for each turn of the drive gear. The driven gear is said to overdrive the drive gear. For this example, the gear ratio is 0.33:1. Overdrive ratios of 0.65:1 and 0.70:1 are typical of those used in automotive applications.

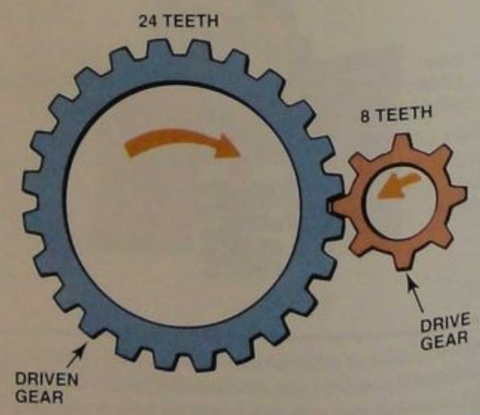


Figure 14–2 The drive gear is attached or is closer to the power source and rotates or drives the driven gear.

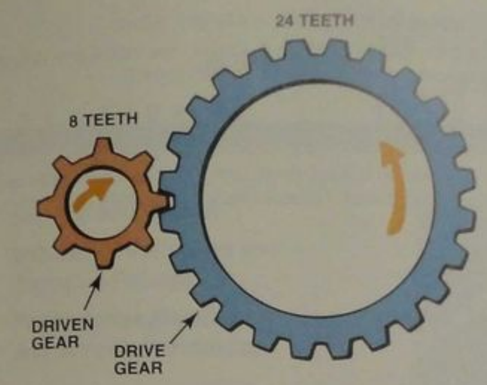


Figure 14–3 If the driven gear is rotating faster than the drive gear, it is called an overdrive ratio.

> **NOTE:** Ratios always end in 1 with a colon in between. Therefore, the first number is less than 1 if it is an overdrive ratio and greater than 1 if it is a gear reduction ratio.

GRAPHS, CHARTS, AND DIAGRAMS

Graph Reading A **graph** is a visual display of information. Graphs are commonly used in the automotive service industry to illustrate trends or specifications along with time or some other variable. A **variable** is a measurement of something that changes, such as engine speed or time. A graph has two variables displayed. One variable changes from left to right on the horizontal axis. This is called the X axis. The other variable is displayed on the vertical axis, called the Y axis.

A graph is created by making a series of dots at various locations and then connecting the dots with a line. See Figure 14–4.

Interpreting a Graph To interpret a graph, select a point along the horizontal axis (X axis) and then look directly above the point



Figure 14–4 A graph showing horsepower and torque. Notice that the curves cross at 5252 RPM or a little bit to the right of the 50, which is expressed in hundreds times 10 (thousands) of RPM.

where the line appears. Mark this spot and then look directly to the left along the vertical axis (Y axis) to see what value is represented by the points on the graph.

Chart Reading A **chart** is used to represent data, such as numbers or specifications, along with another variable, such as model or year of vehicle. A chart is very useful for showing many different specifications or other facts in an easy-to-read format. See Figure 14–5 for an example of a transmission specifications chart, which shows the transmission parts listed along the horizontal axis (X axis) and gear of the automatic transmission along the vertical or Y axis.

Interpreting a Chart A chart can look complicated but if studied, it is easy to interpret. Start by looking along the horizontal or vertical axis for the information, such as model year of the vehicle. Then, look directly above the model year to determine the specification for that particular model year.

RANGE	GEAR	2–4 BAND	REVERSE INPUT CLUTCH	OVERRUN CLUTCH	FORWARD CLUTCH	FORWARD SPRAG CL. ASSEMBLY	3–4 CLUTCH	LO-ROLLER CLUTCH	LO-REV. CLUTCH
PARK-NEUTRAL									
OVERDRIVE	FIRST GEAR				APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED			APPLIED	HOLDING			
	THIRD GEAR				APPLIED	HOLDING	APPLIED		
	FOURTH GEAR	APPLIED			APPLIED		APPLIED		
DRIVE	FIRST GEAR			APPLIED	APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED		APPLIED	APPLIED	HOLDING			
	THIRD GEAR			APPLIED	APPLIED	HOLDING	APPLIED		
MANUAL 2ND	FIRST GEAR			APPLIED	APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED		APPLIED	APPLIED	HOLDING			
MANUAL 1ST	FIRST GEAR			APPLIED		HOLDING		HOLDING	APPLIED
REVERSE	REVERSE		APPLIED						APPLIED

Figure 14–5 A typical chart showing what is applied in what gear in an automatic transmission.

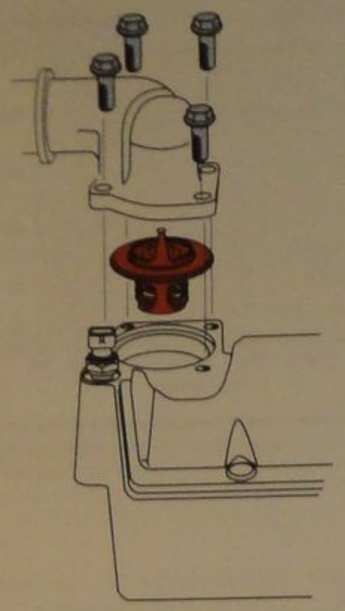


Figure 14–6 An exploded view showing how the thermostat is placed in the engine.

Diagram Reading A **diagram** is a graphic design that explains or shows the arrangement of parts. Diagrams are commonly used in the automotive service industry to show how a component is assembled and in which order the parts are placed together. See Figure 14–6 for an example.

Interpreting a Diagram A diagram usually shows the relationship of many parts. Lines are used to show the centerline of the part and the identity of the part is often shown as a number or letter. A separate chart or area of the diagram needs to be looked at to determine the name of the part. Diagrams are most helpful when disassembling or assembling a component, such as a transmission. For best results, use electronic information and print out the diagram so it can be written on and can be thrown away when the repair has been completed. This process also helps prevent getting grease on the pages of a service manual.

SUMMARY

1. Decimals are used in many automotive applications and specifications.
2. Adding and subtracting decimal numbers are needed for many automotive service procedures.
3. A formula is used to determine the volume of something if other values are known.
4. A gear ratio is determined by dividing the number of teeth on the driven gear by the number of teeth on the drive gear.

REVIEW QUESTIONS

1. What is the formula for determining fuel economy?
2. Why are the torque and horsepower of an engine equal at 5252 RPM?
3. What service operation may require the technician to add and subtract?
4. What service operation may require the technician to multiply or divide?
5. How is fuel economy expressed in the metric system?
6. What math function is needed to calculate the overall gear ratio if the transmission and differential ratios are both known?

CHAPTER QUIZ

1. Ten of 30 vehicles checked during a safety inspection had at least one tire that was under inflated. This represents what percentage of the vehicles?
   a. 25%
   b. 33%
   c. 43%
   d. 67%
2. Which of the following shows the relationship of parts?
   a. Chart
   b. Graph
   c. Diagram
   d. Schematic
3. Add 0.102 in. and 0.080 inch. The answer is _____.
   a. 0.182 inch
   b. 0.1082 inch
   c. 0.0082 inch
   d. 0.8200 inch
4. Which is the largest?
   a. 1/10
   b. .25
   c. .375
   d. 1/50
5. What is 26 out of 87 in percentage?
   a. 33.5%
   b. 11.3%
   c. 29.97%
   d. 61.0%
6. What number is being represented by the scientific notation 6.28×10^3?
   a. 6.28
   b. 628
   c. 6,280
   d. 62,800
7. 3/16 is what number in decimal form?
   a. 0.1875
   b. 1.875
   c. 0.5333
   d. 5.333
8. How is 0.183 pronounced?
   a. One hundred eighty-three thousandth
   b. One thousand eighty-three
   c. Zero dot one hundred and eighty-three hundredths
   d. One tenth and 83 hundredths
9. Metric fuel economy is measured in what units?
   a. Miles per gallon
   b. Miles per kilometer
   c. Liters per 100 kilometers
   d. Kilometers per liter
10. Which number is the smallest?
    a. 1/16
    b. .25
    c. 3/8
    d. .33

SECTION V

Vehicle Service Information and Routine Maintenance

15 Service Information
16 Vehicle Identification and Emission Ratings
17 Preventative Maintenance and Service Procedures



CHAPTER 15

Service Information

OBJECTIVES: After studying Chapter 15, the reader will be able to: Discuss the importance of vehicle history. • Retrieve vehicle service information. • Read and interpret service manuals and electronic service information. • Describe the use of the vehicle owner's manual.

KEY TERMS: Julian Date (JD) • labor guides • service information • technical service bulletin (TSB)

VEHICLE SERVICE HISTORY RECORDS

Whenever service work is performed, the record of what was done is usually kept on file by the shop or service department for a number of years. The wise service technician will check the vehicle service history if working on a vehicle with an unusual problem. Often, a previous repair may indicate the reason for the current problem or it could be related to the same circuit or components.

OWNER'S MANUALS

It has been said by many automotive professional technicians and service advisors that the owner's manual is not read by many vehicle owners. Most owner's manuals contain all or most of the following information:

1. How to reset the maintenance reminder light
2. Specifications, including viscosity of oil needed and number of quarts (liters)
3. Tire pressures and standard and optional tire sizes
4. Maintenance schedule for all fluids, including coolant, brake fluid, automatic transmission fluid, and differential fluid
5. How to program the remote control as well as the power windows and door locks
6. How to reset the tire pressure monitoring system after a tire rotation

LUBRICATION GUIDES

Lubrication guides, such as those published by Chek-Chart and Chilton, include all specifications for lubrication-related service including:

- Hoisting location
- Lubrication points
- Grease and oil specifications
- Capacities for engine oil, transmission fluid, coolant for cooling systems, and differential fluid

REAL WORLD FIX **Owner's Manual Is the Key to Proper Operation**

A customer purchased a used Pontiac Vibe and complained to a shop that the cruise control would disengage and had to be reset if driven below 25 mph (40 km/h). The service technician was able to verify that in fact this occurred, but did not know if this feature was normal or not. The technician checked the owner's manual and discovered that this vehicle was designed to operate this way. Unlike other cruise control systems, those systems on Toyota-based vehicles are designed to shut off below 25 mph, requiring the driver to reset the desired speed. The customer was informed that nothing could be done to correct this concern and the technician also learned something. Vehicles that use the Toyota cruise control system include all Toyotas, plus Lexus, Pontiac Vibe, and Chevrolet Prism.

HINT: Many vehicle manufacturers offer owner's manuals on their website for a free download.

SERVICE MANUALS

Factory and aftermarket service manuals contain specifications and service procedures. While factory service manuals cover just one year and one or more models of the same vehicle, most aftermarket service manuals cover multiple years and/or models in one manual. See Figure 15–1.

Included in most service manuals are the following:

- Capacities and recommended specifications for all fluids
- Specifications including engine and routine maintenance items
- Testing procedures
- Service procedures including the use of special tools when needed

While some factory service manuals are printed in one volume, most factory **service information** is printed in several volumes due to the amount and depth of information presented. The typical factory service manual is divided into sections.

General Information General information includes topics such as:

- Warnings and cautions
- VIN identification numbers on engine, transmission/transaxle, and body parts
- Lock cylinder coding
- Fastener information
- Decimal and metric equivalents
- Abbreviations and standard nomenclature used
- Service parts identification label and process code information

Maintenance and Lubrication Information Maintenance and lubrication information includes topics such as:

- Schedule for "normal" as well as "severe" usage time and mileage charts
- Specified oil and other lubricant specifications
- Chassis lubrication points
- Tire rotation methods
- Periodic vehicle inspection services (items to check and time/mileage intervals)
- Maintenance item part numbers, such as oil and air filter numbers, and specifications, such as oil capacity and tire pressures

Engines

- Engine electrical diagnosis (battery, charging, cranking, ignition, and wiring)
- Engine mechanical diagnosis
- Specific engine information for each engine that may be used in the vehicle(s) covered by the service manual, including:
  - Engine identification
  - On-vehicle service procedures
  - Description of the engine and the operation of the lubrication system
  - Exploded views showing all parts of the engine
  - Disassembly procedures
  - Inspection procedures and specifications of the parts and subsystems
  - Assembly procedures
  - Torque specifications for all fasteners, including the torque sequence

TECH TIP **Exploded Views**

Exploded views of components such as engines and transmissions are available in shop manuals and electronic service information, as well as in parts and labor time guides. These views, showing all of the parts as if the assembly was blown apart, give the service technician a clear view of the various parts and their relationship to other parts in the assembly. See Figure 15–2.



Figure 15–1 Many service manuals include diagnostic information as well as specifications and repair procedures.

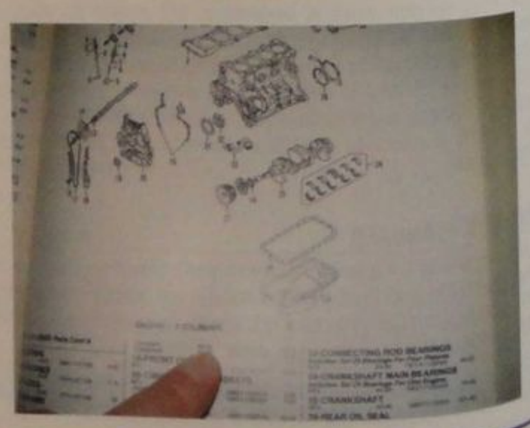


Figure 15–2 An exploded view of an engine as shown in a time and parts guide.

Automatic Transmission/Transaxle

- General information (identification and specifications)
- Diagnosis procedures, including preliminary checks and fluid level procedures
- General service, including leak detection and correction
- Cooler flushing procedures
- Unit removal procedures
- Unit disassembly procedures and precautions
- Unit assembly procedures and torque specifications

Electrical Systems

- Symbols used
- Troubleshooting procedures
- Repair procedures (wire repair, connectors, and terminals)
- Power distribution
- Ground distribution
- Component location views
- Harness routing views
- Individual electrical circuits, including circuit operation and schematics

Heating, Ventilation, and Air Conditioning

- Heater system
  - General description
  - Heater control assembly
  - Diagnosis, including heater electrical wiring and vacuum system
  - Blower motor and fan assembly diagnosis and servicing procedures
  - Air distribution values
  - Fastener torque specifications
- Air-conditioning system
  - General description and system components
  - Air-conditioning system diagnosis, including leak detection
  - Air-conditioning and heater function tests
  - Air-conditioning service procedures
  - Refrigerant recovery, recycling, adding oil, evacuating procedures, and charging procedures
  - Troubleshooting guide

Engine Performance (Driveability and Emissions)

- Vehicle emission control information (VECI) label, visual/physical under-hood inspection
- On-board diagnostic system
- Scan tool values
- Wiring harness service
- Symptom charts

TECH TIP **Print It Out**

It is often a benefit to have the written instructions or wiring diagrams at the vehicle while diagnosing or performing a repair. One advantage of a hard copy service manual is that it can be taken to the vehicle and used as needed. However, dirty hands can often cause pages to become unreadable. The advantage of electronic format service information is that the material can be printed out and taken to the vehicle for easy access. This also allows the service technician to write or draw on the printed copy, which can be a big help when performing tests such as electrical system measurements. These notes can then be used to document the test results on the work order.

ADVANTAGES OF HARD COPY VERSUS ELECTRONIC SERVICE INFORMATION

All forms of service information have some advantages, including:

Hard Copy	Electronic Service Information
• Easy to use—no hardware or expensive computers needed	• Information can be printed out and taken to the vehicle
• Can be taken to the vehicle for reference	• Has a search function for information
• Can view several pages easily for reference	• Internet or network access allows use at several locations in the shop

DISADVANTGES OF HARD COPY VERSUS ELECTRONIC SERVICE INFORMATION

All forms of service information have some disadvantages, including:

Hard Copy	Electronic Service Information
• Can be lost or left in the vehicle	• Requires a computer and printer
• Cost is high for each manual	• Internet or network access can be a challenge
• Can get dirty and unreadable	• Cost can be high

TECH TIP **Look for Severe Service Times**

Many time guides provide additional time for vehicles that may be excessively rusted due to climate conditions or have been subjected to abuse. Be sure to quote the higher rate if any of these conditions are present on the customer's vehicle. See Figure 15–3.

TYPES OF SERVICE INFORMATION

Various hard copy manuals are available, including:

- Wiring diagrams—see Figure 15–4.
- Vacuum hose diagrams—see Figure 15–5.
- Electrical troubleshooting and/or schematic manuals—see Figures 15–6 and 15–7.
- Electrical component location guide—see Figures 15–8 and 15–9.

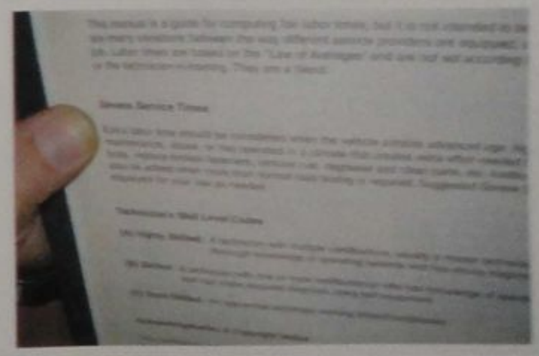


Figure 15–3 Extra time should be added if work is being performed on a vehicle that has excessive rust or other factors as stated in the time guide.

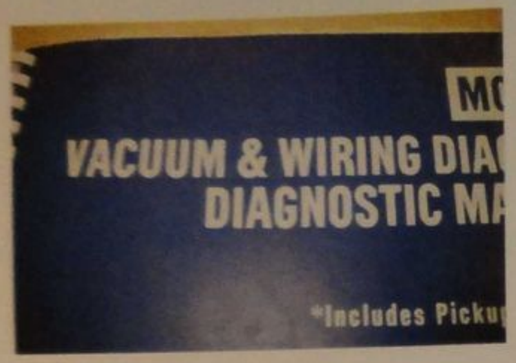


Figure 15–4 Often wiring diagrams and vacuum diagrams are combined into one manual.

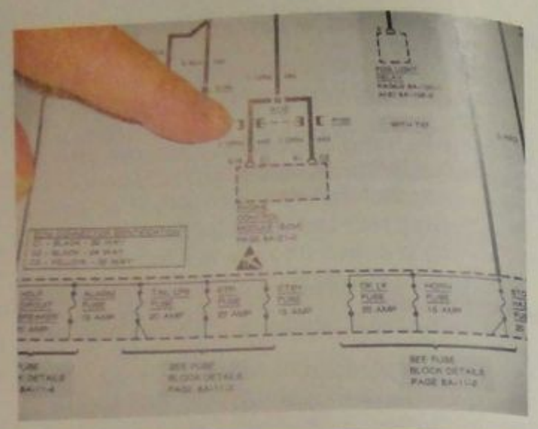


Figure 15–7 Typical factory service manual wiring schematic.

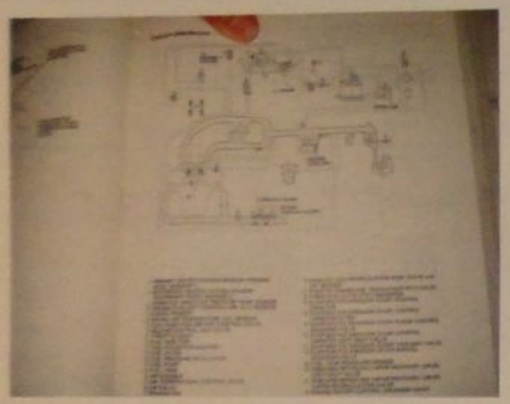


Figure 15–5 Typical vacuum diagram as shown in a factory service manual.



Figure 15–8 A component locator manual is a helpful manual to have, especially if work is being performed on a vehicle with which you are not familiar.



Figure 15–6 A typical electrical wiring diagram manual.

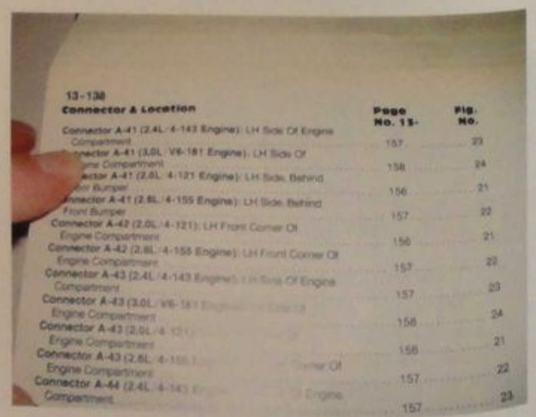


Figure 15–9 A component location guide typically shows the location of components in words and in figures.

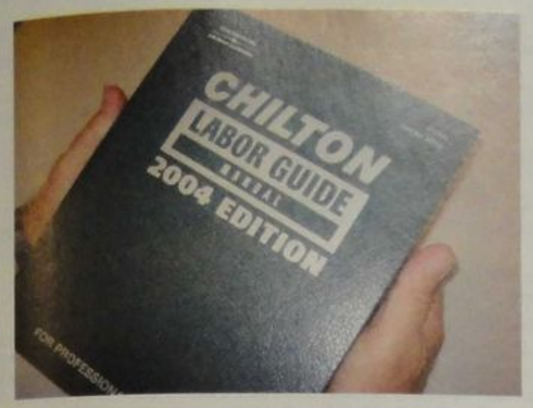


Figure 15–10 Some guides include labor information only.

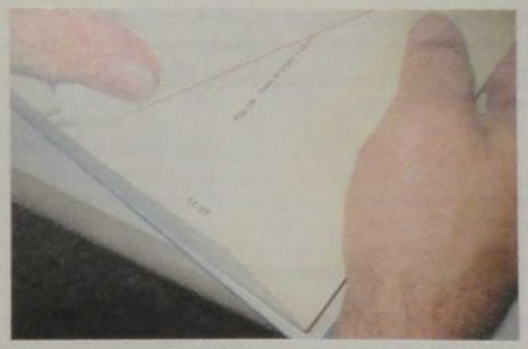


Figure 15–13 Many pages are numbered with the section, as in this case 11, followed by the page number 27 in that section.

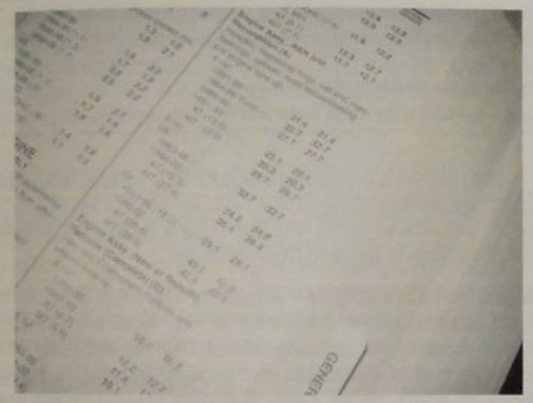


Figure 15–11 A typical time guide showing the times specified for the replacement or reconditioning of components.



Figure 15–14 The component location section of a service manual is very helpful, especially when working on an unfamiliar vehicle.



Figure 15–12 The wise service technician starts to look for service information at the front of the manual in the table of contents.

LABOR GUIDE MANUALS

Labor guides, also called flat-rate manuals, list vehicle service procedures and the time it should take an average technician to complete the task. This flat-rate time is then the basis for estimates and for pay for technicians. Some manuals also include a parts list, including the price of the part to help service advisors create complete estimates for both labor and parts. These manuals are usually called "parts and time guides." Some guides include labor time only. See Figure 15–10.

See Figure 15–11 for an example of a time guide showing both standard and severe service times.

HOW TO USE HARD COPY MANUALS

The most efficient way to find information in a manual is to look at the table of contents in the front of the book first. See Figure 15–12.

Next, go to the page (or pages) where the desired information is located. See Figure 15–13.

If bulb information or location of a component is needed, check the table of contents for the location of this information. See Figure 15–14.

Service information and testing procedures should be closely followed including any symptom charts or flow charts. A sample of a symptom information chart is shown in Table 15.1.

TABLE 15.1 Hesitation

Possible Cause	Reason
Throttle-position (TP) sensor	• The TP sensor should be within the specified range at idle. If too high or too low, the computer may not provide a strong enough extra pulse to prevent a hesitation. • An open or short in the TP sensor can result in hesitation because the computer would not be receiving correct information regarding the position of the throttle.
Throttle-plate deposit buildup (port fuel-injected engines)	An airflow restriction at the throttle plates creates not only less air reaching the engine but also swirling air due to the deposits. This swirling or uneven airflow can cause an uneven air-fuel mixture being supplied to the engine, causing poor idle quality and a sag or hesitation during acceleration.
Manifold absolute pressure (MAP) sensor fault	The MAP sensor detects changes in engine load and signals to the computer to increase the amount of fuel needed for proper operation. Check the vacuum hose and the sensor itself for proper operation.
Check the throttle linkage for binding	A kinked throttle cable or cruise (speed) control cable can cause the accelerator pedal to bind.
Contaminated fuel	Fuel contaminated with excessive amounts of alcohol or water can cause a hesitation or sag during acceleration. ***HINT:*** To easily check for the presence of alcohol in gasoline, simply get a sample of the fuel and place it in a clean container. Add some water and shake. If no alcohol is in the gasoline, the water will settle to the bottom and be clear. If there is alcohol in the gasoline, the alcohol will absorb the water. The alcohol-water combination will settle to the bottom of the container, but will be cloudy rather than clear.
Clogged, shorted, or leaking fuel injectors	Any injector problem that results in less than an ideal amount of fuel being delivered to the cylinders can result in a hesitation, a sag, or stumble during acceleration.
Spark plugs or spark plug wires	Any fault in the ignition system such as a defective spark plug wire or cracked spark plug can cause hesitation, a sag, or stumble during acceleration. At higher engine speeds, a defective spark plug wire is not as noticeable as it is at lower speeds, especially in vehicles equipped with a V-8 engine.
EGR valve operation	Hesitation, a sag, or stumble can occur if the EGR valve opens too soon or is stuck partially open.
False air	A loose or cracked intake hose between the mass airflow (MAF) sensor and the throttle plate can be the cause.

ELECTRONIC SERVICE INFORMATION

There are many programs available that will provide service information for the automotive industry. Sometimes the vehicle makers make information available online. However, many shops choose to purchase software from an aftermarket supplier. ALL Data and Mitchell On-Demand are commonly used software programs that include service information for many vehicles.

Home Screen The Home screen is the first screen displayed when you start. It displays buttons that represent the major sections of the program. Access to the Home screen is available from anywhere within the program by clicking the Home button on the toolbar.

Toolbars A main toolbar is displayed on most screens, providing quick access to certain functions. This toolbar varies somewhat, depending upon what information is being accessed.

Electronic Service Information Electronic service information is available mostly by subscription and provides access to an Internet site where service manual–type information is available. Most vehicle manufacturers also offer electronic service information to their dealers and to most schools and colleges that offer corporate training programs.

Technical Service Bulletins Technical service bulletins, often abbreviated **TSBs,** are issued by the vehicle manufacturer to notify service technicians of a problem and include the necessary corrective action. Technical service bulletins are designed for dealership technicians but are republished by aftermarket companies and made available along with other service information to shops and vehicle repair facilities.

Internet The Internet has opened the field for information exchange and access to technical advice. One of the most useful websites is the International Automotive Technician's network at *www.iatn.net.* This is a free site but service technicians need to register to join. For a small monthly sponsor fee, the shop or service technician can gain access to the archives, which include thousands of successful repairs in the searchable database.

Recalls and Campaigns A recall or campaign is issued by a vehicle manufacturer and a notice is sent to all owners in the event of a safety- or emission-related fault or concern. While these faults may be repaired by independent shops, it is generally handled by a local dealer. Items that have created recalls in the past have included potential fuel system leakage problems, exhaust leakage, or electrical malfunctions that could cause a possible fire or the engine to stall. Unlike technical service bulletins whose cost is only covered when the vehicle is within the warranty period, a recall or campaign is always done at no cost to the vehicle owner.

FREQUENTLY ASKED QUESTION ???

What Is the Julian Date?

The **Julian date** (abbreviated **JD**) is the number of the day of the year. January 1 is day 001. The Julian date is named for Julius Caesar, who developed the current calendar.

HOTLINE SERVICES

A hotline service provider is a subscription-based helpline to assist service technicians solve technical problems. While services vary, most charge a monthly fee for a certain amount of time each month to talk to an experienced service technician who has a large amount of resource materials available for reference. Often, the technician hired by the hotline services specializes in one vehicle make and is familiar with many of the pattern failures that are seen by other technicians in the field. Hotline services are an efficient way to get information on an as-needed basis.

TECH TIP ✔ **Use a Bluetooth Hands-Free Telephone**

When talking to a hotline service provider, it is wise to be looking at the vehicle during the call to be able to provide information about the vehicle and perform the suggested tests. This makes the job of troubleshooting easier and faster for both the technician and the service provider, resulting in shorter length calls. Using a Bluetooth hands-free telephone should help shorten the length of calls, which means the cost will be less for the help service.

Some examples of hotline automotive service providers include:

- Identifix
- Autohotlineusa
- Taylor Automotive Tech-Line
- Aspire

SPECIALITY REPAIR MANUALS

Examples of specialty repair manuals include unit repair for assembled components, such as automatic transmission/transaxle, manual transmission/transaxle, differentials, and engines. Some specialty repair manuals cover older or antique vehicles, which may include unit repair sections.

AFTERMARKET SUPPLIES GUIDES AND CATALOGS

Aftermarket supplies guides and catalogs often include expanded views of assembled parts along with helpful hints and advice. Sometimes the only place where this information is available is at trade shows associated with automotive training conferences and expos. Go to the following websites for examples of training conferences with trade shows:

- *www.lindertech.com*
- *www.avtechexpo.com*
- *www.visionkc.com* (Vision Expo)

SUMMARY

1. Vehicle history records are sometimes very helpful in determining problems that may be related to a previous fault or repair.
2. The vehicle owner's manual is very helpful to the service technician because it includes the procedures for resetting the maintenance reminder light (oil change light), as well as how to reset the tire pressure monitoring system after a tire rotation, and other important settings and specifications.
3. Lubrication guides provide information on the specified oil and lubricants needed along with the capacities and the location of lubrication points.
4. Factory service manuals or electronic services include information that is vehicle and year specific and very detailed.
5. Other types of service information are labor and parts guides, vacuum hose and wiring diagrams, component locator manuals, specialty manuals, and aftermarket supplies guides and catalogs.
6. Hotline services are subscription based and allow a technician to talk to an experienced technician who has many resources.

REVIEW QUESTIONS

1. What is included in the vehicle owner's manual that could be helpful for a service technician?
2. Lubrication service guides include what type of information?
3. Explain why factory service manuals or factory electronic service information is the most detailed of all service information.
4. Explain how flat rate and parts guides are useful to customers.
5. List additional types of service manuals that are available.
6. Describe how hotline services and Internet sites assist service technicians.

CHAPTER QUIZ

1. What type of information is commonly included in the owner's manual that would be a benefit to service technicians?
   a. Maintenance reminder light reset procedures
   b. Tire pressure monitoring system reset procedures
   c. Maintenance items specifications
   d. All of the above
2. Two technicians are discussing the need for the history of the vehicle. Technician A says that an accident could cause faults to occur after the repair due to hidden damage. Technician B says that some faults could be related to a previous repair. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. The viscosity of engine oil is found where?
   a. Owner's manual
   b. Factory service manual or service information
   c. Lubrication guide
   d. All of the above
4. Wiring diagrams are usually found where?
   a. Owner's manuals
   b. Factory service manuals
   c. Unit repair manuals
   d. Lubrication guides
5. What type of manual includes time needed to perform service procedures?
   a. Flat-rate manuals
   b. Owner's manuals
   c. Factory service manuals
   d. Parts guide
6. Component location can be found in _____.
   a. Factory service manuals
   b. Owner's manuals
   c. Component location manuals
   d. Both a and c
7. Aftermarket service information is available in what format?
   a. Manuals
   b. CDs or DVDs
   c. Internet
   d. All of the above are possible source formats
8. Hotline services are _____.
   a. Free
   b. Available for a service fee
   c. Available on CD or DVD format
   d. Accessed by the Internet
9. Aftermarket parts catalogs can be a useful source of information and they are usually _____.
   a. Free
   b. Available by paid subscription
   c. Available on CD or DVD
   d. Available for a fee on a secured Internet site
10. Which type of manual or service information includes the flat-rate time and the cost of parts?
    a. Parts and time guides
    b. Factory service manuals
    c. Component location guides
    d. Free Internet sites

CHAPTER 16

Vehicle Identification and Emission Ratings

OBJECTIVES: After studying Chapter 16, the reader will be able to: Identify a vehicle. • Interpret vehicle identification numbers and placard information. • Interpret vehicle emissions and emission control information. • Read and interpret casting numbers. • Locate calibration codes.

KEY TERMS: bin number • calendar year (CY) • calibration codes • California Air Resources Board (CARB) • casting numbers • country of origin • Environmental Protection Agency (EPA) • gross axle weight rating (GAWR) • gross vehicle weight rating (GVWR) • model year (MY) • tier 1 • tier 2 • vehicle emissions control information (VECI) • vehicle identification number (VIN)

PARTS OF A VEHICLE

The names of the parts of a vehicle are based on the location and purpose of the component.

Left Side of the Vehicle—Right Side of the Vehicle Both of these terms refer to the left and right as if the driver is sitting behind the steering wheel. Therefore, the left side (including components under the hood) is on the driver's side.

Front and Rear The proper term for the back portion of any vehicle is rear (for example, left rear tire).

FRONT-WHEEL DRIVE VERSUS REAR-WHEEL DRIVE

Front-wheel drive (FWD) means that the front wheels are being driven by the engine, as well as turned by the steering wheel. Rear-wheel drive (RWD) means that the rear wheels are driven by the engine. If the engine is in the front, it can be either front- or rear-wheel drive. In many cases, a front engine vehicle can also drive all four wheels called four-wheel drive (4WD) or all-wheel drive (AWD). If the engine is located at the rear of the vehicle, it can be rear-wheel drive or four-wheel (AWD) drive.

VEHICLE IDENTIFICATION

All service work requires that the vehicle, including the engine and accessories, be properly identified. The most common identification is the make, model, and year of the vehicle.

Make: e.g., Chevrolet

Model: e.g., Trailblazer

Year: e.g., 2007

The year of the vehicle is often difficult to determine exactly. A model may be introduced as the next year's model as soon as January of the previous year. Typically, a new **model year** (abbreviated **MY**) starts in September or October of the year prior to the actual new year, but not always. This is why the **vehicle identification number,** usually abbreviated **VIN,** is so important. See Figure 16–1.

Since 1981 all vehicle manufacturers have used a VIN that is 17 characters long. Although every vehicle manufacturer assigns various letters or numbers within these 17 characters, there are some constants, including:

- The first number or letter designates the **country of origin.**
- The model of the vehicle is commonly the fourth and/or fifth character.



Figure 16–1 Typical vehicle identification number (VIN) as viewed through the windshield.

1 = United States	6 = Australia	L = China	V = France
2 = Canada	8 = Argentina	R = Taiwan	W = Germany
3 = Mexico	9 = Brazil	S = England	X = Russia
4 = United States	J = Japan	T = Czechoslovakia	Y = Sweden
5 = United States	K = Korea	U = Romania	Z = Italy

- The eighth character is often the engine code. (Some engines cannot be determined by the VIN number.)
- The tenth character represents the **calendar year** (abbreviated **CY**) on all vehicles. See the following chart.

VIN Year Chart ***(The Pattern Repeats Every 30 Years)***

A = 1980/2010	J = 1988/2018	T = 1996/2026	4 = 2004/2034
B = 1981/2011	K = 1989/2019	V = 1997/2027	5 = 2005/2035
C = 1982/2012	L = 1990/2020	W = 1998/2028	6 = 2006/2036
D = 1983/2013	M = 1991/2021	X = 1999/2029	7 = 2007/2037
E = 1984/2014	N = 1992/2022	Y = 2000/2030	8 = 2008/2038
F = 1985/2015	P = 1993/2023	1 = 2001/2031	9 = 2009/2039
G = 1986/2016	R = 1994/2024	2 = 2002/2032	
H = 1987/2017	S = 1995/2025	3 = 2003/2033	

VEHICLE SAFETY CERTIFICATION LABEL

A vehicle safety certification label is attached to the left side pillar post on the rearward-facing section of the left front door. This label indicates the month and year of manufacture as well as the **gross vehicle weight rating (GVWR),** the **gross axle weight rating (GAWR),** and the vehicle identification number (VIN).

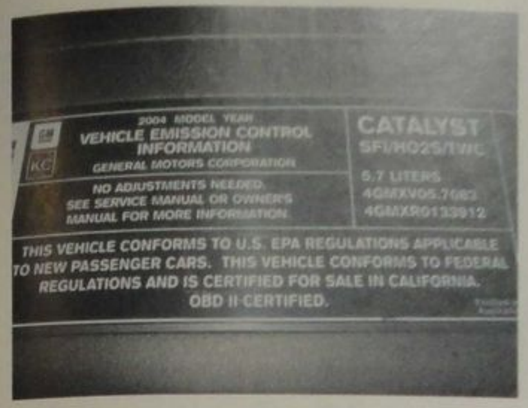


Figure 16–2 A VECI label on a 2004 Pontiac GTO.

VECI LABEL

The **vehicle emissions control information (VECI)** label under the hood of the vehicle shows informative settings and emission hose routing information. See Figure 16–2.

The VECI label (sticker) can be located on the bottom side of the hood, the radiator fan shroud, the radiator core support, or the strut towers. The VECI label usually includes the following information:

- Engine identification
- Emissions standard that the vehicle meets
- Vacuum hose routing diagram
- Base ignition timing (if adjustable)
- Spark plug type and gap
- Valve lash
- Emission calibration code

EMISSION STANDARDS IN THE UNITED STATES

In the United States, emissions standards are managed by the **Environmental Protection Agency (EPA)** as well as some U.S. state governments. Some of the strictest standards in the world are formulated in California by the **California Air Resources Board (CARB).**

Tier 1 and Tier 2 Federal emission standards are set by the Clean Air Act Amendments (CAAA) of 1990 grouped by **tier.** All vehicles sold in the United States must meet **Tier 1** standards that went into effect in 1994 and are the least stringent. Additional **Tier 2** standards have been optional since 2001, and are currently being phased in to be fully adopted by 2009. The current Tier 1 standards are different between automobiles and light trucks (SUVs, pickup trucks, and minivans), but Tier 2 standards are the same for both types.

There are several ratings that can be given to vehicles, and a certain percentage of a manufacturer's vehicles must meet different levels in order for the company to sell its products in affected regions. Beyond Tier 1, and in order by stringency, are the following levels:

- **TLEV—Transitional Low-Emission Vehicle**—More stringent for HC than Tier 1.
- **LEV—(also known as LEV I)—Low-Emission Vehicle**—An intermediate California standard about twice as stringent as Tier 1 for HC and NO_x.



Figure 16–3 The underhood decal showing that this Lexus RX-330 meets both national (Tier 2; BIN 5) and California LEV-II (ULEV) regulation standards.

- **ULEV (also known as ULEV I)**—Ultra-Low-Emission Vehicle—A stronger California standard emphasizing very low HC emissions.
- **ULEV II—Ultra-Low-Emission Vehicle**—A cleaner-than-average vehicle certified under the Phase II LEV standard. Hydrocarbon and carbon monoxide emissions levels are nearly 50% lower than those of a LEV II-certified vehicle. See Figure 16–3.
- **SULEV—Super-Ultra-Low-Emission Vehicle**—A California standard even tighter than ULEV, including much lower HC and NO_x emissions; roughly equivalent to Tier 2 Bin 2 vehicles.
- **ZEV—Zero-Emission Vehicle**—A California standard prohibiting any tailpipe emissions. The ZEV category is largely restricted to electric vehicles and hydrogen-fueled vehicles. In these cases, any emissions that are created are produced at another site, such as a power plant or hydrogen reforming center, unless such sites run on renewable energy.

NOTE: A battery-powered electric vehicle charged from the power grid will still be up to 10 times cleaner than even the cleanest gasoline vehicles over their respective lifetimes.

The current California ZEV regulation allows manufacturers a choice of two options for meeting the ZEV requirements:

1. Vehicle manufacturers can meet the ZEV obligations by meeting standards that are similar to the ZEV rule as it existed in 2001. This means using a formula allowing a vehicle mix of 2% pure ZEVs, 2% AT-PZEVs (vehicles earning advanced technology partial ZEV credits), and 6% PZEVs (extremely clean conventional vehicles). The ZEV obligation is based on the number of passenger cars and small trucks a manufacturer sells in California.
2. Manufacturers may also choose a new alternative ZEV compliance strategy of meeting part of the ZEV requirement by producing the sales-weighted market share of approximately 250 fuel-cell vehicles by 2008. The remainder of the ZEV requirements could be achieved by producing 4% AT-PZEVs and 6% PZEVs. The required number of fuel-cell vehicles will increase to 2,500 from 2009 to 2011, 25,000 from 2012 through 2020, and 50,000 from 2015 through 2017. Manufacturers can substitute battery electric vehicles for up to 50% of the fuel-cell vehicle requirements.
   - **PZEV—Partial-Zero-Emission Vehicle**—Compliant with the SULEV standard; additionally has near zero evaporative emissions and a 15-year/150,000-mile warranty on its emission control equipment.

Tier 2 standards are even more stringent. Tier 2 variations are identified with "EL" such as LEV II or SULEV II. Other categories have also been created:

- **ULEV—Ultra-Low Emission Vehicle**
- **AT-PZEV—Advanced Technology Partial Zero-Emission Vehicle**—If a vehicle meets the PZEV standards and is using high-technology features, such as an electric motor or high-pressure gaseous fuel tanks for compressed natural gas, it qualifies as an AT-PZEV. Hybrid electric vehicles such as the Toyota Prius can qualify, as can internal combustion engine vehicles that run on natural gas (CNG), such as the Honda Civic GX. These vehicles are classified as "partial" ZEV because they receive partial credit for the number of ZEV vehicles that automakers would otherwise be required to sell in California.
- **SULEV—National Low-Emission Vehicle**—All vehicles nationwide must meet this standard, which started in 2001. See Tables 16.1 and 16.2.

Federal EPA Bin Number The higher the tier number, the newer the regulation; the lower the **bin number,** the cleaner the vehicle. The 2004 Toyota Prius is a very clean Bin 3, while the Hummer H2 is a dirty Bin 11. Examples include:

- Tier 1: The former federal standard; carried over to model year 2004 for those vehicles not yet subject to the phase-in.
- Tier 2, Bin 1: The cleanest federal Tier 2 standard; a zero-emission vehicle (ZEV).
- Tier 2, Bins 4–2: Cleaner than the average standard.
- Tier 2, Bin 5: "Average" of new Tier 2 standards, roughly equivalent to a LEV II vehicle.
- Tier 2, Bins 6–9: Not as clean as the average requirement for a Tier 2 vehicle.
- Tier 2, Bin 10: Least-clean Tier 2 bin applicable to passenger vehicles.

See Tables 16.3 and 16.4.

TABLE 16.1 LEV Standard Categories

		NMOG Grams (Mile)	CO Grams (Mile)	NO_x Grams (Mile)
LEV I Cars	TLEV	0.125 (0.156)	3.4 (4.2)	0.4 (0.6)
	LEV	0.075 (0.090)	3.4 (4.2)	0.2 (0.3)
	ULEV	0.040 (0.055)	1.7 (2.1)	0.2 (0.3)
LEV II Cars and Trucks < 8,500 lbs	LEV	0.075 (0.090)	3.4 (4.2)	0.05 (0.07)
	ULEV	0.040 (0.055)	1.7 (2.1)	0.05 (0.07)
	SULEV	−(0.010)	−(1.0)	−(0.02)

NOTE: Numbers in parentheses are 150,000-mile standards for LEV I, and 120,000-mile standards for LEV II. NMOG means non-methane organic gases, which includes alcohol. CO means carbon monoxide. NO_x means oxides of nitrogen. Data compiled from California Environmental Protection Agency—Air Resource Board (CARB) documents.

TABLE 16.2 California LEV II 120,000-Mile Tailpipe Emissions Limits

Certification Level	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)
LEV-II	0.090	4.2	0.07
ULEV-II	0.055	2.1	0.07
SULEV-II	0.010	1.0	0.02

NOTE: Numbers in parentheses are 120,000-mile standards for LEV I, and 120,000-mile standards for LEV II. NMOG means non-methane organic gases, which includes alcohol. CO means carbon monoxide. NO_x means oxides of nitrogen. The specification is in grams per mile (g/mi). Data compiled from California Environmental Protection Agency—Air Resources Board (CARB) documents.

TABLE 16.3 EPA Tier 2—120,000-Mile Tailpipe Emission Limits

Certification Level	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)
Bin 1	0.0	0.0	0.0
Bin 2	0.010	2.1	0.02
Bin 3	0.055	2.1	0.03
Bin 4	0.070	2.1	0.04
Bin 5	0.090	4.2	0.07
Bin 6	0.090	4.2	0.10
Bin 7	0.090	4.2	0.15
Bin 8a	0.125	4.2	0.20
Bin 8b	0.156	4.2	0.20
Bin 9a	0.090	4.2	0.30
Bin 9b	0.130	4.2	0.30
Bin 9c	0.160	4.2	0.30
Bin 10a	0.156	4.2	0.60
Bin 10b	0.230	6.4	0.60
Bin 10c	0.230	6.4	0.60
Bin 11	0.230	7.3	0.90

NOTE: The bin number is determined by the type and weight of the vehicle. The highest bin allowed for vehicles built after January 1, 2007, is Bin 8. Data compiled from the Environmental Protection Agency (EPA).

TABLE 16.4 Air Pollution Score

U.S. EPA Vehicle Information Program (The Higher the Score, the Lower the Emissions)	
Selected Emissions Standards	**Score**
Bin 1 and ZEV	10
PZEV	9.5
Bin 2	9
Bin 3	8
Bin 4	7
Bin 5 and LEV II cars	6
Bin 6	5
Bin 7	4
Bin 8	3
Bin 9a and LEV I cars	2
Bin 9b	2
Bin 10a	1
Bin 10b and Tier 1 cars	1
Bin 11	0

Courtesy of the Environmental Protection Agency (EPA).

CALIBRATION CODES

Calibration codes are usually located on power train control modules (PCMs) or other controllers. Some calibration codes are only accessible with a scan tool. Whenever diagnosing an engine operating fault, it is often necessary to know the calibration code to be sure that the vehicle is the subject of a technical service bulletin or other service procedure. See Figure 16–4.

CASTING NUMBERS

Whenever an engine part such as a block is cast, a number is put into the mold to identify the casting. See Figure 16–5. These **casting numbers** can be used to check dimensions such as the cubic inch displacement and other information. Sometimes changes are made to the mold, yet the casting number is not changed. Most often the casting number is the best piece of identifying information that the service technician can use for identifying an engine.



Figure 16–4 A typical computer calibration sticker on the case of the controller. The information on the sticker is often needed when ordering parts or a replacement controller.



Figure 16–5 Engine block identification number cast into the block is used for identification.

SUMMARY

1. The front, rear, left, and right side of a vehicle are as viewed from the driver's seat.
2. The vehicle identification number (VIN) is very important as it includes when the vehicle was built, as well as the engine code and many other details about the vehicle.
3. The VECI label under the hood often needs to be checked by the technician to properly service the vehicle.
4. Other vehicle information that the technician may need for a service or repair include calibration codes, casting numbers, and emissions rating.

REVIEW QUESTIONS

1. From what position are the terms left and right determined?
2. What are the major pieces of information that are included in the vehicle identification number (VIN)?
3. What information is included on the VECI label under the hood?
4. What does Tier 2 Bin 5 mean?

CHAPTER QUIZ

1. The passenger side is called the _____.
   a. Right side
   b. Left side
   c. Either right or left side, depending on how the vehicle is viewed
   d. Both a and b
2. A vehicle with the engine in the front can be _____.
   a. Front-wheel drive
   b. Rear-wheel drive
   c. Four-wheel drive
   d. Any of the above
3. The vehicle identification number (VIN) is how many characters long?
   a. 10
   b. 12
   c. 17
   d. 21
4. The tenth character represents the year of the vehicle. If the tenth character is a "Y," what year is the vehicle?
   a. 1998
   b. 2000
   c. 2002
   d. 2004
5. The first character of the vehicle identification number is the country of origin. Where was the vehicle built that has a "5" as the first character?
   a. United States
   b. Canada
   c. Mexico
   d. Japan
6. The VECI label includes all *except* _____.
   a. Engine identification
   b. Horsepower and torque rating of the engine
   c. Spark plug type and gap
   d. Valve lash
7. The vehicle safety certification label includes all *except* _____.
   a. VIN
   b. GVWR
   c. Tire pressure recommendation
   d. GAWR
8. What are the characters that are embedded in most engine blocks and are used for identification?
   a. VIN
   b. Calibration codes
   c. Bin number
   d. Casting number
9. If the first number of the VIN is an "S," where was the vehicle made?
   a. United States
   b. Mexico
   c. Canada
   d. England
10. Technician A says that the lower the Bin number is, the cleaner. Technician B says that SULEV has cleaner standards than ULEV. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 17

Preventative Maintenance and Service Procedures

OBJECTIVES: After studying Chapter 17, the reader will be able to: Prepare for ASE Engine Repair (A1) certification test content area "A" (General Engine Diagnosis) and content area "D" (Lubrication and Cooling Systems Diagnosis and Repair). • Perform routine fluid and service checks. • Describe how to install wheels and tighten lug nuts using a torque wrench and the proper sequence. • Describe the proper procedure for changing the engine oil and performing complete chassis system lubrication and under-vehicle inspection. • Beginning automotive service technicians are often required to perform routine service operations. It is the purpose of this chapter to introduce the reader to these various service procedures.

KEY TERMS: air filter • alamite fittings • algorithm • American Petroleum Institute (API) • American Society for Testing Materials (ASTM) • antidrainback valve • Association des Constructeurs Européens d'Automobiles (ACEA) • automatic transmission fluid (ATF) • brake fluid • bypass • cabin filter • dipstick • DOT 3 • DOT 4 • DOT 5 • National Lubricating Grease Institute (NLGI) • penetration test • polyglycol • serpentine (Poly V) • silicone brake fluid • syncromesh transmission fluid (STF) • viscosity • winter (W) • Zerk fittings

TECH TIP ✔ **Do No Harm**

As stated in the Hippocratic oath, a doctor agrees first to do no harm to the patient during treatment. Service technicians should also try to do no harm to the vehicle while it is being serviced.

Always ask, "Am I going to do any harm if I do this?" before you do it.

GETTING READY FOR SERVICE

Before most service work is done, protect the inside of the vehicle by using commercially available plastic or paper protective coverings for the seats, floor, and steering wheel. See Figure 17–1. The hood (engine compartment cover) must be opened. Often the struts that hold a hood open are weak or defective. Therefore, before starting to work under the hood, always make sure that the hood is securely held open.



Figure 17–1 Before service begins be sure to cover the seats, floor, and steering wheel with protective covering.



Figure 17–2 An exhaust system hose should be connected to the tailpipe(s) whenever the engine is being run indoors.

Also be sure to connect an exhaust system hose to the tailpipe(s) before work is started that will involve operating the engine. See Figure 17–2.

WIPER BLADE INSPECTION AND REPLACEMENT

Windshield wiper blades are constructed of rubber and tend to become brittle due to age. Wiper blades should be cleaned whenever the vehicle is cleaned using water and a soft cloth. Wiper blade or wiper blade insert replacement includes the following steps:

- Turn the ignition switch to on (run).
- Turn the wiper switch on and operate the wipers.
- When the wipers are located in an easy-to-reach location, turn the ignition switch off. The wipers should stop.
- Remove the insert or the entire arm as per the instructions on the replacement windshield wiper blade package.
- After double-checking that the wiper is securely attached, turn the ignition switch on (run).
- Turn the wiper switch off and allow the wipers to reach the park position. Check for proper operation.

See Figure 17–3.

CABIN FILTER REPLACEMENT

A **cabin filter** is a filter used in the heating, ventilation, and air conditioning (HVAC) system in the outside air passage. Some filters could include activated charcoal to help eliminate odors. The cabin air filter should be replaced regularly about every two years or every 24,000 miles (39,000 km). The cabin air filter can be accessed from:

- Under the hood at the cowl (bulkhead)
- Under the dash, usually behind the glove compartment (instrument panel compartment)

See Figure 17–4.



Figure 17–3 Installing a wiper blade insert into a wiper arm.

AIR FILTER INSPECTION/REPLACEMENT

An **air filter** filters dirt from the air before it enters the intake system of the engine. The air filter should be replaced according to vehicle manufacturer's recommendations. Many vehicle manufacturers recommend replacing the air filter every 30,000 miles (50,000 km) or more frequently under dusty conditions. Many service technicians recommend replacing the air filter every year. See Figure 17–5.

BRAKE FLUID LEVEL INSPECTION

Brake fluid is used to transmit the force of the driver's foot on the brake pedal to each individual wheel brake. The brake fluid should be checked at the same time the engine oil is changed (every 3,000 miles [4,800 km] or every three months, whichever occurs first). There are two types of brake master cylinders:

- **Transparent reservoir**—This type allows viewing of the brake fluid (and hydraulic clutch master cylinder if so equipped) without having to remove the cover of the reservoir. See Figure 17–6. The proper level should be between the MIN (minimum) level indicated and the MAX (maximum) level indicated on the clear plastic reservoir.
- **Metal or nontransparent plastic reservoir**—This type of reservoir used on older vehicles requires that the cover be removed to check the level of the brake fluid. The proper level of brake fluid should be 1/4" (6 mm) from the top.

CAUTION: Do not overfill a brake master cylinder. The brake fluid gets hotter as the brakes are used and there must be room in the master cylinder reservoir for the brake fluid to expand.

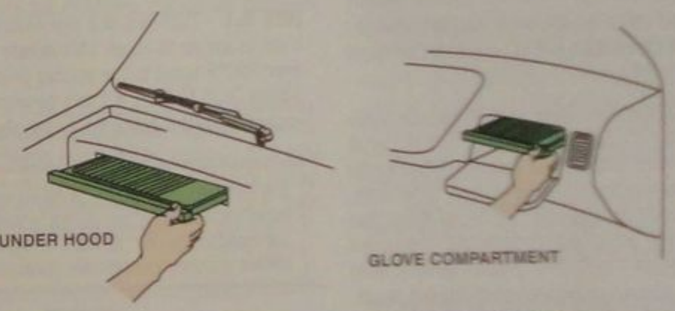
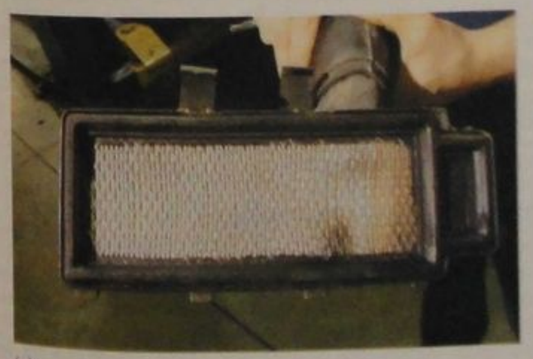


Figure 17–4 A cabin filter can be accessed either through the glove compartment or under the hood on most vehicles.



(a)



(b)

Figure 17–5 (a) A typical dirty air filter. (b) Always check the inlet passage leading to the air filter for debris that can reduce airflow to the engine.



Figure 17–6 A master brake cylinder with a transparent reservoir. The brake fluid should be between the "MAX" and the "MIN" levels as indicated on the reservoir.

BRAKE FLUID TYPES

Brake fluid is made from a combination of various types of glycol, a non-petroleum-based fluid. Brake fluid is a polyalkylene-glycol-ether mixture called **polyglycol** for short. *All polyglycol brake fluid is clear to amber in color.*

CAUTION: DOT 3 brake fluid is a very strong solvent and can remove paint! Care is required when working with DOT 3 brake fluid to avoid contact with the vehicle's painted surfaces. It also takes the color out of leather shoes.

All automotive brake fluid must meet Federal Motor Vehicle Safety Standard 116. The Society of Automotive Engineers (SAE) and the Department of Transportation (DOT) have established brake fluid specification standards.

DOT 3 DOT 3 is the brake fluid most often used. It absorbs moisture and according to SAE, DOT 3 can absorb 2% of its volume in water per year. Moisture is absorbed by the brake fluid through microscopic seams in the brake system and around seals. Over time, the water will corrode the system and thicken the brake fluid. The moisture also can cause a spongy brake pedal action due to reduced vapor-lock temperature. See Figure 17–7. DOT 3 must be used from a sealed (capped) container. If allowed to remain open for any length of time, DOT 3 will absorb moisture from the surrounding air.

DOT 4 DOT 4 brake fluid is formulated for use by all vehicles, imported or domestic. It is commonly called LMA (low moisture absorption) because DOT 4 does not absorb water as fast as DOT 3. It is still affected by moisture, however, and should be used only from a sealed container. The cost of DOT 4 is approximately double the cost of DOT 3.

DOT 5 DOT 5 is commonly called **silicone brake fluid** and is made from polydimethylsiloxanes. It does not absorb any water and is therefore called nonhygroscopic. DOT 5 brake fluid does not mix with and should not be used with DOT 3 or DOT 4 brake fluid.

NOTE: Even though DOT 5 does not normally absorb water, it is still tested using standardized SAE procedures in a humidity chamber. After a fixed amount of time, the brake fluid is measured for boiling point. Since it has had a chance to absorb moisture, the boiling point after this sequence is called the minimum wet boiling point.

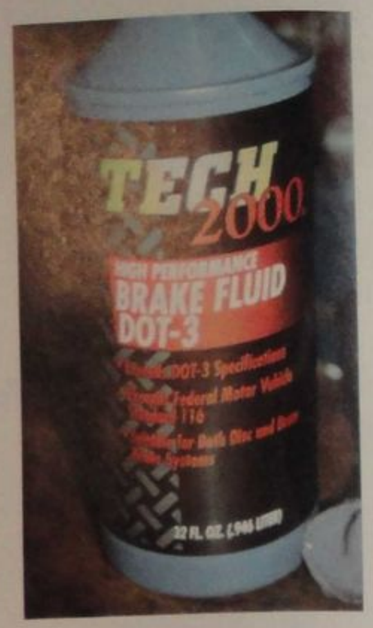


Figure 17–7 DOT 3 brake fluid. Always use brake fluid from a sealed container because the fluid absorbs moisture from the air. Such contaminated brake fluid has a lower boiling point and can cause rust to form in the brake system components.

DOT 5 brake fluid is purple (violet) in color to distinguish it from DOT 3 or DOT 4 brake fluid.

DOT 5.1 DOT 5.1 is a non-silicone-based polyglycol fluid and is clear to amber in color. This severe duty fluid has a boiling point of over 500°F equal to the boiling point of silicone-based DOT 5 fluid. Unlike DOT 5, DOT 5.1 can be mixed with either DOT 3 or DOT 4 according to the brake fluid manufacturer's recommendations.

CAUTION: Some vehicle manufacturers such as Chrysler do not recommend the use of or the mixing of other types of polyglycol brake fluid and specify the use of DOT 3 brake fluid only. Always follow the vehicle manufacturer's recommendation.

Brake Fluid Boiling Point

	Dry	Wet
DOT 3	401	284
DOT 4	446	311
DOT 5.1	500	365
DOT 5*	500	356

*Do not use DOT 5 in vehicles with ABS.

ENGINE OIL LEVEL AND CONDITION

The oil level should be checked when the vehicle is parked on level ground and after the engine has been off for at least several minutes. Remove the oil level indicator, commonly called a **dipstick**, wipe the oil off, and reinsert it all the way down. See Figure 17–8. Once again remove the dipstick and check where the oil level touches the indicator. The "add" mark is usually at the one quart low point. See Figure 17–9. If oil needs to be added, use the proper oil and add to the engine through the oil fill opening. Engine oil

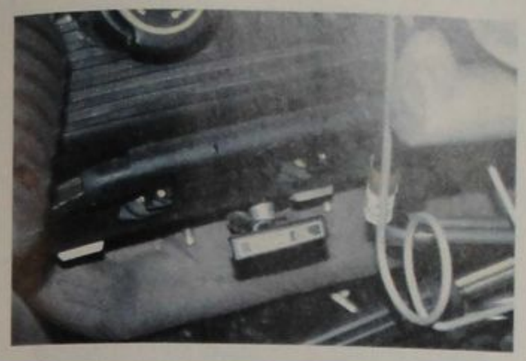


Figure 17–8 A typical engine oil level indicator (dipstick).

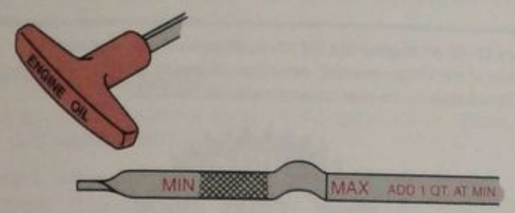


Figure 17–9 The oil level should read no higher than the "MAX" level and no lower than the "MIN" level when the vehicle is parked on a level surface and the oil has had some time to sit with the engine off. This time is necessary to allow the oil to flow from the upper region of the engine down into the oil pan.

specifications and the procedure for changing the oil are included later in this chapter.

ENGINE OIL CHANGES

Most automotive experts recommend that the engine oil be replaced and a new oil filter installed every 3,000 miles (4,800 km) or every three months, whichever occurs first. Most vehicle manufacturers recommend that the oil be changed according to a "normal" or "severe use" schedule, described below.

Normal Use	Severe Use
Most trips over 10 miles (16 km).	Most trips less than 4 to 10 miles (6–16 km).
Operating a vehicle when the outside temperature is above freezing (32°F/0°C).	Operating the vehicle when the outside temperature is below freezing (32°F/0°C).
Most trips do not include slow or stop-and-go driving.	Most trips include slow or stop-and-go driving.
Not towing a trailer or carrying a heavy load.	Towing a trailer or hauling a heavy load.
Driving without dusty conditions.	Driving in dusty conditions.
No police, taxi, or commercial use of the vehicle.	Use by police, taxi, or commercial operation.
The oil change interval recommended by most vehicle manufacturers under normal conditions is 7,500 miles (12,000 km) or six months, whichever occurs first.	The oil change interval recommended by most vehicle manufacturers operating under severe conditions is every 3,000 miles (4,800 km) or every three months, whichever occurs first.

Most vehicles are driven under severe conditions if all of the factors above are considered.

TECH TIP — Follow the Seasons

Vehicle owners often forget when they last changed the oil. This is particularly true of the person who owns or is responsible for several vehicles. A helpful method for remembering when the oil should be changed is to change the oil at the start of each season of the year.

- **Fall** (September 21)
- **Winter** (December 21)
- **Spring** (March 21)
- **Summer** (June 21)

Remembering that the oil needs to be changed on these dates helps owners budget for the expense and the time needed.

VISCOSITY OF OIL (SAE RATING)

The word **viscosity** means resistance to flow. An oil with a high viscosity has a higher resistance to flow and is thicker than a lower-viscosity oil.

Oil is tested and assigned a viscosity number according to standards established by the Society of Automotive Engineers (SAE). It is tested at two different temperatures and assigned a number based on the oil's flow characteristics at that temperature. A thin oil is assigned a lower number and a thicker oil is assigned a higher number. Oil tested at 0°F (−18°C) has the letter W after its number. The **W** represents **winter.** For example, a SAE 10W engine oil was tested at 0°F and assigned a thickness rating of 10. Oil tested at 212°F (100°C) has no letter after its number. Again, the higher the number assigned, the thicker the oil. For example, a SAE 30 oil is an oil tested at 212°F.

Multi-Viscosity Engine Oils Viscosity index (VI) improvers can be added to engine oil to prevent it from becoming thin at higher temperatures. For example, SAE 5W oil with the VI improvers added can be rated as a SAE 30 when tested at 212°F. This oil is therefore rated as a SAE 5W-30 indicating that it flowed the same as a SAE 5W when tested at 0°F and flowed the same as a SAE 30 when tested at 212°F.

Because of the wide range of temperatures at which this oil can function, multi-viscosity oils such as SAE 5W-30 and SAE 10W-30 are often the only oils recommended for use.

NOTE: Some vehicle manufacturers such as Ford and Honda recommend the exclusive use of SAE 5W-20 or SAE 0W-20 engine oil. The owner's manual warns that this is the only viscosity that is acceptable to use under all temperatures and operating conditions. Always follow the vehicle manufacturer's recommended engine oil and viscosity.

QUALITY OF OIL (API RATING)

Although it is generally difficult to purchase low-quality oil today, it is possible to select the incorrect grade for the intended application. The quality rating is established by test procedures set up by the American Petroleum Institute (API), formerly the American Society for Testing and Materials (ASTM), with the cooperation of the Society of Automotive Engineers.

In gasoline engine oil ratings, the letter *S* means *service*, but it can be remembered as standing for oil to be used in *s*park ignition engines. The rating system is open-ended, so newer, improved ratings can be readily added as necessary (skipping the letter *I* to avoid confusion with the number 1).

SA Straight mineral oil (no additives), not suitable for use in any engine
SB Nondetergent oil with additives to control wear and oil oxidation
SC Obsolete (1964)
SD Obsolete (1968)
SE Obsolete (1972)
SF Obsolete (1980)
SG Obsolete (1988)
SH Obsolete (1993)
SJ Obsolete (1997)
SL 2001 to 2004
SM 2004 +

See Figure 17–10.

NOTE: Older-model vehicles for which older, now obsolete ratings were specified can use the newer, higher-rated engine oil. Newly overhauled antique cars or engines can also use the newer, improved oils. The new oils give all the protection of the older oils, plus additional protection.

Diesel classifications begin with the letter *C*, which stands for commercial, but which can also be remembered as standing for oil to be used in compression ignition or diesel engines.

Diesel Engines

Category	Status	Service
CJ-4	Current	For use in 2007 and newer diesel engines designed to operate on ultra-low-sulfur diesel (ULSD) fuel.
CH-4	Current	Introduced December 1, 1998. For high-speed, four-stroke engines designed to meet 1998 exhaust emission standards. Can be used in place of CD, CE, CF-4, and CG-4 oils.
CG-4	Current	Introduced in 1995. For severe duty, high-speed, four-stroke engines using fuel with less than 0.5% weight sulfur. Can be used in place of CD, CE, and CF-4 oils.
CF-4	Current	Introduced in 1990. For high-speed, four-stroke, naturally aspirated and turbocharged engines. Can be used in place of CD and CE oils.
CF-2	Current	Introduced in 1994. For severe duty, two-stroke-cycle engines. Can be used in place of CD-II oils.
CF	Current	Introduced in 1994. For off-road, indirect-injected and other diesel engines including those using fuel with over 0.5% weight sulfur. Can be used in place of CD oils.
CE	Obsolete	Introduced in 1987. For high-speed, four-stroke, naturally aspirated and turbocharged engines. Can be used in place of CC and CD oils.
CD-II	Obsolete	Introduced in 1987. For two-stroke-cycle engines.
CD	Obsolete	Introduced in 1955. For certain naturally aspirated and turbocharged engines.
CC	Obsolete	For engines introduced in 1961.
CB	Obsolete	For moderate duty engines from 1949 to 1960.
CA	Obsolete	For light duty engines (1940s and 1950s).

ILSAC OIL RATING

The International Lubricant Standardization and Approval Committee (ILSAC) developed an oil rating that consolidates the SAE viscosity rating and the API quality rating. If an engine oil meets the standards, a "starburst" symbol is displayed on the front of the oil container. If the starburst is present, the vehicle owner and technician know that the oil is suitable for use in almost any gasoline engine. The original GF-1 (gasoline fueled) rating was updated to GF-2 in 1997, to GF-3 in 2001, and GF-4 in 2004. See Figure 17–11.

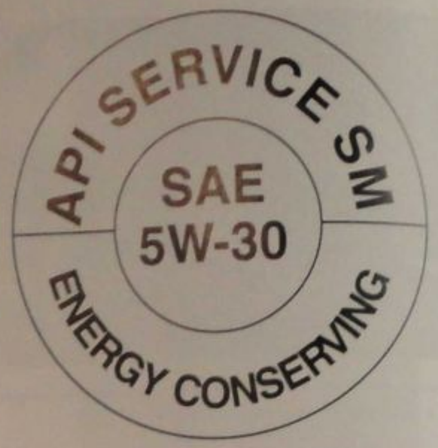


Figure 17–10 API doughnut for a SAE 5W-30, SM engine oil. When compared to a reference oil, the "energy conserving" designation indicates a 1.1% better fuel economy for SAE 10W-30 oils and 0.5% better fuel economy for SAE 5W-30 oils.



Figure 17–11 The International Lubricant Standardization and Approval Committee (ILSAC) starburst symbol. If this symbol is on the front of the container of oil, then it is acceptable for use in almost any gasoline engine.

FREQUENTLY ASKED QUESTION ???

How Does an Oil Life Monitor Work?

While some vehicle manufacturers, such as Mercedes, use a sensor to measure oil temperature, most vehicle oil change monitors function two ways:

1. **Vehicle mileage.** This is the most commonly used vehicle service monitoring system. When a certain number of miles has occurred since it was reset, the control (usually the power train control module—PCM) will turn on a dash light that states that maintenance is required.
2. **Oil life computer program.** A computer program called an **algorithm**, or a series of mathematical calculations, is used to determine the life of the engine oil. For example, when the oil change warning light is reset, the oil life is reset to 100%. Then the power train control module (PCM) keeps track of the number of engine starts, the outside temperature, when the engine was started, based on intake air temperature (IAT) sensor input, as well as the number of miles traveled. Because long drives are easier on engine oil than short stop-and-go driving, the PCM deducts numbers faster during this condition.



Figure 17–12 Mobil 1 synthetic engine oil is used by several vehicle manufacturers in new engines.

SYNTHETIC ENGINE OIL

According to the Society of Automotive Engineers publications, engine oil is classified into groups as follows.

Group I—Mineral, nonsynthetic, base oil with few if any additives. This type of oil is suitable for light lubricating needs and rust protection and is not to be used in an engine.

Group II—Mineral oils with quality additive packages. Most of the conventional engine oils are Group II.

Group III—Hydrogenated (hydroisomerized) synthetic compounds commonly referred to as hydrowaxes or hydrocracked oil. This is the lowest cost of synthetic engine oils. Castrol Syntec is a Group III oil.

Group IV—Synthetic oils made from mineral oil and monomolecular oil called polyalphaolefin or PAO. Mobil 1 is an example of a Group IV synthetic oil as shown in Figure 17–12.

Group V—Non-mineral sources such as alcohol from corn called diesters or polyolesters. Red Line synthetic oil is an example of a Group V oil.

Groups III, IV, and V are all considered to be synthetic because the molecular structure of the finished product does not occur naturally and is man-made through chemical processes. All synthetic engine oils perform better than Group II (mineral) oils especially when tested according to the Noack Volatility Test ASTM D-5800. This test procedure measures the ability of an oil to stay in grade after it has been heated to 300°F (150°C) for one hour. The oil is then measured for percentage of weight loss. As the lighter components boil off, the oil's viscosity will increase. If you start with an SAE 5W oil, it could test as an SAE 15W or even an SAE 20W at the end of the test. It is important that the oil you buy stay in grade for the proper lubrication of your engine.

TECH TIP ✓ Use Synthetic Engine Oil in Lawn and Garden Equipment

Most 4-cycle lawn and garden equipment engines are air cooled and operate hotter than many liquid cooled engines. Lawn mowers and other small engines are often operated near or at maximum speed and power output for hours at a time. These operating conditions are hard on any engine oil. Try using a synthetic oil. The cost is not as big a factor because most small 4-cycle lawn mower engines require only about 1/2 quart (1/2 liter) of oil. The synthetic oil is able to perform under high temperatures better than conventional mineral oils.

Another major advantage of using synthetic engine oil is its ability to remain fluid at very low temperatures. This characteristic of synthetic oil makes it popular in colder climates where cold-engine cranking is important.

The major disadvantage is cost. The cost of synthetic engine oils can be four or five times the cost of Group II mineral engine oils. Some synthetic engine oils are blended with Group II mineral oils and these must be labeled as *blends*.

EUROPEAN OIL RATING SYSTEM

The **Association des Constructeurs Européens d'Automobiles (ACEA)** rates the oil according to the following:

Gasoline Engine Oils

ACEA A1	Low-friction, low-viscosity oil (not suitable for some engines).
ACEA A2	General-purpose oil intended for normal oil change intervals. Not suitable for some engines or extended oil drain intervals in any engine.
ACEA A3	Oil is designed for high-performance engines and/or extended oil drain intervals and under all temperature ranges.
ACEA A4	Designed to meet the requirements for gasoline direct injection (GDI) engines.
ACEA A5	A low-viscosity, low-friction oil not suitable for some engines.

Diesel Engine Oils

ACEA B1	This diesel engine oil is designed for use in a passenger vehicle diesel engine that is equipped with an indirect injection system. This low-viscosity oil is not suitable for some diesel engines.
ACEA B2	Oil meeting this designation is designed to be used in passenger vehicle diesel engines using indirect injection and using normal oil drain intervals.
ACEA B3	Oil meeting this designation is intended for use in a high-performance, indirect-injected passenger vehicle diesel engine and used under extended oil drain interval conditions.
ACEA B4	Oils meeting this standard are intended to be used in direct-injected passenger vehicle diesel engines and used year-round and can be used in an indirect-injected diesel engine.
ACEA B5	A low-viscosity oil designed for extended oil drain intervals and not suitable for some engines.
ACEA C1, C2, C3	The ACEA C ratings are specifications for catalyst compatible oils, which have limits on the amount of sulfur, zinc, and other additives that could harm the catalytic converter.

Starting in 2004, the ACEA began using combined ratings such as A1/B1, A3/B3, A3/B4, and A5/B5.

TECH TIP ✓ **Make Sure the Oil Meets Specific Vehicle Specifications**

Some oils can meet the industry specifications, such as SAE, API, and/or ILSAC ratings, but not pass the tests specified by the vehicle manufacturer. The oil used should meet those of the vehicle manufacturer, which include the following:

BMW—Longlife 98 and longlife-01 (abbreviated LL-01), LL-04

General Motors—GM 6094M, GM 4718M (synthetic oil specification)

General Motors—GM LL-A-25 (gasoline engines) and GM LL-B-25 for GM vehicles equipped with diesel or European-built engines.

Ford—WSS-M2C153-H, WSS-M2C929-A (low viscosity rating—SAE 5W-20), WSS-M2C930-A, WSS-M2C931-A, and WSS-M2C934-A

Chrysler—MS-6395 (2005+ vehicles), MS-10725

Mercedes—229.3, 229.5, 229.1, 229.3, 229-31, 229.5, and 229.51

Volkswagen (VW and Audi)—502.00, 505.00, 505.01, 503, 503.01, 505, 506 diesel, 506.1 diesel, and 507 diesel

Honda—HTO-06

ENGINE OIL DISPOSAL

All used engine oil should be disposed of or recycled according to federal, state, provincial, or local rules and regulations. Used engine oil is considered to be hazardous due to the dissolved metals and acids that are created in an operating engine.

OIL FILTERS

The oil within the engine is pumped from the oil pan through the filter before it goes into the engine lubricating system passages. The filter is made from either closely packed cloth fibers or a porous paper. Large particles are trapped by the filter, while microscopic particles will flow through the filter pores. These particles are so small that they can flow through the bearing oil film and not touch the surfaces, so they do no damage. See Figure 17–14.

TECH TIP ✓ **The Pick Trick**

Removing an oil filter that is installed upside down can be a real mess. When this design filter is loosened, oil flows out from around the sealing gasket. To prevent this from happening, use a pick and poke a hole in the top of the filter, as shown in Figure 17–13. This small hole allows air to get into the filter, thereby allowing the oil to drain back into the engine rather than remain in the filter. After punching the hole in the filter, be sure to wait several minutes to allow time for the trapped oil to drain down into the engine before loosening the filter.



(a)

Figure 17–13 (a) A pick is pushed through the top of an oil filter that is positioned vertically.



(b)

Figure 17–13 (b) When the pick is removed, a small hole allows air to get into the top of the filter which then allows the oil to drain out of the filter and back into the engine.



Figure 17–14 A cutaway of a typical spin-on oil filter. Engine oil enters the filter through the small holes around the center of the filter and flows through the pleated paper filtering media and out through the large hole in the center of the filter. The center metal cylinder with holes is designed to keep the paper filter from collapsing under the pressure.

Many oil filters are equipped with an **antidrainback valve** that prevents oil from draining out of the filter when the engine is shut off. See Figure 17–15. This valve keeps oil in the filter and allows the engine to receive immediate lubrication as soon as the engine starts.

Either the engine or the filter has a **bypass** that will allow the oil to go around the filter element. The bypass allows the engine to be lubricated with dirty oil, rather than having no lubrication, if the filter becomes plugged. The oil also goes through the bypass when the oil is cold and thick. Most engine manufacturers recommend



Figure 17–15 A rubber diaphragm acts as an antidrainback valve to keep the oil in the filter when the engine is stopped and the oil pressure drops to zero.



Figure 17–16 A typical filter crusher. The hydraulic ram forces out most of the oil from the filter. The oil is trapped underneath the crusher and is recycled.

filter changes at every other oil change period. Correct oil filter selection includes using a filter with an internal bypass when the engine is not equipped with one.

Oil filters should be crushed and/or drained of oil before discarding. See Figure 17–16. After the oil has been drained, the filter can usually be disposed of as regular metal scrap. Always check and follow local, state, or regional oil filter disposal rules, regulations, and procedures.

COOLING SYSTEM SERVICE

Normal maintenance involves an occasional check on the coolant level. The front of the radiator should be carefully inspected and cleaned of bugs, dirt, or mud that can often restrict airflow. Maintenance should also include a visual inspection for signs of coolant system leaks and for the condition of the coolant hoses and accessory drive belts.

FREQUENTLY ASKED QUESTION ???

What Is the Magnuson-Moss Act?

The Magnuson-Moss Act was passed into law in 1975 and allows the use of nonoriginal equipment replacement parts during the service or repair of a vehicle without losing the factory warranty. This means that any oil or air filter, spark plug, or other service part can be used unless the vehicle manufacturer furnishes these parts for free during the warranty period.

The vehicle manufacturer cannot deny paying a warranty claim for a fault unless the replacement part is proved to be the cause of the condition needed to be covered by the warranty.

Therefore, it is up to the business owner, service manager, or the technician to determine if the replacement part is of good quality. While this is very difficult or impossible, unless defects are obviously visible, the best solution is to use the original equipment manufacturer (OEM) parts or service parts from a well-known company.

FREQUENTLY ASKED QUESTION ???

Does the Oil Filter Remove All the Dirt?

Many persons believe that oil filters will remove all dirt from the oil being circulated through the filtering material. Most oil filters will filter particles that are about 10 to 20 microns in size. A micron is a millionth of a meter, or 0.000039 inch.

Most dirt and carbon particles that turn engine oil black are less than a micron in size. In other words, it takes about 3,000,000 (three million) of these carbon particles to cover a pinhead. To help visualize how small a micron is, consider that a typical human hair is 60 microns in diameter. In fact, anything smaller than 40 microns is not visible to the human eye. Dispersants are added to engine oil to prevent dirt from adhering together to form sludge. It is the same dispersant additive that prevents dirt from being filtered or removed by other means. If an oil filter could filter particles down to one micron in size, the engine would not receive sufficient oil through the filter for lubrication. Oil recycling companies use special chemicals to break down the dispersants, which permits the dirt in the oil to combine into larger units that can be filtered or processed out of the oil.

CAUTION: The coolant level should only be checked when the engine is cool. Removing the pressure cap from a hot engine will release the cooling system pressure when the coolant temperature is above its atmospheric boiling temperature. When the cap is removed, the pressure will instantly drop to atmospheric pressure level, causing the coolant to boil immediately. Vapors from the boiling liquid will blow coolant from the system. Coolant will be lost, and a person may be injured or burned by the high-temperature coolant that is blown out of the filler opening.

TYPES OF COOLANTS

Antifreeze coolant contains about 93% ethylene glycol plus water and additives. There are three basic types of coolant available today, which are grouped according to the additives used for rust and corrosion protection.

Inorganic Additive Technology (IAT) This is conventional coolant that has been used for over 50 years. The additives used to protect against rust and corrosion include phosphate and silicates. Silicates have been found to be the cause of erosive wear to water pump impellers. The color of IAT coolant is usually green. Phosphates in these coolants can cause deposits to form if used with water that is hard (contains minerals).



Figure 17–17 Since the mid-1990s, many vehicle manufacturers have been using antifreeze coolant that is silicate and phosphate free. Always check the owner's manual for the specifications for the recommended engine coolant.

Organic Acid Technology (OAT) This type of coolant uses organic acids to help protect the metals in the cooling system from corrosion. OAT coolant is usually orange. DEX-COOL is an example of an OAT coolant. See Figure 17–17.

Hybrid Organic Acid Technology (HOAT) Hybrid organic acid technology (HOAT) coolant contains organic acids for corrosion protection plus a low amount of silicates. HOAT coolants can be green, orange, yellow, gold, pink, red, or blue.

Some samples of HOAT coolants include:

- VW/Audi pink
- Mercedes yellow
- Ford yellow
- Honda blue (TYPE 2)
- European blue
- Asian red—this coolant contains no silicates but has some phosphate

FREQUENTLY ASKED QUESTION ???

What Is "Pet Friendly" Antifreeze?

Conventional ethylene glycol antifreeze, regardless of the additives used, is attractive to pets and animals because it is sweet. Ethylene glycol is fatal to any animal if swallowed and therefore, any spill should be cleaned up quickly. Another type of antifreeze coolant, called propylene glycol, is less attractive to pets and animals because it is less sweet, but is still harmful if swallowed. This type of coolant should not be mixed with ethylene glycol coolant.

CAUTION: Some vehicle manufacturers do not recommend the use of propylene glycol coolant. Check the recommendation in the owner's manual or service information before using it in a vehicle.

ANTIFREEZE/COOLANT DISPOSAL

Used coolant drained from vehicles can usually be disposed of by combining it with used engine oil. The equipment used for recycling the used engine oil can easily separate the coolant from the waste oil. Check with recycling companies authorized by local or state government for the exact method recommended for disposal in your area. See Figure 17–18.



Figure 17–18 Used antifreeze coolant should be kept separate and stored in a leak-proof container until it can be recycled or disposed of according to federal, state, and local laws. Note that the storage barrel is placed inside another container to catch any coolant that may spill out of the inside barrel.



Figure 17–19 This old upper hose had a split, causing coolant to squirt out.

RADIATOR AND HEATER HOSES

Upper and lower radiator hoses must be pliable, yet not soft. The lower hose must have a spring inside to prevent the hose from being sucked closed, since the lower hose is attached to the suction side of the water pump. The bypass hose (if equipped) and heater hoses have a 1/2", 5/8", or 3/4" inside diameter and connect the engine cooling system to the heater core. (A heater core looks like a small radiator located inside the vehicle.) All automotive hose is constructed of rubber with reinforcing fabric weaving for strength. All hoses should be inspected for leaks (especially near hose clamps), cracks, swollen areas indicating possible broken reinforcing material, and excessively brittle, soft, and swollen sections. Using a hand-operated pressure pump attached to the radiator opening is an excellent way to check for leaks. See Figure 17–19.

AUTOMATIC TRANSMISSION FLUID CHECK

The **automatic transmission fluid (ATF)** is another important fluid that should be checked regularly. Most automatic

TECH TIP ✔ **The Cut-and-Peel Trick**

It is often difficult to remove a radiator or heater hose from the fittings on the radiator or heater core. To avoid possible damage to expensive radiator or heater core, do not pull or twist the hose to remove it. Simply use a utility knife and slit the hose lengthwise and then use your finger to peel the hose off of the radiator or heater core. Although this procedure will not work if the hose is to be reused, it is a real time saver when it comes to replacing old hoses.

TECH TIP ✔ **Quick-and-Easy Cooling System Problem Diagnosis**

If overheating occurs in slow stop-and-go traffic, the usual cause is low airflow through the radiator. Check for airflow blockages or cooling fan malfunction. If overheating occurs at highway speeds, the cause is usually a radiator or coolant circulation problem. Check for a restricted or clogged radiator.

transmission fluid levels should be checked under the following conditions:

- The vehicle should be parked on a level surface.
- The transmission fluid should be at normal operating temperature. This may require the vehicle to be driven several miles before the level is checked.
- The engine should be running with the transmission in neutral or park as specified by the vehicle manufacturer.

NOTE: Honda and Acura manufacturers usually specify that the transmission fluid be checked with the engine off. The recommended procedure is usually stamped on the transmission dipstick or written in the owner's manual and/or service manual.

To check the automatic transmission fluid, start the engine and move the gear selector to all gear positions and return to park or neutral as specified by the vehicle manufacturer. Remove the transmission/transaxle dipstick (fluid level indicator) and wipe it off using a clean cloth. Then reinsert the dipstick until fully seated. Remove the dipstick again and note the level. See Figure 17–20.

NOTE: The "add" mark on most automatic transmission/transaxle dipsticks mean that 1/2 quart (1/2 liter) of automatic transmission fluid needs to be added.

- **Do not overfill any automatic transmission/transaxle.** Even if just 1/2 quart too much were added by mistake (for example,

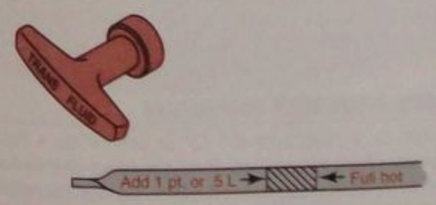


Figure 17–20 A typical automatic transmission dipstick.

adding 1 quart when the fluid was at the "add" line instead of the correct amount of 1/2 quart) could cause the fluid to foam. Foaming of the ATF is caused by the moving parts inside the transmission/transaxle, which stir up the fluid and introduce air into it. This foamy fluid cannot adequately lubricate or operate the hydraulic clutches that make the unit function correctly.

- **Smell the ATF on the dipstick.** If it seems burned or rancid, further service of the automatic transmission/transaxle will be necessary.
- **Look at the color of the fluid.** It should be red or light brown. A dark brown or black color indicates severe oxidation usually caused by too high an operating temperature. Further service and diagnosis of the automatic transmission/transaxle will be required.

NOTE: Chrysler warns that color and smell should not be used to determine the condition of ATF+4 used in most Chrysler-built vehicles since the 2000 model year. The dyes and additives can change during normal use and it is not an indication of fluid contamination. Always follow the vehicle manufacturer's recommendation.

TECH TIP ✔ **The Paper Towel Test**

New ATF will penetrate a paper towel better than used oxidized ATF. To compare old fluid with new, place three drops of new fluid on a paper towel and three drops of used ATF on the paper towel about 3 inches from the first sample. Wait for 30 minutes. The new ATF will have expanded (penetrated through the paper towel) much farther than the old, oxidized fluid. This test can be used to convince a customer that the ATF should be changed according to the vehicle manufacturer's recommended interval even though, to the naked eye, the fluid looks okay.

TYPES OF AUTOMATIC TRANSMISSION FLUID

Automatic transmission fluid is a high-quality oil that has additives that resist oxidation, inhibit rust formation, and allow the fluid to flow easily at all temperatures. The automatic transmission fluid is dyed red for identification. Various vehicle manufacturers recommend a particular type of ATF based mainly on its friction characteristics. Friction is needed between the bands, plates, and clutches of an automatic transmission/transaxle. There are three types of fluid:

- **Nonfriction modified**—This fluid does not contain any friction-reducing additives. Type F is an example of a nonfriction-modified ATF. It was primarily used in band-type Ford automatic transmissions until 1977.
- **Friction modified**—This fluid type has additives that reduce friction. Dexron III® and Mercon V® are examples of friction-modified ATF.

NOTE: Mercon replaced earlier Ford ATF specifications for CJ, H, and MV.

- **Highly friction modified**—This fluid type has additional friction-reducing additives beyond those specified for a friction-modified ATF. Dexron VI, Chrysler Mopar 7176, ATF+2, ATF+3, ATF+4, Honda, and Toyota specific ATF are examples of fluids that are highly friction modified. See Figure 17–21.

Always use the exact ATF recommended by the vehicle manufacturer.



Figure 17–21 Honda ATF is highly friction modified and should be used in all Honda vehicles. Substituting another type of ATF can cause harsh shifting or shudders during acceleration.



Figure 17–22 Many vehicles use a combination filler cap and level indicator (dipstick) that shows the amount of power steering fluid in the reservoir. The power steering fluid should also be checked for color that could indicate wear in the system or contamination.

POWER STEERING FLUID

The correct power steering fluid is *critical* to the operation and service life of the power steering system! The *exact* power steering fluid to use varies by vehicle manufacturer and sometimes between models made by the same vehicle manufacturer because of differences among various steering component manufacturers. See Figure 17–22.

NOTE: Remember, multiple-purpose power steering fluid does not mean all-purpose power steering fluid. Always consult the power steering reservoir cap, service manual, or owner's manual for the exact fluid to be used in the vehicle being serviced.



(a)



(b)

Figure 17–23 (a) Windshield washer fluid caps are usually labeled with this symbol. (b) Only use the recommended windshield washer fluid. Do not use water in climates where freezing temperatures are possible or damage to the reservoir, pump, and lines could result when the water freezes and expands.

WINDSHIELD WASHER FLUID

Windshield washer fluid level should be checked regularly and refilled as necessary. Use only the fluid that is recommended for use in vehicle windshield washer systems. See Figure 17–23. Most windshield washer fluid usually looks like blue water. It is actually water with an alcohol (methanol) additive to prevent freezing and to help clean the windshield by dissolving bugs, etc.

CAUTION: Some mixed fluids are for summer use only and do not contain antifreeze protection. Read the label carefully! Some fluids must be mixed with water because they are in concentrated form. Follow the directions on the container *exactly*. If not enough water is used, the additives in the washer fluid could damage the paint on the roof and trunk lid. Windshield washer fluid may also be flammable because it often contains alcohol. Keep the fluid away from open flames or excessive heat.

ACCESSORY DRIVE BELT INSPECTION

There should be a *maximum* of 1/2" of play when a belt is depressed midway between pulleys. Power steering (PS) and air conditioning (A/C) belts usually must be even tighter. The work these belts are required to perform is deceptive. For example, an air conditioning belt must transfer approximately 12 horsepower

whenever the A/C is being used. This could not be accomplished with a belt which depended on tightness alone. Most V-belts (called this because of their shape) are 34 degrees at the V. The pulley they ride through is generally 36 degrees. This 2-degree difference results in a wedging action and makes power transmission possible, but it is also the reason why V-belts must be closely inspected.

It is generally recommended that all belts, including the **serpentine** (or **Poly V**) belts be replaced every four years. The old belts could be kept in the trunk for use in an emergency. When a belt that turns the water pump breaks, the engine could rapidly overheat causing serious engine damage, and if one belt breaks, it often causes the other belts to become tangled, causing them to break. See Figures 17–24 through 17–26.

Belt Tension Measurement There are four ways that vehicle manufacturers specify that the belt tension is within factory specifications.

1. **Belt tension gauge**—A belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications or use the table below for an example of the proper tension based on the size of the belt.



Figure 17–24 A special tool is useful when installing a new accessory drive belt. The long-handled wrench fits the hole in the belt tensioner.



Figure 17–25 Typical worn serpentine accessory drive belt. A defective or worn belt can cause a variety of noises, including squealing and severe knocking similar to a main bearing knock, if glazed or loose.

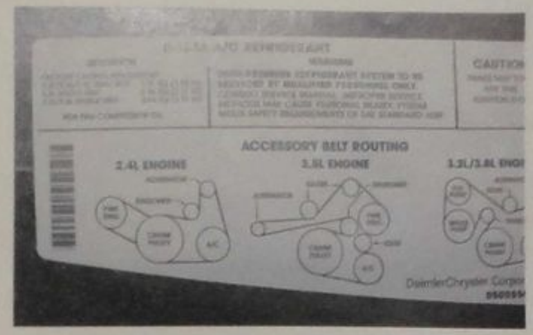


Figure 17–26 Always check the belt routing whenever replacing or checking the operation or noise in the accessory drive belts.



Figure 17–27 A spring-loaded accessory drive belt tensioner.

Serpentine Belts

Number of Ribs Used	Tension Range (lbs.)
3	45–60
4	60–80
5	75–100
6	90–125
7	105–145

Traditional V-Belts

V-Belt Top Width (in.)	Tension Range (lbs.)
1/4	45–65
5/16	60–85
25/64	85–115
31/64	105–145

Replace any serpentine belt that has more than three cracks in any one rib that appears in a 3-inch span.

2. **Marks on a tensioner**—Many tensioners have marks that indicate the normal operating tension range for the accessory drive belt. Check service information for the location of the tensioner mark. See Figure 17–27.

3. **Torque wrench reading**—Some vehicle manufacturers specify that a beam-type torque wrench be used to determine the torque needed to rotate the tensioner. If the torque reading is below specifications, the tensioner must be replaced.
4. **Deflection**—Depress the belt between the two pulleys that are the farthest apart and the flex or deflection should be 1/2 inch.

TECH TIP ✓ **The Hand Cleaner Trick**

Lower-than-normal alternator output could be the result of a loose or slipping drive belt. All belts (V and serpentine multigroove) use an interference angle between the angle of the V's of the belt and the angle of the V's on the pulley. A belt wears this interference angle off the edges of the V of the belt. As a result, the belt may start to slip and make a squealing sound even if tensioned properly.

A common trick used to determine if the noise is belt related is to use grit-type hand cleaner or scouring powder. With the engine off, sprinkle some powder onto the pulley side of the belt. Start the engine. The excess powder will fly into the air, so get out from under the hood when the engine starts. If the belts are now quieter, you know that it was the glazed belt that made the noise.

NOTE: Often, belt noise sounds exactly like a noisy bearing. Therefore, before you start removing and replacing parts, try the hand cleaner trick.

Often, the grit from the hand cleaner will remove the glaze from the belt and the noise will not return. However, if the belt is worn or loose, the noise will return and the belt should be replaced. A fast alternative method to determine if the noise is from the belt is to spray water from a squirt bottle at the belt with the engine running. If the noise stops, the belt is the cause of the noise. The water quickly evaporates and therefore, unlike the gritty hand cleaner, water just finds the problem—it does not provide a short-term fix.

CHECKING TIRE PRESSURE

Tire pressures should be checked when the tires are cold. As a vehicle is driven, the flexing of the tire and friction between the tire and the road causes an increase in temperature. As the tire heats up, the air inside the tire also increases in temperature. The increased temperature of the air increases the air pressure inside the tire. The air pressure typically increases in pressure 4 to 6 PSI after the vehicle has been driven several miles. If air is then removed from the hot tire, the tire would be underinflated. The tire pressure specified is for a tire that has not been driven and is therefore cold, so the air pressure should be checked before the vehicle has been driven more than 2 miles (3 km).

NOTE: Tire pressure changes according to air temperature about 1 PSI per 10°F; therefore, during a change of season the tire pressure has to be adjusted. For example, when the summer temperature of 80°F changes to 40°F in the fall, the tire pressure will drop about 4 PSI (80 – 40 = 40).

Use a good-quality tire pressure gauge and push it against the tire valve stem after removing the cap. Compare the pressure reading with the specified tire pressure. The specified pressure is located on a placard attached to the driver's door or door post or in the glove compartment. See Figure 17–28.

CAUTION: Do not inflate tires to the maximum rating on the tire sidewall. Even though this pressure represents the maximum tire pressure, inflating the tires to this pressure usually results in a very hard ride and often unacceptable handling.

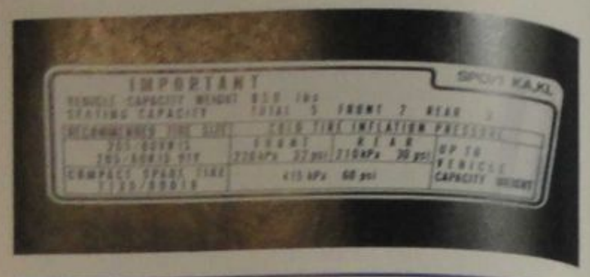


Figure 17–28 Many vehicle manufacturers print the recommended tire pressure on a placard attached to the driver's door or the door jamb.

The recommended tire pressure often specifies a different pressure for front and rear tires. This is very important to remember especially when the tires are being rotated. Tire pressure should be checked and adjusted if necessary after a tire rotation has been completed. The recommendation often includes a statement about tire pressures to use if operating under all highway driving conditions or operating the vehicle in a fully loaded condition. Specifications for these conditions commonly include increasing the pressure (usually about 4 to 6 PSI or 27 to 41 kPa).

TIRE ROTATION

To assure long life and even tire wear, it is important to rotate each tire to another location. Some rear-wheel-drive vehicles, for example, may show premature tire wear on the front tires. The wear usually starts on the outer tread row and usually appears as a front-to-back (high and low) wear pattern on individual tread blocks. These *blocks of tread* rubber are deformed during cornering, stopping, and turning, which can cause tire noise and/or tire roughness. While some shoulder wear on front tires is normal, it can be reduced by proper inflation, alignment, and tire rotation. For best results, tires should be rotated every 6,000 miles or six months. See Figure 17–29 for suggested methods of rotation.

NOTE: Radial tires can cause a radial pull due to their construction. If the wheel alignment is correct, attempt to correct a pull by rotating the tires front to rear or, if necessary, side to side.

HINT: To help remember when to rotate the tires, just remember that it should be done at every other oil change. Most manufacturers recommend changing the engine oil every 3,000 miles (4,800 km) or every three months and recommend tire rotation every 6,000 (9,600 km) miles or every six months.

WHEEL MOUNTING TORQUE

Make certain that the wheel studs are clean and dry and torqued to manufacturer's specifications. Most vehicles specify a tightening torque of between 80 and 100 lb-ft.

CAUTION: Most manufacturers warn that the wheel studs should not be oiled or lubricated with grease because this can cause the wheel lug nuts to loosen while driving.

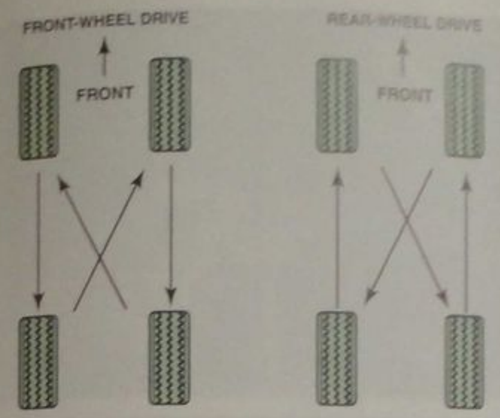


Figure 17–29 The preferred method most often recommended is the modified X method. Using this method, each tire eventually is used at each of the four wheel locations. An easy way to remember the sequence, whether front wheel drive or rear wheel drive, is to say to yourself, "Drive wheels straight, cross the nondrive wheels."

Always tighten lug nuts gradually tighter in the proper sequence (tighten one nut, skip one, and tighten the next nut). See Figure 17–30. This helps prevent warping the brake drums or rotors, or bending a wheel.

NOTE: Anytime you install a brand-new set of aluminum wheels, retorque the wheels after the first 25 miles. The soft aluminum often compresses slightly, loosening the torque on the wheels.

TECH TIP ✓ **Two Quick Checks**

If the vehicle is hoisted on a frame-contact lift, spin each tire to check that the brakes are not dragging. You should be able to turn all four wheels by hand if the parking brake is off and the transmission is in neutral. Also, when spinning the tire, look over the top of the tire to check if it is round. An improperly mounted tire or a tire that is out-of-round can be detected by watching for the outside of the tire to move up and down as it is being rotated.



(a)

(b)

Figure 17–30 (a) A torque absorbing adapter (often called a torque stick) being used to tighten lug nuts. The adapter should not be held as it could change the torque calibration or cause personal injury if the adapter were to break. (b) An assortment of torque limiting adapters.

REAL WORLD FIX **Waiting for the Second Click Story**

A student service technician was observed applying a lot of force to a torque wrench attached to a wheel lug nut. When the instructor asked what he was doing, the student replied that he was turning the lug nut tighter until he heard a second click from the torque wrench.

This was confusing to the instructor until the student explained that he had heard a second click of the torque wrench during the demonstration. The instructor at once realized that the student had heard a click when the proper torque was achieved, plus another click when the force on the torque wrench was released.

No harm occurred to the vehicle because all of the lug nuts were reinstalled and properly torqued. The instructor learned that a more complete explanation for the use of click-type torque wrenches was needed.

TIRE INSPECTION

All tires should be carefully inspected for faults in the tire itself or for signs that something may be wrong with the steering or suspension systems of the vehicle. See Figures 17–31 through 17–33 for examples of common problems.

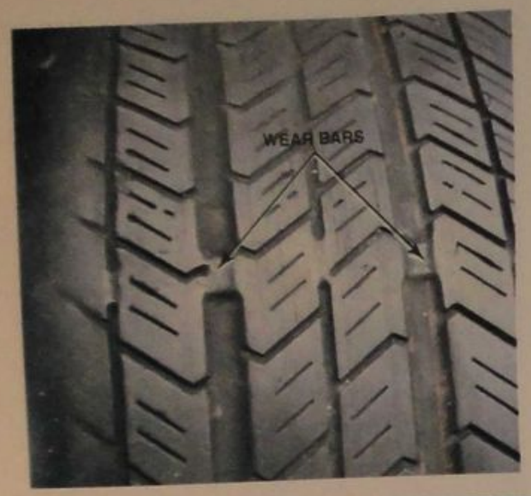


Figure 17–31 All tires should be checked for wear by observing the wear bars. These strips cause the tire to be bald in this area when the tire tread depth is less than 2/32".



Figure 17–32 This tire is worn on the outside. If both front tires are worn the same way, then excessive toe-in is most likely the cause. If just one tire shows this type of wear, then the camber is not correct and the vehicle should be inspected for a fault in the suspension system.

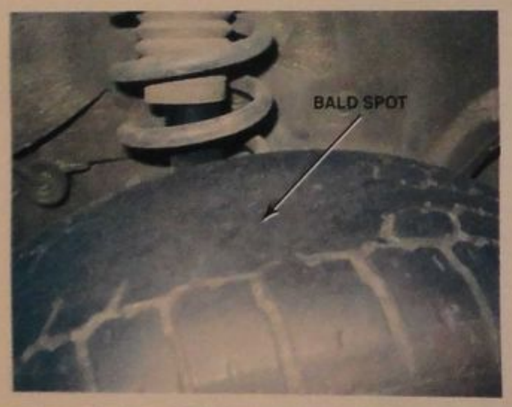


Figure 17–33 This tire should be replaced. The unusual wear pattern indicates a possible fault with the tire itself or a suspension fault that has caused the wheel/tire assembly to wear unevenly.



Figure 17–34 A hand-operated grease gun is being used to lubricate a grease fitting on a pitman arm.

CHASSIS LUBRICATION

Chassis lubrication refers to the greasing of parts that rub against each other or installing grease into a pivot (or ball joints) through a grease fitting. Grease fittings are also called **Zerk fittings** (named for Oscar U. Zerk) or **Alamite fittings** (named for the manufacturer of early grease fittings). These fittings contain a one-way check valve that prevents the grease from escaping. See Figure 17–34. Grease fittings are used on steering components, such as tie-rod ends, and in the suspension ball joints, which require lubrication to prevent wear and noise caused by the action of a ball rotating within a joint during vehicle operation.

CAUTION: If too much grease is forced into a sealed grease boot, the boot itself may rupture requiring the entire joint to be replaced.

CHASSIS GREASE

Vehicle manufacturers specify the type and consistency of grease for each application. The technician should know what these specifications mean. Grease is an oil with a thickening agent added to allow it to be installed in places where a liquid lubricant would not stay. Greases are named for their thickening agent, such as aluminum, barium, calcium, lithium, or sodium.

The **American Society for Testing Materials (ASTM)** specifies the consistency of grease using a **penetration test.** The **National Lubricating Grease Institute (NLGI)** uses the penetration test as a guide to assign the grease a number. Low numbers are very fluid and higher numbers are more firm or hard. Most vehicle manufacturers specify NLGI #2 for wheel bearing and chassis lubrication. See Figure 17–35.

NLGI also specifies grease by its use:

The "GC" designation is acceptable for wheel bearings.

The "LB" designation is acceptable for chassis lubrication.

Many greases are labeled with both GC and LB and are therefore acceptable for both wheel bearings and chassis use, such as in lubricating ball joints, tie-rod ends, etc.

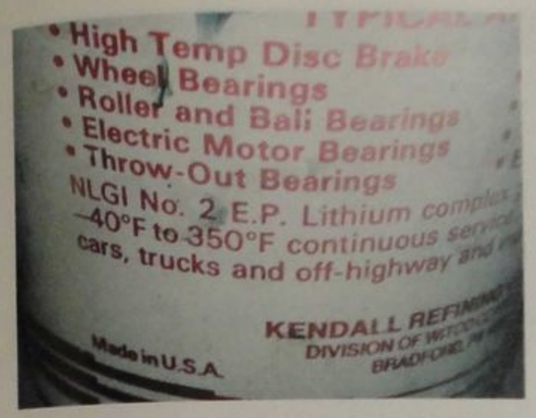


Figure 17–35 Most vehicle manufacturers recommend the use of grease rated NLGI #2 and "GC" for wheel bearing, and "LB" for chassis lubrication. Many greases have both designations and are therefore acceptable for use as wheel bearing grease as well as chassis grease for ball joints and tie-rod ends.



Figure 17–36 This broken coil spring was found during an under-vehicle inspection. The owner was unaware of the problem and it did not make any noise.



Figure 17–37 This corroded muffler was found during a visual inspection and yet was not detected by the driver because it was relatively quiet.



Figure 17–38 A visual inspection should include checking the differential fluid, especially after noting that a leak has occurred.

OTHER UNDER-THE-VEHICLE LUBRICATION CHECKS

Other items underneath the vehicle that may need checking or lubricating include:

- Shock absorbers and springs. See Figure 17–36.
- The transmission/transaxle shift linkage (check the service manual for the correct lubricant to use)
- Exhaust system including all pipes and hangers. See Figure 17–37.
- The parking brake cable guides

CAUTION: Do not lubricate plastic-coated parking brake cables. The lubricant can destroy the plastic coating.

DIFFERENTIAL FLUID CHECK

Rear-wheel-drive vehicles use a differential in the rear of the vehicle to change the direction of power flow from the engine to the rear wheels. The differential also provides a gear reduction to increase engine torque applied to the drive wheels. Four-wheel-drive vehicles also use a differential at the front of the vehicle in addition to the differential in the rear. To check the differential fluid level and condition, perform the following:

- Hoist the vehicle safely.
- Visually check for any signs of leakage. See Figure 17–38.
- Remove the inspection plug from the side of the differential assembly.
- Insert your small finger into the hole in the housing and then remove your finger.
  1. If the differential fluid is on your finger, then the level of the fluid is okay. Rub the fluid between your fingers. If the fluid is not gritty feeling, reinstall the inspection plug. If the fluid is gritty feeling, further service will be necessary to determine the cause and correct it.
  2. If the differential fluid is not on your finger, then the level of the fluid is too low.

NOTE: The reason for the low fluid level should be determined. If repairs are not completed immediately, additional differential fluid should be added by pumping it into the differential through the inspection hole.

DIFFERENTIAL LUBRICANTS

All differentials use hypoid gear sets and a special lubricant is necessary because the gears both roll and slide between their meshed teeth. Gear lubes are specified by the **American Petroleum Institute (API)**. Most differentials require:

1. SAE 80W-90 GL-5 *or*
2. SAE 75W-90 GL-5 *or*
3. SAE 80W GL-5

Limited slip differentials (often abbreviated LSD) usually use an additive that modifies the friction characteristics of the rear axle lubricant to prevent chattering while cornering.

MANUAL TRANSMISSION/TRANSAXLE LUBRICANT CHECK

Manual transmissions/transaxles may use any one of the following lubricants:

- Gear lube (usually SAE 80W-90)
- Automatic transmission fluid (ATF)
- Engine oil (usually SAE 5W-30)
- Manual transmission fluid (sometimes called **synchromesh transmission fluid (STF)**—this type of lubricant is similar to ATF with special additives to ease shifting especially when cold)

To check manual transmissions/transaxles lubricant, perform the following:

- Hoist the vehicle safely.
- Locate the transmission/transaxle inspection (fill) plug. Consult the factory service manual for the proper plug to remove to check the fluid level.
- If the fluid drips out of the hole, then the level is correct. If the fluid runs out of the hole, the level is too full. Allow it to flow out until it stops. The correct level of fluid is at the bottom of the inspection hole.
- If low, first determine the correct fluid to use and then fill until the fluid level is at the bottom of the inspection hole or until the fluid runs out of the inspection hole.

TECH TIP ✔ **Use a Hydrocarbon Detector**

One of the many items that should be inspected while underneath the vehicle is the condition of all the fuel lines. Many gasoline (fuel) leaks do not show as wet areas. A hydrocarbon detector available from automotive test equipment suppliers is an excellent tool to use to locate small gasoline leaks that may not be visible. See Figure 17–39.



Figure 17–39 An electronic hand-held hydrocarbon tester is an excellent tool to use to check for possible gasoline leaks from lines or components.

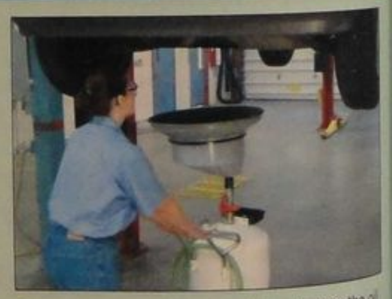
PHOTO SEQUENCE Oil Change



P17–1 Before entering the customer's car for the first time, be sure to install a seat cover as well as a steering wheel cover to protect the vehicle's interior.



P17–2 Run the engine until it is close to operating temperature. This will help the used oil drain more quickly and thoroughly.



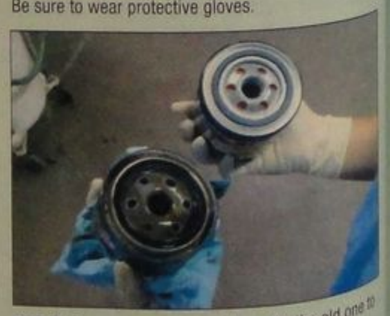
P17–3 Raise the vehicle on a hoist, and place the oil drain container in position under the oil drain plug. Be sure to wear protective gloves.



P17–4 Remove the plug and allow the hot oil to drain from the engine. Use caution during this step as hot oil can cause painful burns!



P17–5 While the engine oil continues to drain, remove the engine oil filter using a filter wrench. Some oil will drain from the filter, so be sure to have the oil drain container underneath when removing it.



P17–6 Compare the new oil filter with the old one to be sure that it is the correct replacement.

PHOTO SEQUENCE Oil Change—continued



P17–7 The wise service technician adds oil to the oil filter whenever possible. This provides faster filling of the filter during start-up and a reduced amount of time that the engine does not have oil pressure.



P17–8 Apply a thin layer of clean engine oil to the gasket of the new filter. This oil film will allow the rubber gasket to slide and compress as the oil filter is being tightened.



P17–9 Clean the area where the oil filter gasket seats to be sure that no part of the gasket remains that could cause an oil leak if not fully removed.



P17–10 Install the new oil filter and tighten it by hand. Do not use an oil filter wrench to tighten the filter! Most filters should be tightened 3/4 of a turn after the gasket contacts the engine.



P17–11 Carefully inspect the oil drain plug and gasket. Replace the gasket as needed. Install the drain plug and tighten firmly but do not overtighten!



P17–12 Lower the vehicle and clean around the oil fill cap before removing it.



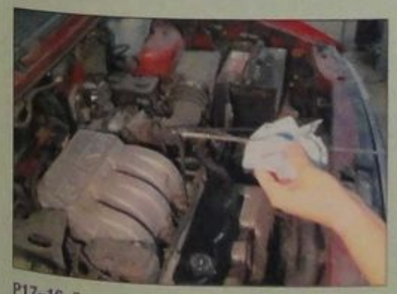
P17–13 Use a funnel to add the specified amount of oil to the engine at the oil fill opening. When finished, replace the oil fill cap.



P17–14 Start the engine and allow it to idle while watching the oil pressure gauge and/or oil pressure warning lamp. Oil pressure should be indicated within 15 seconds of starting the engine.



P17–15 Stop the engine and let it sit for a few minutes to allow the oil to drain back into the oil pan. Look underneath the vehicle to check for any oil leaks at the oil drain plug(s) or oil filter.



P17–16 Remove the oil-level dipstick and wipe it clean with a shop cloth.



P17–17 Reinstall the oil-level dipstick. Remove the dipstick a second time and read the oil level.



P17–18 The oil level should be between the MIN and the MAX lines. In this case, the oil level should be somewhere in the cross-hatched area of the dipstick.

SUMMARY

1. Prior to servicing a vehicle, protective coverings should be used on the steering wheel, seats, and floor.
2. Brake fluid should be checked regularly and not filled above 1/4" from the top of the reservoir or above the "maximum" line imprinted on the side of the master cylinder.
3. Most vehicle manufacturers specify DOT 3 brake fluid.
4. Most vehicle manufacturers specify SAE 5W-30 or 10W-30 engine oil with an API rating of SM and an ILSAC rating of GF-4.
5. The engine oil should be changed more frequently if the vehicle is driven under severe conditions such as stop-and-go city-type driving.
6. When replacing any radiator or heater hose, the end of the hose should be cut to prevent possible damage to the radiator or heater core.
7. Always use the specified automatic transmission fluid when topping off or when changing the fluid. Using the wrong type of ATF can cause the transmission to shift too harshly or cause a vibration when the transmission shifts.
8. The tire pressure should be checked when the tires are cold, and the tires should be inflated to the pressure specified on the door placard or in the owner's manual.
9. Tires should be rotated every 5,000 to 7,000 miles (8,000 to 11,000 km) or at every other oil change.
10. Wheels should always be tightened with a torque wrench to the proper torque and in a star pattern.
11. All grease fittings should be cleaned before using a grease gun to lubricate any greaseable joints under the vehicle.
12. Most differentials require a SAE 80W-90 GL-5 rated lubricant.
13. Manual transmissions/transaxles may require one of several different lubricants including gear lube such as SAE 80W-90, ATF, engine oil (SAE 5W-30), or special manual transmission fluid.

REVIEW QUESTIONS

1. Explain why brake fluid should not be filled above the full or MAX level as indicated on the master cylinder reservoir.
2. Explain why brake fluid should be kept in an airtight container.
3. Explain the terms SAE 5W-30, API SM, and GF-4.
4. List three types of automotive transmission fluid.
5. Describe the most common sequence for tire rotation.
6. Discuss how to check differential fluid.
7. List four lubricants that a manual transmission/transaxle *may* require depending on exact year, make, and model of vehicle.

CHAPTER QUIZ

1. Which is an oil rating?
   a. ACEA C2
   b. 229.1
   c. 4718M
   d. All of the above
2. Most vehicle manufacturers specify brake fluid that meets what specification?
   a. DOT 2
   b. DOT 3
   c. DOT 4
   d. DOT 5
3. The thicker the engine oil, the better the quality.
   a. True
   b. False
4. The letter *W* as in SAE 10W-30 means
   a. Weight
   b. Wrought
   c. With
   d. Winter
5. Most antifreeze coolant is
   a. Phosphate
   b. Propylene glycol
   c. Ethylene glycol
   d. Dexthylene
6. Dexron and Mercon are examples of which type of ATF?
   a. Nonfriction modified
   b. Friction modified
   c. Highly friction modified
   d. Straight-weight mineral oil
7. Using the modified X tire rotation method on a front-wheel-drive vehicle would place the right front tire on the _____.
   a. Left front
   b. Left rear
   c. Right rear
   d. Right front
8. Most vehicle manufacturers specify a lug nut (wheel nut) tightening torque specification of about _____.
   a. 80 to 100 lb-ft.
   b. 100 to 125 lb-ft.
   c. 125 to 150 lb-ft.
   d. 150 to 175 lb-ft.
9. A grease labeled NLGI #2 GC is suitable for use on what vehicle components?
   a. Wheel bearings
   b. Chassis parts
   c. Both wheel bearings and chassis parts
   d. Door hinges only
10. A service technician removed the inspection/fill plug from the differential of a rear-wheel-drive vehicle and gear lube started to flow out. Technician A says to quickly replace the plug to prevent any more loss of gear lube. Technician B says to catch the fluid and allow the fluid to continue to drain. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

SECTION VI Engine Repair



18 Gasoline Engine Operation, Parts, and Specifications
19 Diesel Engine Operation and Diagnosis
20 Cooling System Operation and Diagnosis
21 Lubrication System Operation and Diagnosis
22 Intake and Exhaust Systems
23 Turbocharging and Supercharging
24 Engine Condition Diagnosis
25 Engine Disassembly, Cleaning, and Crack Detection
26 Cylinder Heads and Valves
27 Camshafts and Valve Trains
28 Pistons, Rings, and Connecting Rods
29 Engine Blocks, Crankshafts, and Bearings
30 Engine Blueprinting and Assembly

CHAPTER 18 Gasoline Engine Operation, Parts, and Specifications

OBJECTIVES: After studying Chapter 18, the reader will be able to: Prepare for Engine Repair (A1) ASE certification test content area "A" (General Engine Diagnosis). • Explain how a four-stroke cycle gasoline engine operates. • List the various characteristics by which vehicle engines are classified. • Discuss how a compression ratio is calculated. • Explain how engine size is determined. • Describe how turbocharging or supercharging increases engine power. • The engine converts part of the fuel energy to useful power. This power is used to move the vehicle.

KEY TERMS: block • bore • boxer • cam-in-block design • camshaft • combustion • combustion chamber • compression ratio (CR) • connecting rod • crankshaft • cycle • cylinder • displacement • double overhead camshaft (DOHC) • exhaust valve • external combustion engine • four-stroke cycle • intake valve • internal combustion engine • mechanical force • mechanical power • naturally aspirated • nonprincipal end • oil galleries • pancake • piston stroke • principal end • pushrod engine • rotary engine • single overhead camshaft (SOHC) • stroke • supercharger • top dead center (TDC) • turbocharger • Wankel engine

ENERGY AND POWER

Energy is used to produce power. The chemical energy in fuel is converted to heat by the burning of the fuel at a controlled rate. This process is called **combustion.** If engine combustion occurs within the power chamber, the engine is called an **internal combustion engine.**

NOTE: An **external combustion engine** is an engine that burns fuel outside of the engine itself, such as a steam engine.

Engines used in automobiles are internal combustion heat engines. They convert the chemical energy of the gasoline into heat

within a power chamber that is called a **combustion chamber.** Heat energy released in the combustion chamber raises the temperature of the combustion gases within the chamber. The increase in gas temperature causes the pressure of the gases to increase. The pressure developed within the combustion chamber is applied to the head of a piston or to a turbine wheel to produce a usable **mechanical force,** which is then converted into useful **mechanical power.**

ENGINE CONSTRUCTION OVERVIEW

Block All automotive and truck engines are constructed using a solid frame, called a **block.** A block is constructed of cast iron or aluminum and provides the foundation for most of the engine components and systems. The block is cast and then machined to very close tolerances to allow other parts to be installed.

Rotating Assembly Pistons are installed in the block and move up and down during engine operation. Pistons are connected to connecting rods, which connect the pistons to the crankshaft. The crankshaft converts the up-and-down motion of the piston to rotary motion, which is then transmitted to the drive wheels and propels the vehicle. See Figure 18–1.

Cylinder Heads All engines use a cylinder head to seal the top of the cylinders, which are in the engine block. The cylinder head also contains valves that allow air and fuel into the cylinder, called intake valves and exhaust valves, which open after combustion to allow the hot gases left over to escape from the engine. Cylinder heads are constructed of cast iron or aluminum and are then machined for the valves and other valve-related components. Cooling passages are formed during the casting process and coolant is circulated around the combustion chamber to keep temperatures controlled. See Figure 18–2.

Intake and Exhaust Manifolds Air and fuel enters the engine through an intake manifold and exits the engine through the exhaust manifold. Intake manifolds operate cooler than exhaust manifolds and are therefore constructed of nylon reinforced plastic or aluminum. Exhaust manifolds must be able to withstand hot exhaust gases and therefore most are constructed from cast iron.

Cooling System All engines must have a cooling system to control engine temperatures. While some older engines were air



Figure 18–1 The rotating assembly for a V-8 engine that has eight pistons and connecting rods and one crankshaft.



Figure 18–2 A cylinder head with four valves per cylinder, two intake valves (larger) and two exhaust valves (smaller) per cylinder.



Figure 18–3 The coolant temperature is controlled by the thermostat which opens and allows coolant to flow to the radiator when the temperature reaches the rating temperature of the thermostat.

cooled, all current production passenger vehicle engines are cooled by circulating antifreeze coolant through passages in the block and cylinder head. The coolant picks up the heat from the engine and after the thermostat opens, the water pump circulates the coolant through the radiator where the excess heat is released to the outside air, cooling the coolant. The coolant is continuously circulated through the cooling system and the temperature is controlled by the thermostat. See Figure 18–3.

Lubrication System All engines contain moving and sliding parts that must be kept lubricated to reduce wear and friction. The oil pan, bolted to the bottom of the engine block, holds 4 to 7 quarts (liters) of oil. An oil pump, which is driven by the engine, forces the oil through the oil filter and then into passages in the crankshaft and block. These passages are called **oil galleries.** The oil is also thrown up to the valves and then falls down through openings in the cylinder head and block back into the oil pan. See Figure 18–4.

Fuel System and Ignition System All engines require a fuel and an ignition system to ignite the fuel–air mixture in the cylinders. The fuel system includes the following components:

- Fuel tank where fuel is stored
- Fuel filter and lines
- Fuel injectors, which spray fuel into the intake manifold or directly into the cylinder, depending on the type of system used

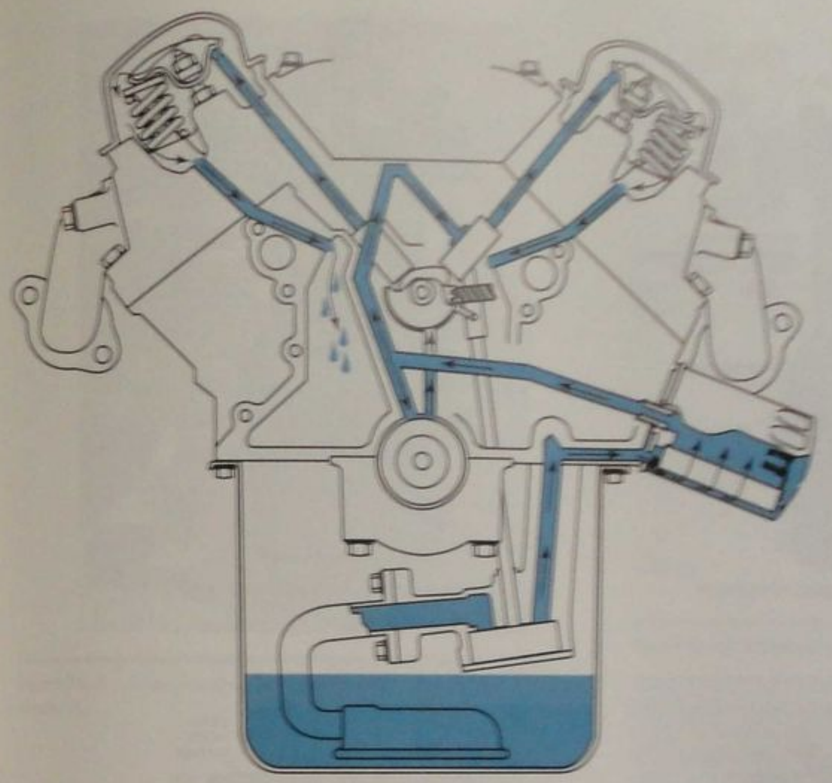


Figure 18–4 A typical lubrication system, showing the oil pan, oil pump, oil filter, and oil passages.

The ignition system is designed to take 12 volts from the battery and convert it to 5,000 to 40,000 volts needed to jump the gap of a spark plug. Spark plugs are threaded into the cylinder head of each cylinder, and when the spark occurs, it ignites the air–fuel mixture in the cylinder creating pressure and forcing the piston down in the cylinder. The components included on the ignition system include:

- Spark plugs
- Ignition coils
- Ignition control module (ICM)
- Associated wiring

FOUR-STROKE CYCLE OPERATION

Most automotive engines use the four-stroke cycle of events, begun by the starter motor which rotates the engine. The four-stroke cycle is repeated for each cylinder of the engine. See Figure 18–5.

- **Intake stroke.** The **intake valve** is open and the piston inside the cylinder travels downward, drawing a mixture of air and fuel into the cylinder.
- **Compression stroke.** As the engine continues to rotate, the intake valve closes and the piston moves upward in the cylinder, compressing the air–fuel mixture.
- **Power stroke.** When the piston gets near the top of the cylinder (called **top dead center [TDC]**), the spark at the spark plug ignites the air–fuel mixture, which forces the piston downward.
- **Exhaust stroke.** The engine continues to rotate, and the piston again moves upward in the cylinder. The exhaust valve opens, and the piston forces the residual burned gases out of the **exhaust valve** and into the exhaust manifold and exhaust system.

This sequence repeats as the engine rotates. To stop the engine, the electricity to the ignition system is shut off by the ignition switch.

A piston that moves up and down, or reciprocates, in a **cylinder** can be seen in this illustration. The piston is attached to a **crankshaft** with a **connecting rod.** This arrangement allows the piston to reciprocate (move up and down) in the cylinder as the crankshaft rotates. See Figure 18–6.

The combustion pressure developed in the combustion chamber at the correct time will push the piston downward to rotate the crankshaft.

THE 720° CYCLE

Each cycle of events requires that the engine crankshaft make two complete revolutions or 720° (360° × 2 = 720°). The greater the number of cylinders, the closer together the power strokes occur. To find the angle between cylinders of an engine, divide the number of cylinders into 720°.

Angle with three cylinders = 720°/3 = 240°
Angle with four cylinders = 720°/4 = 180°
Angle with five cylinders = 720°/5 = 144°
Angle with six cylinders = 720°/6 = 120°
Angle with eight cylinders = 720°/8 = 90°
Angle with ten cylinders = 720°/10 = 72°

This means that in a four-cylinder engine, a power stroke occurs at every 180° of the crankshaft rotation (every 1/2 rotation). A V-8 is a much smoother operating engine because a power stroke occurs twice as often (every 90° of crankshaft rotation).

Engine cycles are identified by the number of piston strokes required to complete the cycle. A **piston stroke** is a one-way piston movement between the top and bottom of the cylinder. During one stroke, the crankshaft revolves 180° (1/2 revolution). A **cycle** is a

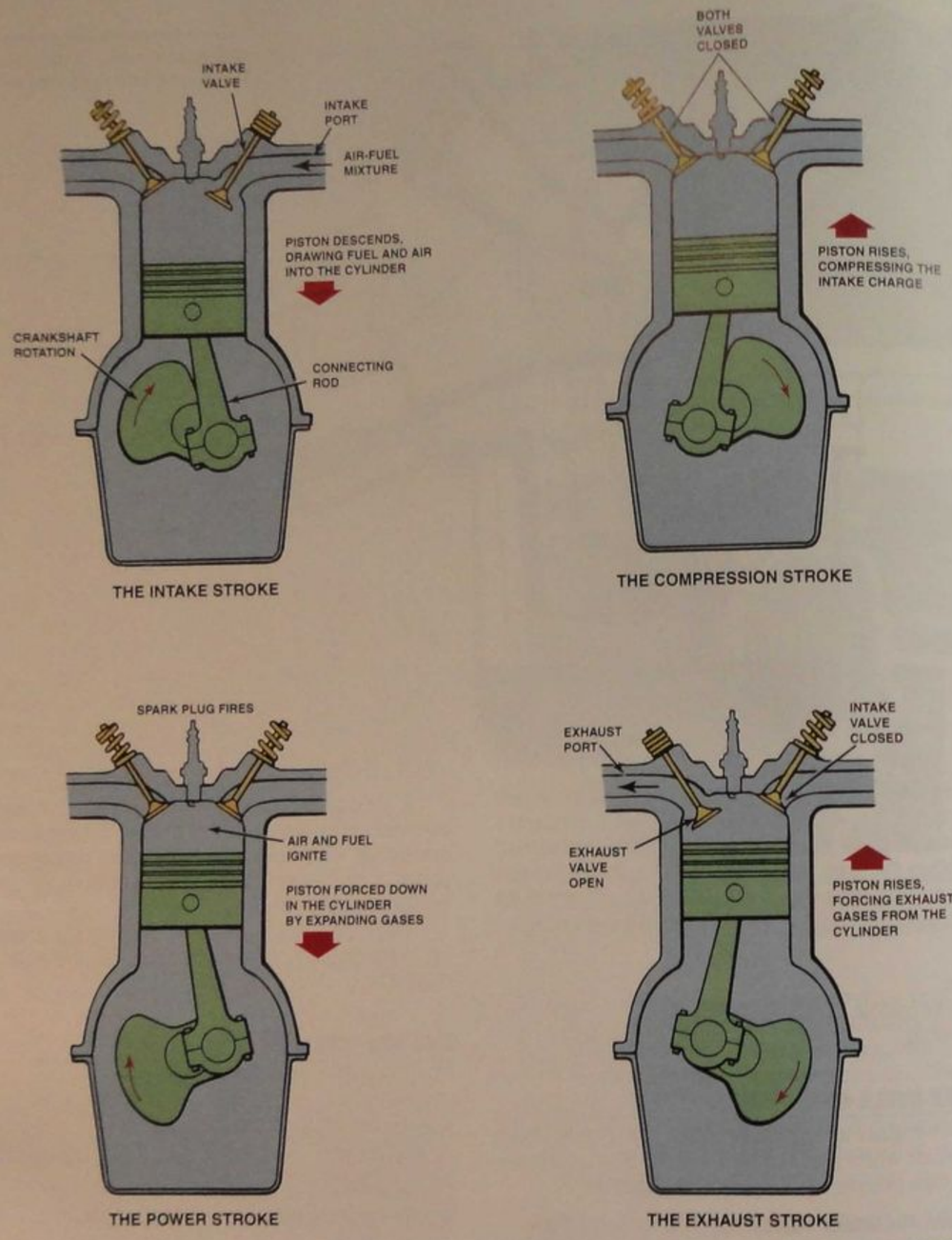


Figure 18–5 The downward movement of the piston draws the air–fuel mixture into the cylinder through the intake valve on the intake stroke. On the compression stroke, the mixture is compressed by the upward movement of the piston with both valves closed. Ignition occurs at the beginning of the power stroke, and combustion drives the piston downward to produce power. On the exhaust stroke, the upward-moving piston forces the burned gases out the open exhaust valve.

complete series of events that continually repeat. Most automobile engines use a **four-stroke cycle.**

ENGINE CLASSIFICATION AND CONSTRUCTION

Engines are classified by several characteristics including:

- **Number of strokes.** Most automotive engines use the four-stroke cycle.
- **Cylinder arrangement.** An engine with more cylinders is smoother operating because the power pulses produced by the power strokes are more closely spaced. An inline engine places all cylinders in a straight line. Four- , five- , and six-cylinder engines are commonly manufactured inline engines. A V-type engine, such as a V-6 or V-8, has the number of cylinders split and built into a V-shape. See Figure 18–7. Horizontally opposed four- and six-cylinder engines have two banks of cylinders that are horizontal, resulting in a low engine. This style of engine is used in Porsche and Subaru engines and is often called the **boxer** or **pancake** engine design. See Figure 18–8.
- **Longitudinal or transverse mounting.** Engines may be mounted either parallel with the length of the vehicle (longitudinally) or crosswise (transversely). See Figures 18–9 and 18–10. The same engine may be mounted in various vehicles in either direction.

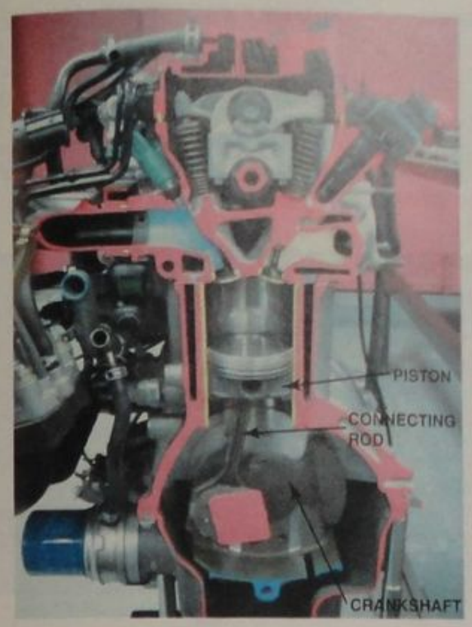


Figure 18–6 Cutaway of an engine showing the cylinder, piston, connecting rod, and crankshaft.

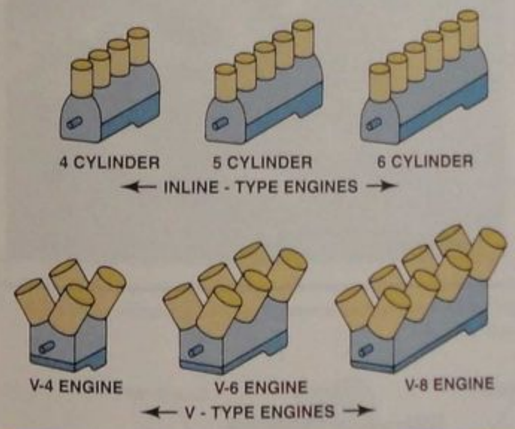


Figure 18–7 Automotive engine cylinder arrangements.

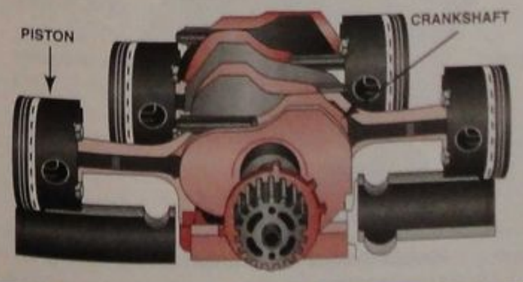


Figure 18–8 A horizontally opposed engine design helps to lower the vehicle's center of gravity.

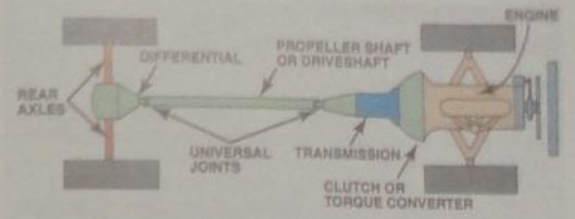


Figure 18–9 A longitudinally mounted engine drives the rear wheels through a transmission, drive shaft, and differential assembly.

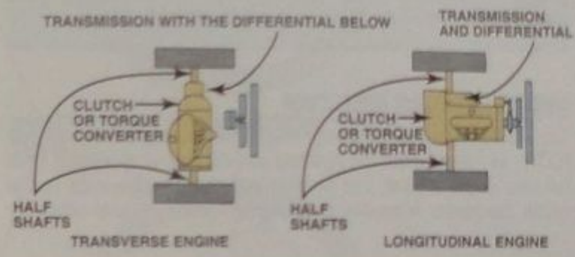


Figure 18–10 Two types of front-engine, front-wheel drive.

NOTE: Although it might be possible to mount an engine in different vehicles both longitudinally and transversely, the engine component parts may *not* be interchangeable. Differences can include different engine blocks and crankshafts, as well as different water pumps.

- **Valve and camshaft number and location.** The number of valves and the number and location of camshafts are a major factor in engine operation. A typical older model engine uses one intake valve and one exhaust valve per cylinder. Many newer engines use two intake and two exhaust valves per cylinder. The valves are opened by a **camshaft.** For high-speed engine operation, the camshaft should be overhead (over the valves). Some engines use one camshaft for the intake valves and a separate camshaft for the exhaust valves. When the camshaft is located in the block, the valves are operated by lifters, pushrods, and rocker arms. See Figure 18–11. This type of engine is called a **pushrod engine** or **cam-in-block design.** An overhead camshaft engine has the camshaft above the valves in the cylinder head. When one overhead camshaft is used, the design is called a **single overhead camshaft (SOHC)** design. When two overhead camshafts are used, the design is called a **double overhead camshaft (DOHC)** design. See Figures 18–12 and 18–13.

NOTE: A V-type engine uses two banks or rows of cylinders. An SOHC design therefore uses two camshafts, but only one camshaft per bank (row) of cylinders. A DOHC V-6, therefore, has four camshafts, two for each bank.

- **Type of fuel.** Most engines operate on gasoline, whereas some engines are designed to operate on methanol, natural gas, propane, or diesel fuel.
- **Cooling method.** Most engines are liquid cooled, but some older models were air cooled.
- **Type of induction pressure.** If atmospheric air pressure is used to force the air–fuel mixture into the cylinders, the engine is called **naturally aspirated.** Some engines use a **turbocharger** or **supercharger** to force the air–fuel mixture into the cylinder for even greater power.

FREQUENTLY ASKED QUESTION ???

What Is a Rotary Engine?

A successful alternative engine design is the **rotary engine**, also called the **Wankel engine** after its inventor. The Mazda RX-7 and RX-8 represents the only long-term use of the rotary engine. The rotating combustion chamber engine runs very smoothly, and it produces high power for its size and weight.

The basic rotating combustion chamber engine has a triangular-shaped rotor turning in a housing. The housing is in the shape of a geometric figure called a two-lobed epitrochoid. A seal on each corner, or apex, of the rotor is in constant contact with the housing, so the rotor must turn with an eccentric motion. This means that the center of the rotor moves around the center of the engine. The eccentric motion can be seen in Figure 18–14.

ENGINE ROTATION DIRECTION

The SAE standard for automotive engine rotation is counterclockwise (CCW) as viewed from the flywheel end (clockwise as viewed from the front of the engine). The flywheel end of the engine is the end to which the power is applied to drive the vehicle. This is called the **principal end** of the engine. The **nonprincipal end** of the engine is opposite the principal end and is generally referred to as the *front* of the engine, where the accessory belts are used. See Figure 18–15.

In most rear-wheel-drive vehicles, therefore, the engine is mounted longitudinally with the principal end at the rear of the engine. Most transversely mounted engines also adhere to the same standard for direction of rotation. Many Honda engines and some marine applications may differ from this standard.

FREQUENTLY ASKED QUESTION ???

Where Does an Engine Stop?

When the ignition system is turned off, the firing of the spark plugs stops and the engine will rotate until it stops due to the inertia of the rotating parts. The greatest resistance that occurs in the engine happens during the compression stroke. It has been determined that an engine usually stops when one of the cylinders is about 70 degrees before top dead center (BTDC) on the compression stroke with a variation of plus or minus 10 degrees.

This explains why technicians discover that the starter ring gear is worn at two locations on a four-cylinder engine. The engine stops at one of the two possible places depending on which cylinder is on the compression stroke.



Figure 18–11 Cutaway of a V-8 engine showing the lifters, pushrods, roller rocker arms, and valves.

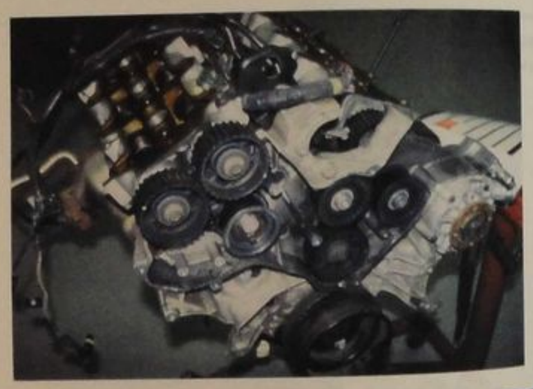


Figure 18–13 A dual overhead comshaft (DOHC) V-8 engine with the cam cover removed.

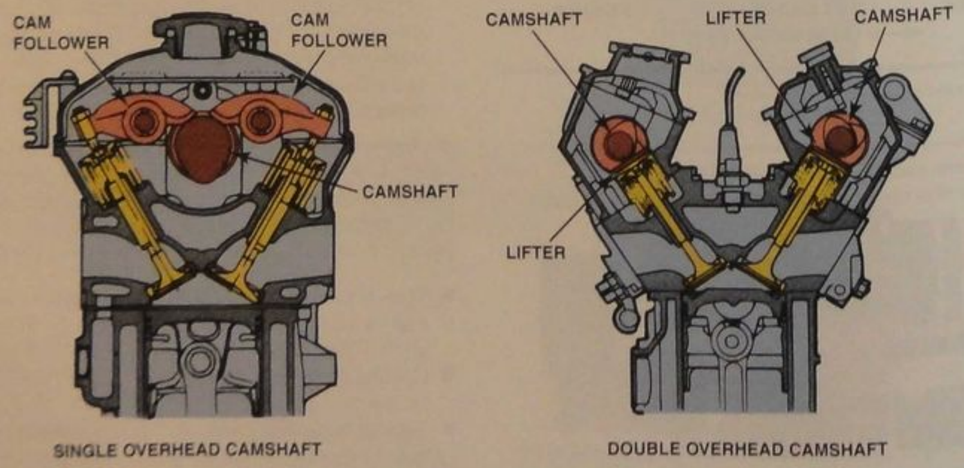


Figure 18–12 SOHC engines usually require additional components such as a rocker arm to operate all of the valves. DOHC engines often operate the valves directly.

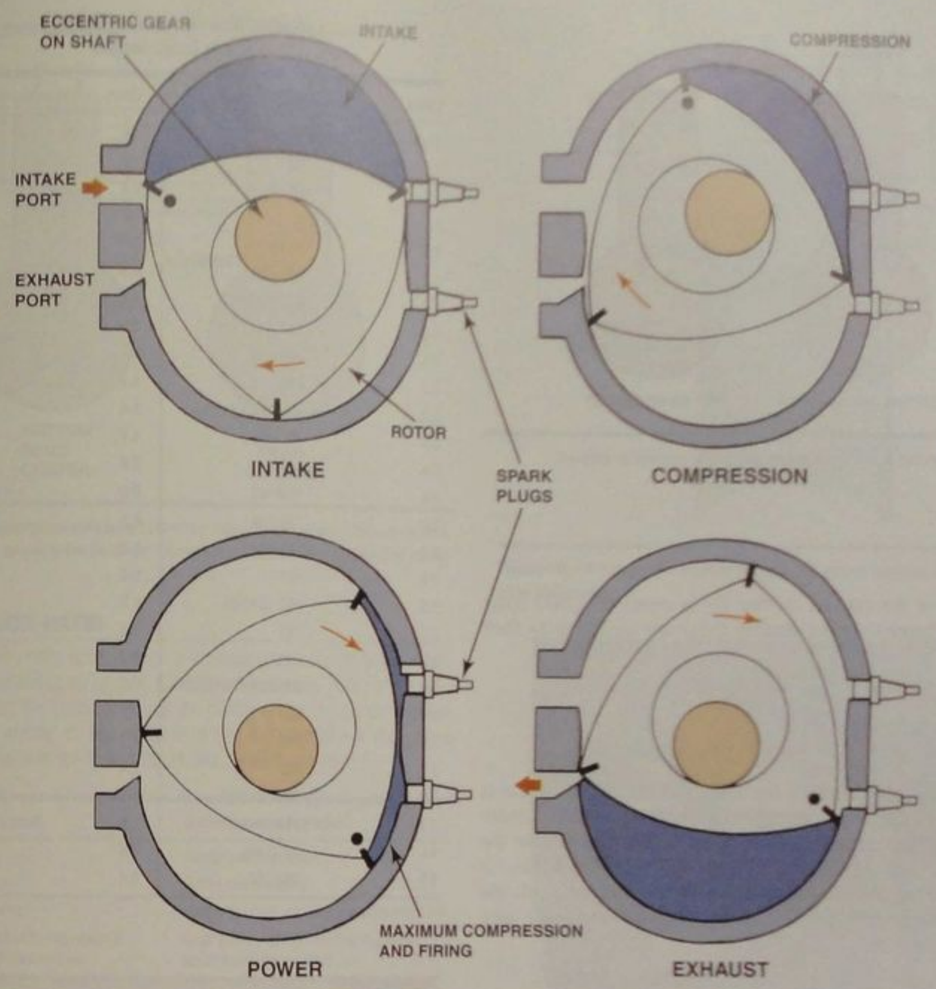


Figure 18–14 Rotary engine operates on the four-stroke cycle but uses a rotor instead of a piston and crankshaft to achieve intake, compression, power, and exhaust stroke.

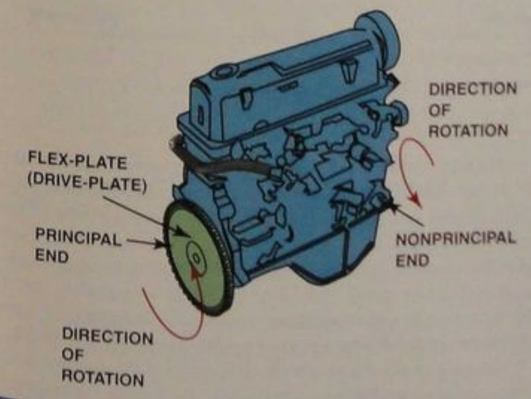


Figure 18–15 Inline four-cylinder engine showing principal and nonprincipal ends. Normal direction of rotation is clockwise (CW) as viewed from the front or accessory belt end (nonprincipal end).

BORE

The diameter of a cylinder is called the **bore.** The larger the bore, the greater the area on which the gases have to work. Pressure is measured in units, such as pounds per square inch (PSI). The greater the area (in square inches), the higher the force exerted by the pistons to rotate the crankshaft. See Figure 18–16.

STROKE

The distance the piston travels down in the cylinder is called the **stroke.** The longer this distance is, the greater the amount of air–fuel mixture that can be drawn into the cylinder. The more air–fuel mixture inside the cylinder, the more force will result when the mixture is ignited.

ENGINE DISPLACEMENT

Engine size is described as displacement. **Displacement** is the cubic inch (cu. in.) or cubic centimeter (cc) volume displaced or

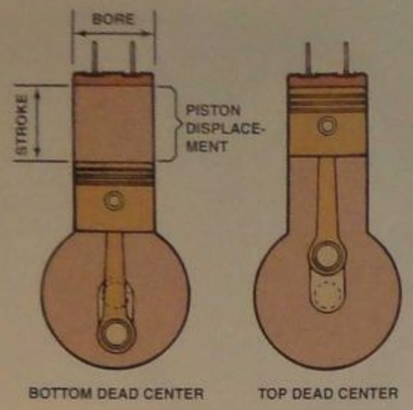


Figure 18–16 The bore and stroke of pistons are used to calculate an engine's displacement.

swept by all of the pistons. A liter (L) is equal to 1,000 cubic centimeters; therefore, most engines today are identified by their displacement in liters.

1 L = 1,000 cc

1 L = 61 cu. in.

1 cu. in. = 16.4 cc

The formula to calculate the displacement of an engine is basically the formula for determining the volume of a cylinder multiplied by the number of cylinders. However, because the formula has been publicized in many different forms, it seems somewhat confusing. Regardless of the method used, the results will be the same. The easiest and most commonly used formula is

Bore × bore × stroke × 0.7854 × number of cylinders

For example, take a 6-cylinder engine where, bore = 4.000 in., stroke = 3.000 in. Applying the formula,

4.000 in. × 4.000 in. × 3.000 in. × 0.7854 × 6 = 226 cu. in.

Because 1 cubic inch equals 16.4 cubic centimeters, this engine displacement equals 3,706 cubic centimeters or, rounded to 3,700 cubic centimeters, 3.7 liters.

How to convert cubic inches to liters: 61.02 cubic inches = 1 liter

Example:

From liter to cubic inch—5.0 L × 61.02 = 305 CID
From cubic inch to liter—305 ÷ 61.02 = 5.0 L

Engine Size versus Horsepower The larger the engine, the more power the engine is capable of producing. Several sayings are often quoted about engine size:

"There is no substitute for cubic inches."

"There is no replacement for displacement."

Although a large engine generally uses more fuel, making an engine larger is often the easiest way to increase power.

Engine Size Conversion Chart
Liters to Cubic Inches

Liters	Cubic Inches	Liters	Cubic Inches
1.0	61	4.2	255/258
1.3	79	4.3	260/262/265
1.4	85	4.4	267
1.5	91	4.5	273
1.6	97/98	4.6	280/281
1.7	105	4.8	292
1.8	107/110/112	4.9	300/301
1.9	116	5.0	302/304/305/307
2.0	121/122	5.2	318
2.1	128	5.3	327
2.2	132/133/134/135	5.4	330
2.3	138/140	5.7	350
2.4	149	5.8	351
2.5	150/153	6.0	366/368
2.6	156/159	6.1	370
2.8	171/173	6.2	381
2.9	177	6.4	389/390/391
3.0	181/182/183	6.5	396
3.1	191	6.6	400
3.2	196	6.9	420
3.3	200/201	7.0	425/427/428/429
3.4	204	7.2	440
3.5	215	7.3	445
3.7	225	7.4	454
3.8	229/231/232	7.5	460
3.9	239/240	7.8	475/477
4.0	241/244	8.0	488
4.1	250/252	8.8	534

TECH TIP ✔ **All 3.8-Liter Engines Are Not the Same!**

Most engine sizes are currently identified by displacement in liters. However, not all 3.8-liter engines are the same. See, for example, the following table:

Engine	Displacement
Chevrolet-built 3.8-L, V-6	229 cu. in.
Buick-built 3.8-L, V-6 (also called 3,800 cc)	231 cu. in.
Ford-built 3.8-L, V-6	232 cu. in.

The exact conversion from liters (or cubic centimeters) to cubic inches is 231.9 cubic inches. However, due to rounding of exact cubic-inch displacement and rounding of the exact cubic-centimeter volume, several entirely different engines can be marketed with the exact same liter designation. To reduce confusion and reduce the possibility of ordering incorrect parts, the vehicle identification number (VIN) should be noted for the vehicle being serviced. The VIN should be visible through the windshield on all vehicles. Since 1980, the engine identification number or letter is usually the eighth digit or letter from the left.

Smaller, 4-cylinder engines can also cause confusion because many vehicle manufacturers use engines from both overseas and domestic manufacturers. Always refer to service manual information to be assured of correct engine identification.

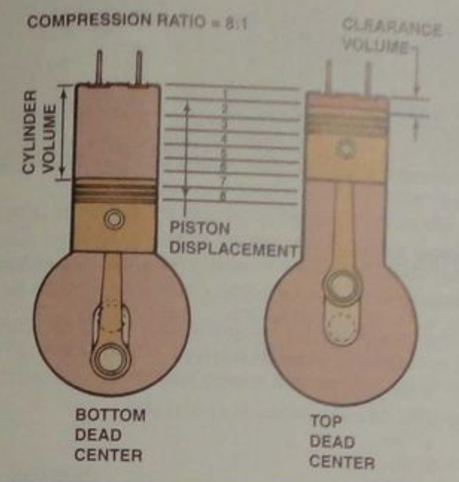


Figure 18–17 Compression ratio is the ratio of the total cylinder volume (when the piston is at the bottom of its stroke) to the clearance volume (when the piston is at the top of its stroke).

COMPRESSION RATIO

The compression ratio of an engine is an important consideration when rebuilding or repairing an engine. **Compression ratio (CR)** is the ratio of the volume in the cylinder above the piston when the piston is at the bottom of the stroke to the volume in the cylinder above the piston when the piston is at the top of the stroke. See Figure 18–17.

If Compression Is Lower	If Compression Is Higher
Lower power	Higher power possible
Poorer fuel economy	Better fuel economy
Easier engine cranking	Harder to crank engine, especially when hot
More advanced ignition timing possible without spark knock (detonation)	Less ignition timing required to prevent spark knock (detonation)

$$CR = \frac{\text{Volume in cylinder with piston at bottom of cylinder}}{\text{Volume in cylinder with piston at top center}}$$

See Figure 18–18.

For example: What is the compression ratio of an engine with 50.3-cu. in. displacement in one cylinder and a combustion chamber volume of 6.7 cu. in.?

$$CR = \frac{50.3 + 6.7 \text{ cu. in.} = 57.0}{6.7 \text{ cu. in.}} = 8.5$$

THE CRANKSHAFT DETERMINES THE STROKE

The stroke of an engine is the distance the piston travels from top dead center (TDC) to bottom dead center (BDC). This distance is determined by the throw of the crankshaft. The throw is the distance from the centerline of the crankshaft to the centerline of the crankshaft rod journal. The throw is one-half of the stroke. See Figure 18–19 for an example of a crankshaft as installed in a GM V-6 engine.

If the crankshaft is replaced with one with a greater stroke, the pistons will be pushed up over the height of the top of the block (deck). The solution to this problem is to install replacement pistons with the piston pin relocated higher on the piston. Another alternative is to replace the connecting rod with a shorter one to prevent the piston from traveling too far up in the cylinder. Changing the connecting rod length does *not* change the stroke of an engine. Changing the connecting rod only changes the position of the piston in the cylinder.

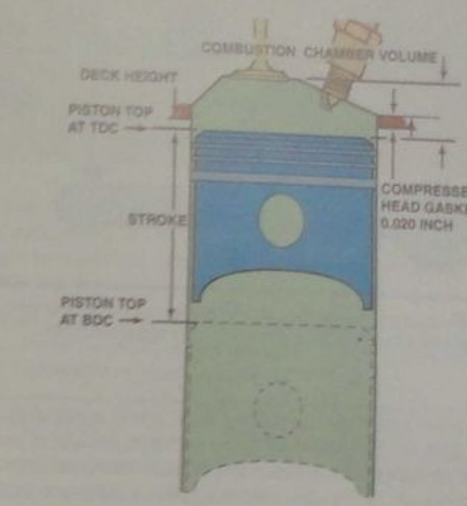


Figure 18–18 Combustion chamber volume is the volume above the piston with the piston at top dead center.



Figure 18–19 The distance between the centerline of the main bearing journal and the centerline of the connecting rod journal determines the stroke of the engine. This photo is a little unusual because this is from a V-6 with a splayed crankshaft used to even out the impulses on a 90°, V-6 engine design.

TORQUE

Torque is the term used to describe a rotating force that may or may not result in motion. Torque is measured as the amount of force multiplied by the length of the lever through which it acts. If a one-foot-long wrench is used to apply 10 pounds of force to the end of the wrench to turn a bolt, then you are exerting 10 pound-feet of torque. See Figure 18–20.

The metric unit for torque is Newton-meters because Newton is the metric unit for force and the distance is expressed in meters.

one pound-foot = 1.3558 Newton-meters

one Newton-meter = 0.7376 pound-foot

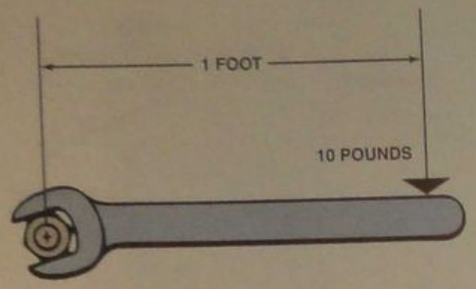


Figure 18–20 Torque is a twisting force equal to the distance from the pivot point times the force applied expressed in units called pound-feet (lb-ft) or Newton-meters (N-m).

POWER

The term power means the rate of doing work. Power equals work divided by time. Work is achieved when a certain amount of mass (weight) is moved a certain distance by a force. If the object is moved in 10 seconds or 10 minutes does not make a difference in the amount of work accomplished, but it does affect the amount of power needed. Power is expressed in units of foot-pounds per minute.

HORSEPOWER AND ALTITUDE

Because the density of the air is lower at high altitude, the power that a normal engine can develop is greatly reduced at high altitude. According to SAE conversion factors, a nonsupercharged or nonturbocharged engine loses about 3% of its power for every 1,000 feet (300 meters [m]) of altitude.

Therefore, an engine that develops 150 brake horsepower at sea level will only produce about 85 brake horsepower at the top of Pike's Peak in Colorado at 14,110 feet (4,300 meters). Supercharged and turbocharged engines are not as greatly affected by altitude as normally aspirated engines. Normally aspirated, remember, means engines that breathe air at normal atmospheric pressure.

TECH TIP ✔ **Quick-and-Easy Engine Efficiency Check**

A good, efficient engine is able to produce a lot of power from little displacement. A common rule of thumb is that an engine is efficient if it can produce *1 horsepower per cubic inch* of displacement. Many engines today are capable of this feat, such as the following:

Ford	4.6-L V-8 (281 cu. in.)—305 hp
Chevrolet	3.4-L V-6 (207 cu. in.)—210 hp
Chrysler	3.5-L V-6 (214 cu. in.)—214 hp
Acura	3.2-L V-6 (195 cu. in.)—270 hp

An engine is very powerful for its size if it can produce *100 hp per liter*. This efficiency goal is harder to accomplish. Most factory stock engines that can achieve this feat are supercharged or turbocharged.

SUMMARY

1. The four strokes of the four-stroke cycle are intake, compression, power, and exhaust.
2. Engines are classified by number and arrangement of cylinders and by number and location of valves and camshafts, as well as by type of mounting, fuel used, cooling method, and induction pressure.
3. Most engines rotate clockwise as viewed from the front (accessory) end of the engine. The SAE standard is counterclockwise as viewed from the principal (flywheel) end of the engine.
4. Engine size is called displacement and represents the volume displaced or swept by all of the pistons.

REVIEW QUESTIONS

1. Name the strokes of a four-stroke cycle.
2. If an engine at sea level produces 100 horsepower, how many horsepower would it develop at 6,000 feet of altitude?

CHAPTER QUIZ

1. All overhead valve engines _____.
   a. Use an overhead camshaft
   b. Have the overhead valves in the head
   c. Operate by the two-stroke cycle
   d. Use the camshaft to close the valves
2. An SOHC V-8 engine has how many camshafts?
   a. One
   b. Two
   c. Three
   d. Four
3. The coolant flow through the radiator is controlled by the _____.
   a. Size of the passages in the block
   b. Thermostat
   c. Cooling fan(s)
   d. Water pump
4. Torque is expressed in units of _____.
   a. Pound-feet
   b. Foot-pounds
   c. Foot-pounds per minute
   d. Pound-feet per second
5. Horsepower is expressed in units of _____.
   a. Pound-feet
   b. Foot-pounds
   c. Foot-pounds per minute
   d. Pound-feet per second
6. A normally aspirated automobile engine loses about _____ power per 1,000 feet of altitude.
   a. 1%
   b. 3%
   c. 5%
   d. 6%
7. One cylinder of an automotive four-stroke cycle engine completes a cycle every _____.
   a. 90°
   b. 180°
   c. 360°
   d. 720°
8. How many rotations of the crankshaft are required to complete each stroke of a four-stroke cycle engine?
   a. One-fourth
   b. One-half
   c. One
   d. Two
9. A rotating force is called _____.
   a. Horsepower
   b. Torque
   c. Combustion pressure
   d. Eccentric movement
10. Technician A says that a crankshaft determines the stroke of an engine. Technician B says that the length of the connecting rod determines the stroke of an engine. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 19 Diesel Engine Operation and Diagnosis

OBJECTIVES: **After studying Chapter 19, the reader will be able to:** Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Explain how a diesel engine works. • Describe the difference between direct injection (DI) and indirect injection (IDI) diesel engines. • List the parts of the typical diesel engine fuel system. • Explain how glow plugs work. • List the advantages and disadvantages of a diesel engine. • Describe how diesel fuel is rated and tested.

KEY TERMS: API gravity • cetane number • cloud point • diesel oxidation catalyst (DOC) • differential pressure sensor (DPS) • Direct injection (DI) • flash point • glow plug • heat of compression • high-pressure common rail (HPCR) • hydraulic electronic unit injection (HEUI) • indirect injection (IDI) • injection pump • lift pump • opacity • pop tester • regeneration • water-fuel separator

DIESEL ENGINES

In 1892, a German engineer named Rudolf Diesel perfected the compression-ignition engine that bears his name. The diesel engine uses heat created by compression to ignite the fuel, so it requires no spark ignition system.

The diesel engine requires compression ratios of 16:1 and higher. Incoming air is compressed until its temperature reaches about 1000°F (540°C). This is called **heat of compression.** As the piston reaches the top of its compression stroke, fuel is injected into the cylinder, where it is ignited by the hot air. See Figure 19–1.

As the fuel burns, it expands and produces power. Because of the very high compression and torque output of a diesel engine, it is made heavier and stronger than the same size gasoline-powered engine.

A common diesel engine uses a fuel system precision **injection pump** and individual fuel injectors. The pump delivers fuel to the injectors at a high pressure and at timed intervals. Each injector sprays fuel into the combustion chamber at the precise moment required for efficient combustion. See Figure 19–2.

In a diesel engine, air is not controlled by a throttle as in a gasoline engine. Instead, the amount of fuel injected is varied to control power and speed. The air–fuel mixture of a diesel can vary from as lean as 85:1 at idle to as rich as 20:1 at full load. This higher air–fuel ratio and the increased compression pressures make the diesel more fuel-efficient than a gasoline engine in part because diesel engines do not suffer from throttling losses. Throttling losses involve the power needed in a gasoline engine to draw air past a closed or partially closed throttle.

In a gasoline engine, the speed and power are controlled by the throttle valve, which controls the amount of air entering the engine. Adding more fuel to the cylinders of a gasoline engine without adding more air (oxygen) will not increase the speed or power of the engine. In a diesel engine, speed and power are not controlled by the amount of air entering the cylinders because the engine air intake is always wide open. Therefore, the engine always has enough oxygen to burn the fuel in the cylinder and will increase speed (and power) when additional fuel is supplied.

Diesel engines are built in both two-stroke and four-stroke versions. The most common two-stroke diesels were the truck and industrial engines made by Detroit Diesel. In these engines, air intake is through ports in the cylinder wall. Exhaust is through poppet valves in the head. A blower pushes air into the air box surrounding liner ports to supply air for combustion and to blow the exhaust gases out of the exhaust valves.

Indirect and Direct Injection In an **indirect injection** (abbreviated **IDI**) diesel engine, fuel is injected into a small prechamber, which is connected to the cylinder by a narrow opening. The initial combustion takes place in this prechamber. This has the effect of slowing the rate of combustion, which tends to reduce noise. See Figure 19–3.

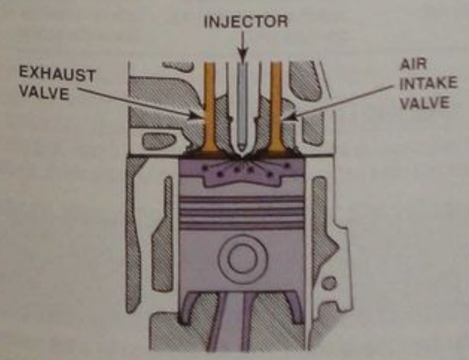


Figure 19–1 Diesel combustion occurs when fuel is injected into the hot, highly compressed air in the cylinder.

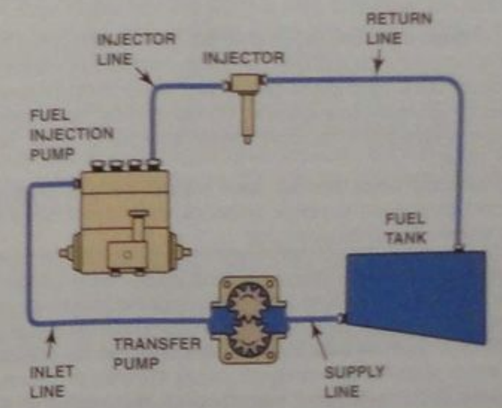


Figure 19–2 A typical injector-pump-type automotive diesel fuel injection system.

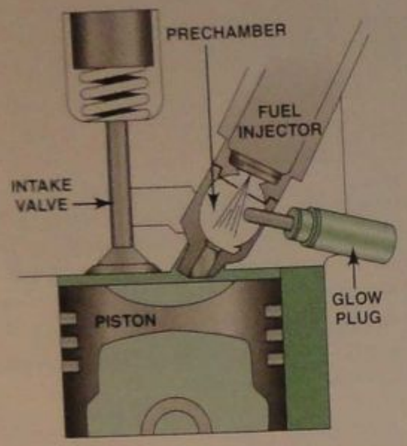


Figure 19–3 An indirect injection diesel engine uses a prechamber and a glow plug.

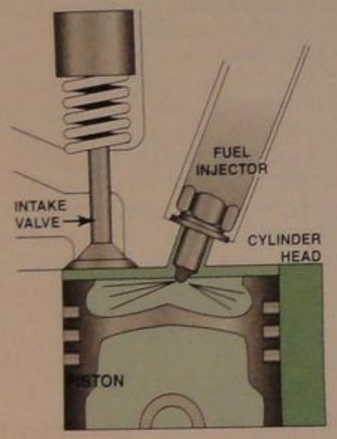


Figure 19–4 A direct injection diesel engine injects the fuel directly into the combustion chamber. Many designs do not use a glow plug.

All indirect diesel injection engines require the use of a glow plug.

In a **direct injection** (abbreviated **DI**) diesel engine, fuel is injected directly into the cylinder. The piston incorporates a depression where initial combustion takes place. Direct injection diesel engines are generally more efficient than indirect injection engines, but have a tendency to produce greater amounts of noise. See Figure 19–4.

While some direct injection diesel engines use glow plugs to help cold starting and to reduce emissions, many direct injection diesel engines do not use glow plugs.

Diesel Fuel Ignition Ignition occurs in a diesel engine by injecting fuel into the air charge, which has been heated by compression to a temperature greater than the ignition point of the fuel or about 1000°F (538°C). The chemical reaction of burning the fuel liberates heat, which causes the gases to expand, forcing the piston to rotate the crankshaft. A four-stroke diesel engine requires two rotations of the crankshaft to complete one cycle. On the intake stroke, the piston passes TDC, the intake valve(s) open, the fresh air is admitted into the cylinder, and the exhaust valve is still open for a few degrees to allow all of the exhaust gases to escape. On the compression stroke, after the piston passes BDC, the intake valve closes and the piston travels up to TDC (completion of the first crankshaft rotation). On the power stroke, the piston nears TDC on the compression stroke, the diesel fuel is injected by the injectors, and the fuel starts to burn, further heating the gases in the cylinder. During this power stroke, the piston passes TDC and the expanding gases force the piston down, rotating the crankshaft. On the exhaust stroke, as the piston passes BDC, the exhaust valves open and the exhaust gases start to flow out of the cylinder. This continues as the piston travels up to TDC, pumping the spent gases out of the cylinder. At TDC, the second crankshaft rotation is complete.

THREE PHASES OF COMBUSTION

There are three distinct phases or parts to the combustion in a diesel engine.

1. **Ignition delay.** Near the end of the compression stroke, fuel injection begins, but ignition does not begin immediately. This period is called delay.
2. **Rapid combustion.** This phase of combustion occurs when the fuel first starts to burn, creating a sudden rise in cylinder pressure. It is this rise in combustion chamber pressure that causes the characteristic diesel engine knock.
3. **Controlled combustion.** After the rapid combustion occurs, the rest of the fuel in the combustion chamber begins to burn and injection continues. This is an area near the injector that contains fuel surrounded by air. This fuel burns as it mixes with the air.

DIESEL ENGINE CONSTRUCTION

Diesel engines must be constructed heavier than gasoline engines because of the tremendous pressures that are created in the cylinders during operation. The torque output of a diesel engine is often double or more than the same size gasoline powered engines. See the comparison chart.

System or Component	Diesel Engine	Gasoline Engine
Block	Cast iron and heavy See Figure 19–5.	Cast iron or aluminum and as light as possible
Cylinder head	Cast iron or aluminum	Cast iron or aluminum
Compression ratio	17:1 to 25:1	8:1 to 12:1
Peak engine speed	2,000 to 2,500 RPM	5,000 to 8,000 RPM
Pistons and connecting rods	Aluminum with combustion pockets and heavy-duty rods See Figure 19–6.	Aluminum, usually flat top or with valve relief but no combustion pockets

FUEL TANK AND LIFT PUMP

A fuel tank used on a vehicle equipped with a diesel engine differs from the one used with a gasoline engine in several ways, including:

- A larger filler neck for diesel fuel. Gasoline filler necks are smaller for the unleaded gasoline nozzle.
- No evaporative emission control devices or charcoal (carbon) canister. Diesel fuel is not as volatile as gasoline and, therefore, diesel vehicles do not have evaporative emission control devices.

The diesel fuel is drawn from the fuel tank by a **lift pump** and delivers the fuel to the injection pump. Between the fuel tank and the lift pump is a **water-fuel separator.** Water is heavier than diesel fuel and sinks to the bottom of the separator. Part of normal

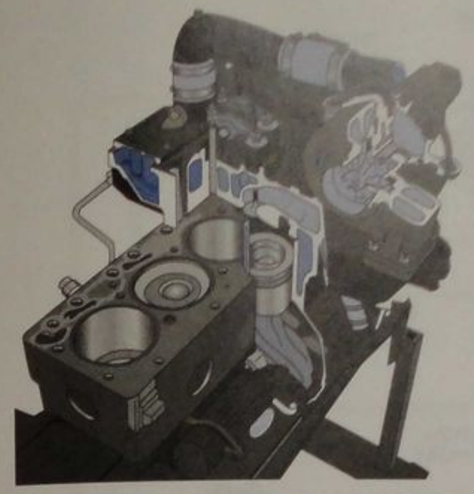


Figure 19–5 The common rail on a Cummins diesel engine. A high-pressure pump (up to 30,000 PSI) is used to supply diesel fuel to this common rail, which has cubes running to each injector. Note the thick cylinder walls and heavy-duty construction.



Figure 19–6 A rod/piston assembly from a 5.9-liter Cummins diesel engine used in a Dodge pickup truck.

routine maintenance on a vehicle equipped with a diesel engine is to drain the water from the water-fuel separator. A float is usually used inside the separator, which is connected to a warning light on the dash that lights if the water reaches a level where it needs to be drained.

NOTE: Water can cause corrosive damage as well as wear to diesel engine parts because water is not a good lubricant. Water cannot be atomized by a diesel fuel injector nozzle and will often "blow out" the nozzle tip.

Many diesel engines also use a fuel temperature sensor. The computer uses this information to adjust fuel delivery based on the density of the fuel. See Figure 19–7.

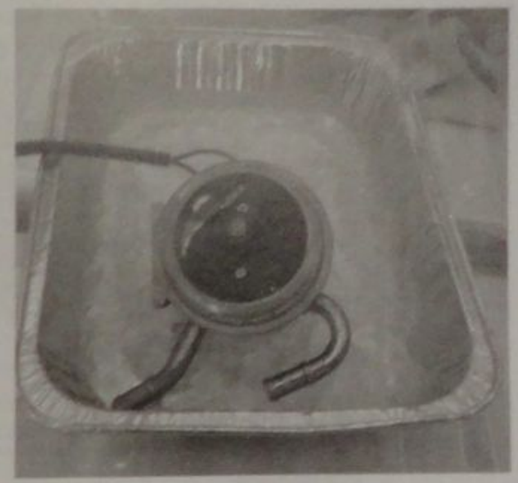


Figure 19–7 Using an ice bath to test the fuel temperature sensor.



Figure 19–8 A typical distributor-type diesel injection pump showing the pump, lines, and fuel filter.

INJECTION PUMP

A diesel engine injection pump is used to increase the pressure of the diesel fuel from very low values from the lift pump to the extremely high pressures needed for injection.

Injection pumps are usually driven by the camshaft at the front of the engine. As the injection pump shaft rotates, the diesel fuel is fed from a fill port to a high-pressure chamber. If a distributor-type injection pump is used, the fuel is forced out of the injection port to the correct injector nozzle through the high-pressure line. See Figure 19–8.

NOTE: Because of the very tight tolerances in a diesel engine, the smallest amount of dirt can cause excessive damage to the engine and to the fuel injection system.

Distributor Injection Pump A distributor diesel injection pump is a high-pressure pump assembly with lines leading to each individual injector. The high-pressure lines between the distributor and

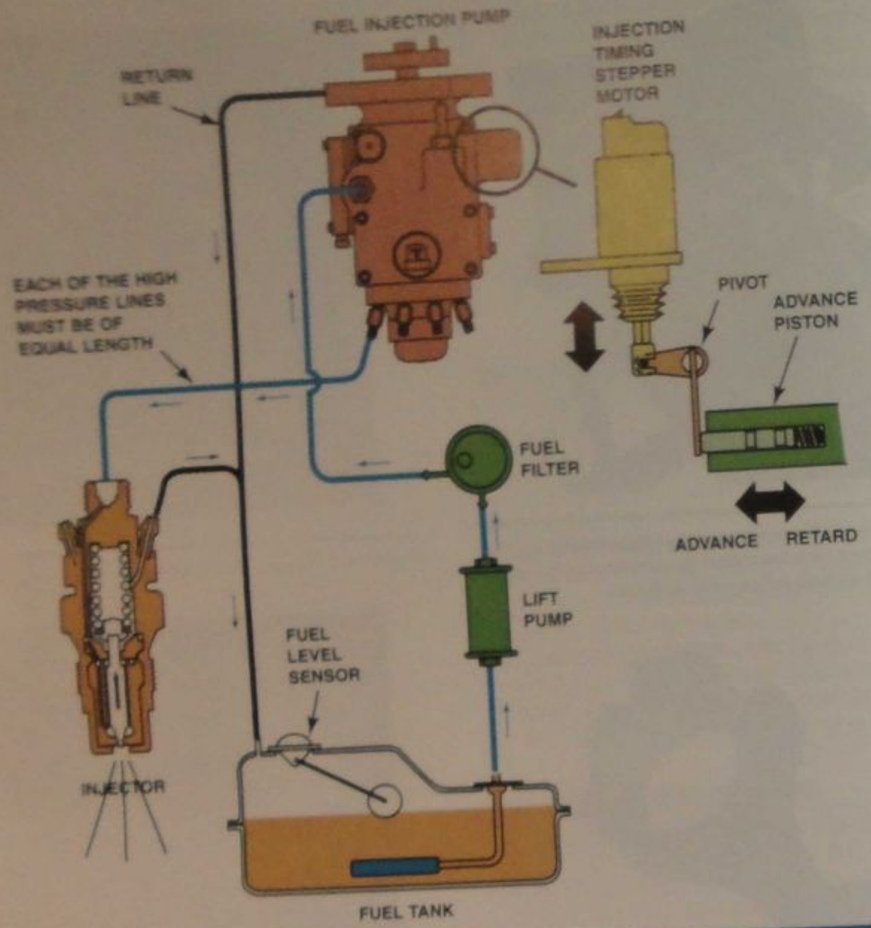


Figure 19–9 A schematic of a Stanadyne diesel fuel injection pump assembly showing all of the related components. *(Courtesy of Stanadyne Corporation)*

the injectors must be the exact same length to ensure proper injection timing. The injection pump itself creates the injection advance needed for engine speeds above idle and the fuel is discharged into the lines. The high-pressure fuel causes the injectors to open. Due to the internal friction of the lines, there is a slight delay before fuel pressure opens the injector nozzle. See Figure 19–9.

NOTE: The lines expand some during an injection event. This is how timing checks are performed. The pulsing of the injector line is picked up by a sensor used to detect the injection event similar to a timing light used to detect a spark on a gasoline engine.

High-Pressure Common Rail Newer diesel engines use a fuel delivery system referred to as a **high-pressure common rail (HPCR)** design. Diesel fuel under high pressure, over 20,000 PSI (138,000 kPa), is applied to the injectors, which are opened by a solenoid controlled by the computer. Because the injectors are computer controlled, the combustion process can be precisely controlled to provide maximum engine efficiency with the lowest possible noise and exhaust emissions. See Figure 19–10.

HEUI SYSTEM

Ford 7.3- and 6.0-liter diesels use a system Ford calls a **Hydraulic Electronic Unit Injection** system, or **HEUI** system. The components that replace the traditional mechanical injection pump include a high-pressure oil pump and reservoir, pressure regulator for the oil, and passages in the cylinder head for flow of fuel to the injectors.

Fuel is drawn from the tank by the tandem fuel pump which circulates fuel at low pressure through the fuel filter/water separator/fuel heater bowl and then fuel is directed back to the fuel pump where fuel is pumped at high pressure into the cylinder head fuel galleries. The injectors, which are hydraulically actuated by the oil pressure from the high-pressure oil pump, are then fired by the power train control module (PCM). The control system for the fuel injectors is the PCM and the injectors are fired based on various inputs received by the PCM. See Figure 19–11.

HEUI injectors rely on O-rings to keep fuel and oil from mixing or escaping, causing performance problems or engine damage. HEUI injectors use five O-rings. The three external O-rings should be replaced with updated O-rings if they fail. The two internal O-rings are not replaceable and if these fail, the injector or injectors must be replaced. The most common symptoms of injector O-ring trouble include:

- Oil getting in the fuel
- The fuel filter element turning black
- Long cranking times before starting
- Sluggish performance

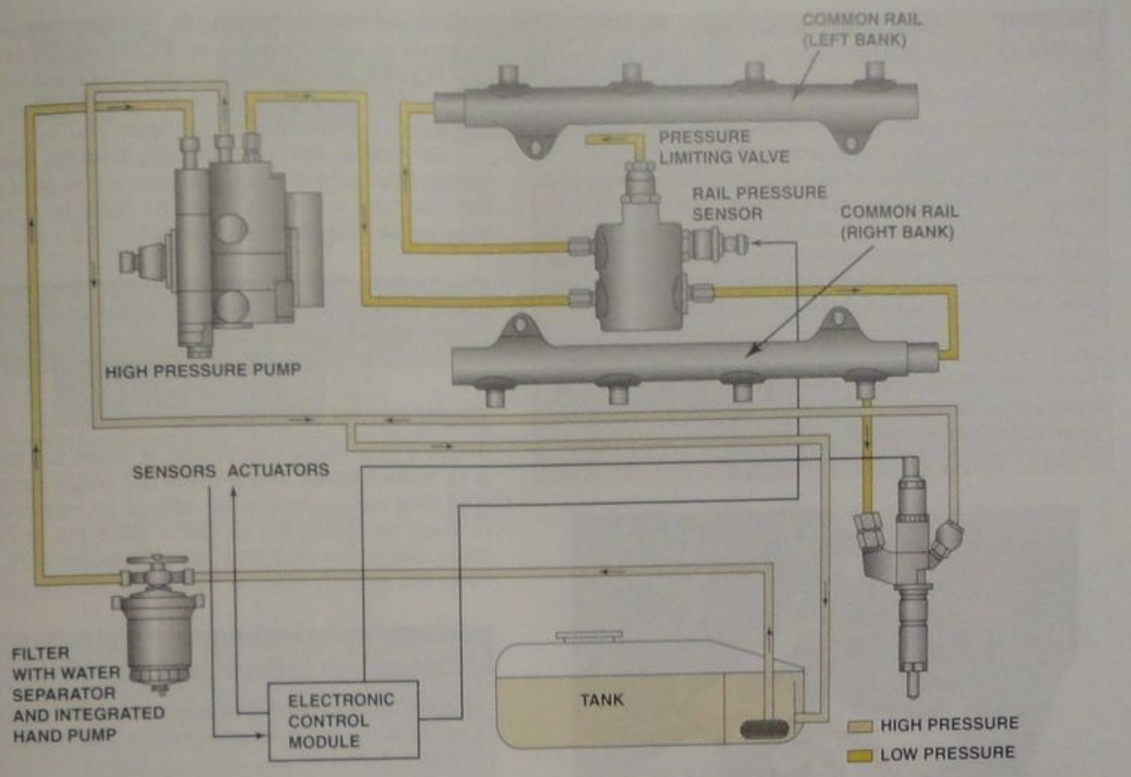


Figure 19–10 Over view of a computer-controlled high-pressure common rail V-8 diesel engine.



Figure 19–11 A HEUI injector from a Ford PowerStroke diesel engine. The grooves indicate the location of the O-rings.

- Reduction in power
- Increased oil consumption often accompanies O-ring problems or any fault that lets fuel in the oil

DIESEL INJECTOR NOZZLES

Diesel injector nozzles are spring-loaded closed valves that spray fuel directly into the combustion chamber or precombustion chamber. Injector nozzles are threaded into the cylinder head, one for each cylinder, and are replaceable as an assembly.

TECH TIP ✓ **Change Oil Regularly in a Ford Diesel Engine**

Ford 7.3- and 6.0-liter diesel engines pump unfiltered oil from the sump to the high-pressure oil pump and then to the injectors. This means that not changing oil regularly can contribute to accumulation of dirt in the engine and will subject the fuel injectors to wear and potential damage as particles suspended in the oil get forced into the injectors.

The top of the injector nozzle has many holes to deliver an atomized spray of diesel fuel into the cylinder. Parts of a diesel injector nozzle include:

- **Heat shield.** This is the outer shell of the injector nozzle and has external threads where it seals in the cylinder head.
- **Injector body.** This is the inner part of the nozzle and contains the injector needle valve and spring, and threads into the outer heat shield.
- **Diesel injector needle valve.** This precision machined valve and the tip of the needle seal against the injector body when it is closed. When the valve is open, diesel fuel is sprayed into the combustion chamber. This passage is controlled by a solenoid on diesel engines equipped with computer-controlled injection.
- **Injector pressure chamber.** The pressure chamber is a machined cavity in the injector body around the tip of the injector needle. Injection pump pressure forces fuel into this chamber, forcing the needle valve open.

TECH TIP ✓ **Never Allow a Diesel Engine to Run Out of Fuel**

If a gasoline-powered vehicle runs out of gasoline, it is an inconvenience and a possible additional expense to get some gasoline. However, if a vehicle equipped with a diesel engine runs out of fuel, it can be a major concern.

Besides adding diesel fuel to the tank, the other problem is getting all of the air out of the pump, lines, and injectors so the engine will operate correctly.

The procedure usually involves cranking the engine long enough to get liquid diesel fuel back into the system, but at the same time keeping cranking time short enough to avoid overheating the starter. Consult service information for the exact service procedure if the diesel engine is run out of fuel.

NOTE: Some diesel engines such as the first generation General Motors Duramax V-8 are equipped with a priming pump located under the hood on top of the fuel filter. Pushing down and releasing the priming pump with a vent valve open will purge any trapped air from the system. Always follow the vehicle manufacturer's instructions.



Figure 19–12 Typical computer-controlled diesel engine fuel injectors.

DIESEL INJECTOR NOZZLE OPERATION

The electric solenoid attached to the injector nozzle is computer controlled and opens to allow fuel to flow into the injector pressure chamber. See Figure 19–12.

The diesel injector nozzle is mechanically opened by the high-pressure fuel delivered to the nozzle by the injector pump. The fuel flows down through a fuel passage in the injector body and into the pressure chamber. The high fuel pressure in the pressure chamber forces the needle valve upward, compressing the needle valve return spring and forcing the needle valve open. When the needle valve opens, diesel fuel is discharged into the combustion chamber in a hollow cone spray pattern.

Any fuel that leaks past the needle valve returns to the fuel tank through a return passage and line.

GLOW PLUGS

Glow plugs are always used in diesel engines equipped with a precombustion chamber and may be used in direct injection diesel engines to aid starting. A **glow plug** is a heating element that uses 12 volts from the battery and aids in the starting of a cold engine. As the temperature of the glow plug increases, the resistance of the heating element inside increases, thereby reducing the current in amperes needed by the glow plugs.

Most glow plugs used in newer vehicles are controlled by the power train control module (PCM), which monitors coolant temperature and intake air temperature. The glow plugs are turned on or pulsed on or off depending on the temperature of the engine. The PCM will also keep the glow plug turned on after the engine starts to reduce white exhaust smoke (unburned fuel) and to improve idle quality after starting. See Figure 19–13.

The "wait to start" lamp will light when the engine and the outside temperature is low to allow time for the glow plugs to get hot. The "wait to start" lamp will not come on when the glow plugs are operating after the engine starts.

NOTE: The glow plugs are removed to test cylinder compression using a special high-pressure reading gauge.

ENGINE-DRIVEN VACUUM PUMP

Because a diesel engine is unthrottled, it creates very little vacuum in the intake manifold. Several engine and vehicle components operate using vacuum, such as the exhaust gas recirculation (EGR) valve and the heating and ventilation blend and air doors. Most diesels used in cars and light trucks are equipped with an engine-driven vacuum pump to supply the vacuum for these components.

FREQUENTLY ASKED QUESTION ???

What Are Diesel Engine Advantages and Disadvantages?

A diesel engine has several advantages compared to a similar size gasoline-powered engine including:

1. More torque output
2. Greater fuel economy
3. Long service life

A diesel engine has several disadvantages compared to a similar size gasoline-powered engine including:

1. Engine noise, especially when cold and/or at idle speed
2. Exhaust smell
3. Cold weather startability
4. A vacuum pump is needed to supply the vacuum needs of the heat, ventilation, and air conditioning system
5. Heavier than a gasoline engine. See Figure 19–14.
6. Fuel availability

DIESEL FUEL

Diesel fuel must meet an entirely different set of standards than gasoline. The fuel in a diesel engine is not ignited with a spark, but is ignited by the heat generated by high compression. The pressure of compression (400 to 700 PSI or 2,800 to 4,800 kPa) generates temperatures of 1,200° to 1,600°F (700° to 900°C) which speeds the preflame reaction to start the ignition of fuel injected into the cylinder.

All diesel fuel must be clean, be able to flow at low temperatures, and be of the proper cetane rating.

- **Cleanliness.** It is imperative that the fuel used in a diesel engine be clean and free from water. Unlike the case with gasoline engines, the fuel is the lubricant and coolant for the diesel injector pump and injectors. Good-quality diesel fuel contains additives such as oxidation inhibitors, detergents, dispersants, rust preventatives, and metal deactivators.
- **Low-temperature fluidity.** Diesel fuel must be able to flow freely at all expected ambient temperatures. One specification for diesel fuel is its "pour point," which is the temperature below which the fuel would stop flowing. **Cloud point** is another concern with diesel fuel at lower temperatures. Cloud point is the low-temperature point at which the waxes present in most diesel fuel tend to form wax crystals that clog the fuel filter. Most diesel fuel suppliers distribute fuel with the proper pour point and cloud point for the climate conditions of the area.
- **Cetane number.** The cetane number for diesel fuel is the opposite of the octane number for gasoline. The **cetane number** is a measure of the ease with which the fuel can be ignited. The cetane rating of the fuel determines, to a great extent, its ability to start the engine at low temperatures and to provide smooth warm-up and even combustion. The cetane rating of diesel fuel should be between 45 and 50. The higher the cetane rating, the more easily the fuel is ignited, whereas the higher the octane rating, the more slowly the fuel burns.

Other diesel fuel specifications include its flash point, sulfur content, and classification. The **flash point** is the temperature at which the vapors on the surface of the fuel will ignite if exposed to an open flame. The flash point does *not* affect diesel engine operation. However, a lower than normal flash point could indicate contamination of the diesel fuel with gasoline or a similar substance.

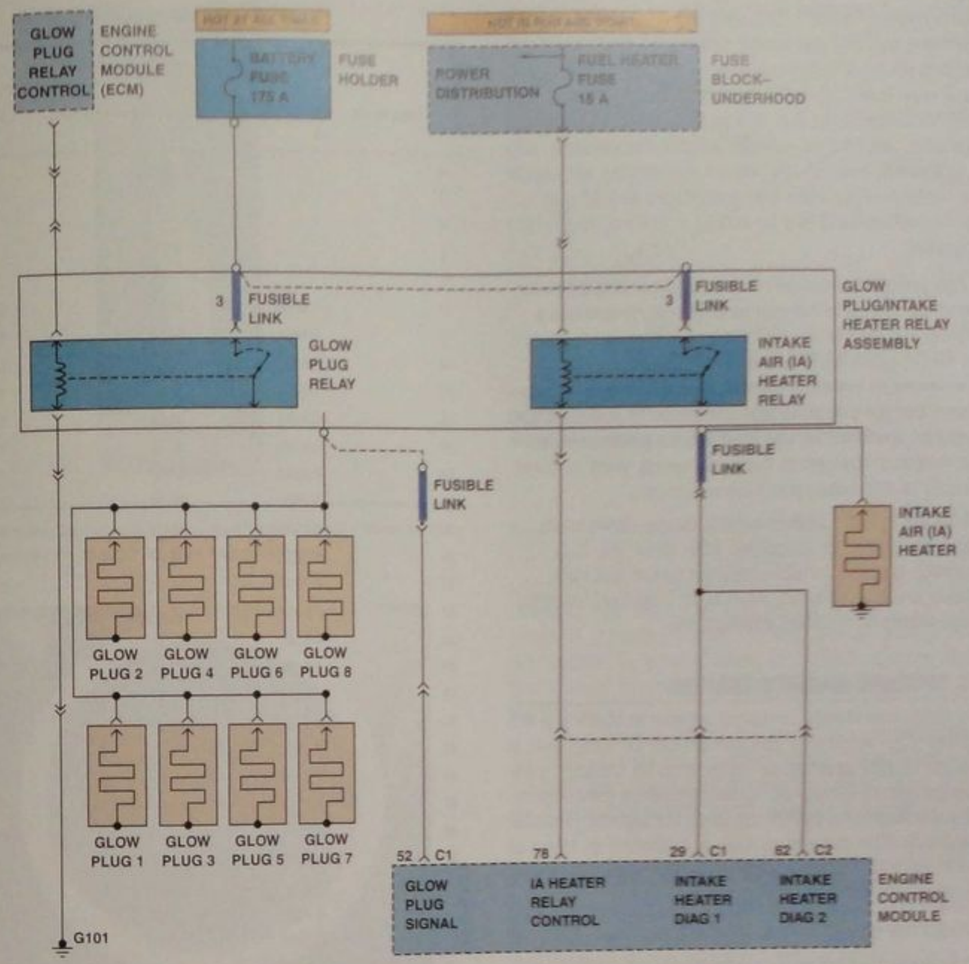


Figure 19–13 A schematic of a typical glow plug circuit. Notice that the relay for the glow plug and intake air heater are both computer controlled.



Figure 19–14 Roller lifter from a GM Duramax 6.6-liter V-8 diesel engine. Notice the size of this lifter compared to a roller lifter used in a gasoline engine.

The sulfur content of diesel fuel is very important to the life of the engine. Starting in 2007, all diesel fuel has to have less than 15 parts per million (PPM) of sulfur and is called ultra low sulfur diesel (ULSD). This is way down from the previous limit for low sulfur diesel of 500 PPM. Sulfur in the fuel creates sulfuric acid during the combustion process, which can damage engine components and cause piston ring wear. Federal regulations are getting extremely tight on sulfur content. High-sulfur fuel contributes to acid rain.

ASTM also classifies diesel fuel by volatility (boiling range) into the following grades:

Grade #1. This grade of diesel fuel has the lowest boiling point and the lowest cloud and pour points; it also has a lower BTU content—less heat per pound of fuel. As a result, grade #1 is suitable for use during low-temperature (winter) operation. Grade #1 produces less heat per pound of fuel compared to grade #2 and may be specified for use in diesel engines involved in frequent changes in load and speed, such as those found in city buses and delivery trucks.

Grade #2. This grade has a higher boiling range, cloud point, and pour point as compared with grade #1. It is usually specified where constant speed and high loads are encountered, such as in long-haul trucking and automotive diesel applications.

DIESEL FUEL SPECIFIC GRAVITY TESTING

The density of diesel fuel should be tested whenever there is a driveability concern. The density or specific gravity of diesel fuel is measured in units of **API gravity.** API gravity is an arbitrary scale expressing the gravity or density of liquid petroleum products devised jointly by the American Petroleum Institute and the National Bureau of Standards. The measuring scale is calibrated in terms of degrees API. Oil with the least-specific gravity has the highest API gravity. The formula for determining API gravity is as follows:

Degrees API gravity = (141.5/specific gravity at 60°F) − 131.5

The normal API gravity for #1 diesel fuel is 39 to 44 (typically 40). The normal API gravity for #2 diesel fuel is 30 to 39 (typically 35). A hydrometer calibrated in API gravity units should be used to test diesel fuel. See Figure 19–15.

FREQUENTLY ASKED QUESTION ???

How Can You Tell If Gasoline Has Been Added to the Diesel Fuel by Mistake?

If gasoline has been accidentally added to diesel fuel and is burned in a diesel engine, the result can be very damaging to the engine. The gasoline can ignite faster than diesel fuel, which would tend to increase the temperature of combustion. This high temperature can harm injectors and glow plugs, as well as pistons, head gaskets, and other major diesel engine components. If contaminated fuel is suspected, first smell the fuel at the filler neck. If the fuel smells like gasoline, then the tank should be drained and refilled with diesel fuel. If the smell test does not indicate a gasoline (or any rancid smell), then test a sample for proper API gravity.

NOTE: Diesel fuel designed for on-road use should be green in color. Red diesel fuel (high sulfur) should only be found in off-road or farm equipment.

API Gravity Comparison Chart

	Values for API Scale Oil		
API Gravity Scale	Specific Gravity S	Weight Density, lb/ft P	Pounds per Gallon
0			
2			
4			
6			
8			
10	1.0000	62.36	8.337
12	0.9861	61.50	8.221
14	0.9725	60.65	8.108
16	0.9593	59.83	7.998
18	0.9465	59.03	7.891
20	0.9340	58.25	7.787
22	0.9218	57.87	7.736
24	0.9100	56.75	7.587
26	0.8984	56.03	7.490
28	0.8871	55.32	7.396
30	0.8762	54.64	7.305
32	0.8654	53.97	7.215
34	0.8550	53.32	7.128
36	0.8448	52.69	7.043
38	0.8348	51.06	6.960
40	0.8251	51.46	6.879
42	0.8155	50.86	6.799
44	0.8030	50.28	6.722
46	0.7972	49.72	6.646
48	0.7883	49.16	6.572
50	0.7796	48.62	6.499
52	0.7711	48.09	6.429
54	0.7628	47.57	6.359
56	0.7547	47.07	6.292
58	0.7467	46.57	6.225
60	0.7389	46.08	6.160
62	0.7313	45.61	6.097
64	0.7238	45.14	6.034
66	07165	44.68	5.973
68	0.7093	44.23	5.913
70	0.7022	43.79	5.854
72	0.6953	43.36	5.797
74	0.6886	42.94	5.741
76	0.6819	42.53	5.685
78	0.6754	41.72	5.631
80	0.6690	41.32	5.577
82	0.6628	41.13	5.526
84	0.6566	40.95	5.474
86	0.6506	40.57	5.424
88	0.6446	40.20	5.374
90	0.6388	39.84	5.326
92	0.6331	39.48	5.278
94	0.6275	39.13	5.231
96	0.6220	38.79	5.186
98	0.6116	38.45	5.141
100	0.6112	38.12	5.096



Figure 19–15 A hydrometer is used to measure the API specific gravity of diesel fuel. The unit of measure is usually the American Petroleum Institute (API) scale.



Figure 19–16 A wire wound electrical heater is used to warm the intake air on some diesel engines.

DIESEL FUEL HEATERS

Diesel fuel heaters help prevent power loss and stalling in cold weather. The heater is placed in the fuel line between the tank and the primary filter. Some coolant heaters are thermostatically controlled, which allows fuel to bypass the heater once it has reached operating temperature.

HEATED INTAKE AIR

Some diesels, such as the General Motors 6.6-liter Duramax V-8, use an electrical heater wire to warm the intake air to help in cold weather starting and running. See Figure 19–16.

ACCELERATOR PEDAL POSITION SENSOR

Some light truck diesel engines are equipped with an electronic throttle to control the amount of fuel injected into the engine.

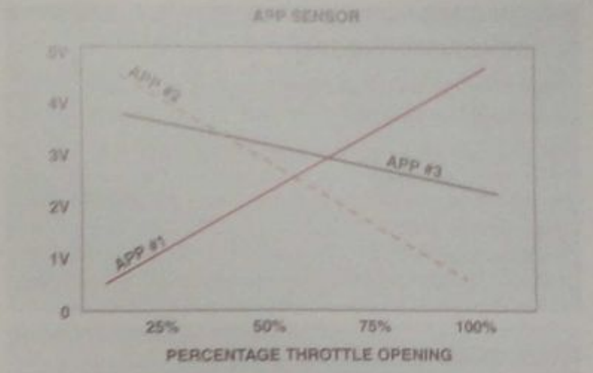


Figure 19–17 A typical accelerator pedal position (APP) sensor uses three different sensors in one package with each creating a different voltage as the accelerator is moved.

Because a diesel engine does not use a throttle in the air intake, the only way to control engine speed is by controlling the amount of fuel being injected into the cylinders. Instead of a mechanical link from the accelerator pedal to the diesel injection pump, a throttle-by-wire system uses an accelerator pedal position sensor. To ensure safety, it consists of three separate sensors that change in voltage as the accelerator pedal is depressed. See Figure 19–17.

The computer checks for errors by comparing the voltage output of each of the three sensors inside the APP and compares them to what they should be if there are no faults. If an error is detected, the engine and vehicle speed are often reduced.

SOOT OR PARTICULATE MATTER

Soot particles may come directly from the exhaust tailpipe or they can also form when emissions of nitrogen oxide and various sulfur oxides chemically react with other pollutants suspended in the atmosphere. Such reactions result in the formation of ground-level ozone, commonly known as smog. Smog is the most visible form of what is generally referred to as particulate matter. Particulate matter refers to tiny particles of solid or semi-solid material suspended in the atmosphere. This includes particles between 0.1 micron and 50 microns in diameter. The heavier particles, larger than 50 microns, typically tend to settle out quickly due to gravity. Particulates are generally categorized as follows:

- **TSP, Total Suspended Particulate**—Refers to all particles between 0.1 and 50 microns. Up until 1987, the EPA standard for particulates was based on levels of TSP.
- **PM10**—Particulate matter of 10 microns or less (approximately 1/6 the diameter of a human hair). EPA has a standard for particles based on levels of PM10.
- **PM2.5**—Particulate matter of 2.5 microns or less (approximately 1/20 the diameter of a human hair), also called "fine" particles. In July 1997, the EPA approved a standard for PM2.5.

In general, soot particles produced by diesel combustion fall into the categories of fine, that is, less than 2.5 microns and ultrafine, less than 0.1 micron. Ultrafine particles make up about 80% to 95% of soot.

FREQUENTLY ASKED QUESTION ???

What Is the Big Deal for the Need to Control Very Small Soot Particles?

For many years soot or particulate matter (PM) was thought to be less of a health concern than exhaust emissions from gasoline engines. It was felt that the soot could simply fall to the ground without causing any noticeable harm to people or the environment. However, it was discovered that the small soot particulates when breathed in are not expelled from the lungs like larger particles but instead get trapped in the deep areas of the lungs where they accumulate.

DIESEL OXIDATION CATALYST (DOC)

Diesel oxidation catalyst (DOC) consists of a flow-through honeycomb-style substrate structure that is washcoated with a layer of catalyst materials, similar to those used in a gasoline engine catalytic converter. These materials include the precious metals platinum and palladium, as well as other base metals catalysts. Catalysts chemically react with exhaust gas to convert harmful nitrogen oxide into nitrogen dioxide, and to oxidize absorbed hydrocarbons. The chemical reaction acts as a combustor for the unburned fuel that is characteristic of diesel compression ignition. The main function of the DOC is to start a regeneration event by converting the fuel-rich exhaust gases to heat.

The DOC also reduces carbon monoxide, hydrocarbons, plus odor-causing compounds such as aldehydes and sulfur, and the soluble organic fraction of particulate matter. During a regeneration event, the Catalyst System Efficiency test will run. The engine control module (ECM) monitors this efficiency of the DOC by determining if the exhaust gas temperature sensor (EGT Sensor 1) reaches a predetermined temperature during a regeneration event.

DIESEL EXHAUST PARTICULATE FILTER (DPF)

The heated exhaust gas from the DOC flows into the diesel particulate filter (DPF), which captures diesel exhaust gas particulates (soot) to prevent them from being released into the atmosphere. This is done by forcing the exhaust through a porous cell which has a silicon carbide substrate with honeycomb-cell-type channels that trap the soot. The channels are washcoated with catalyst materials similar to those in the DOC filter. The main difference between the DPF and a typical catalyst filter is that the entrance to every other cell channel in the DPF substrate is blocked at one end. So instead of flowing directly through the channels, the exhaust gas is forced through the porous walls of the blocked channels and exits through the adjacent open-ended channels. This type of filter is also referred to as a "wall-flow" filter.

Soot particulates in the gas remain trapped on the DPF channel walls where, over time, the trapped particulate matter will begin to clog the filter. The filter must therefore be purged periodically to remove accumulated soot particles. The process of purging soot from the DPF is described as **regeneration.** See Figure 19–18.

Exhaust Gas Temperature Sensors There are two exhaust gas temperature sensors that function in much the same way as engine temperature sensors. EGT Sensor 1 is positioned between the DOC and the DPF where it can measure the temperature of the exhaust gas entering the DPF. EGT Sensor 2 measures the temperature of the exhaust gas stream immediately after it exits the DPF.

The engine control module (ECM) monitors the signals from the EGT sensors as part of its calibrations to control DPF regeneration. The ECM supplies biased 5-volts to the signal circuit and a ground on the low reference circuit to EGT Sensor 1. When the EGT Sensor 1 is cold, the sensor resistance is high. As the temperature increases, the sensor resistance decreases. With high sensor resistance, the ECM detects a high voltage on the signal circuit. With lower sensor resistance, the ECM detects a lower voltage on the signal circuit. Proper exhaust gas temperatures at the inlet of the DPF are crucial for proper operation and for starting the regeneration process. Too high a temperature at the DPF will cause the DPF substrate to melt or crack. Regeneration will be terminated at temperatures above 1470°F (800°C). With too low a temperature, self-regeneration will not fully complete the soot burning process.



Figure 19–18 A diesel exhaust particulate filter on a Cummins 6.7-liter diesel engine.



Figure 19–19 A differential pressure sensor showing the two hoses from the diesel exhaust particulate filter.

DPF Differential Pressure Sensor (DPS) The DPF **differential pressure sensor (DPS)** has two pressure sample lines:

- One line is attached before the DPF, labeled P1
- The other is located after the DPF, labeled P2

The exact location of the DPS varies by vehicle model type (medium duty, pickup or van). By measuring P1 exhaust supply pressure from the DOC, and P2, post DPF pressure, the ECM can determine differential pressure, also referred to as "delta" pressure, across the DPF. Data from the DPF differential pressure sensor is used by the ECM to calibrate for controlling DPF exhaust system operation. See Figure 19–19.

FREQUENTLY ASKED QUESTION ???

What Is an Exhaust Air Cooler?

An exhaust air cooler is simply a length of tubing with a narrowed center section that acts as a venturi. The cooler is attached to the tailpipe with a bracket that provides a gap between the two. As hot exhaust rushes past the gap, the venturi effect draws surrounding air into the cooler and reduces the exhaust temperature. The cooler significantly lowers exhaust temperature at the tailpipe from a potential 788° to 806°F (420° to 430°C) to approximately 520°F (270°C).

Diesel Particulate Filter Regeneration Soot particulates in the gas remain trapped on the DPF channel walls where, over time, the buildup of trapped particulate matter will begin to clog the filter. The filter must therefore be purged periodically to remove accumulated soot particles. The process of purging soot from the DPF by incineration is described as regeneration. When the temperature of the exhaust gas is increased sufficiently, the heat incinerates the soot particles trapped in the filter, leaving only residual ash from the engine's combustion of lubrication oil. The filter is effectively renewed.

The primary reason for soot removal is to prevent the buildup of exhaust back pressure. Excessive back pressure increases fuel consumption, reduces power output, and can potentially cause engine damage. There are a number of operational factors that can trigger the diesel engine control module to initiate a DPF regeneration sequence. The ECM monitors:

- Distance since last DPF regeneration
- Fuel used since last DPF regeneration
- Engine run time since last DPF regeneration
- Exhaust differential pressure across the DPF

DPF Regeneration Process A number of engine components are required to function together for the regeneration process to be performed. ECM controls that impact DPF regeneration include late post-injections, engine speed, and adjusting fuel pressure. Adding late post-injection pulses provides the engine with additional fuel to be oxidized in the DOC which increases exhaust temperatures entering the DPF to about 900°F (500°C) and higher. The intake air valve acts as a restrictor that reduces air entry to the engine which increases engine operating temperature. The intake air heater may also be activated to warm intake air during regeneration.

The variable vane turbocharger also plays a role in achieving regeneration temperatures by reducing or increasing boost depending on engine load.

Types of DPF Regeneration DPF regeneration can be initiated in a number of ways, depending on the vehicle application and operating circumstances. The two main regeneration types are:

- Passive
- Active

Passive Regeneration During normal vehicle operation when driving conditions produce sufficient load and exhaust temperatures, passive DPF regeneration may occur. This passive regeneration occurs without input from the ECM or the driver. A passive regeneration may typically occur while the vehicle is being driven at highway speed or towing a trailer.

Active Regeneration Active regeneration is commanded by the ECM when it determines that the DPF requires it to remove excess soot buildup and conditions for filter regeneration have been met. Active regeneration is usually not noticeable to the driver. The vehicle needs to be driven at speeds above 30 mph for approximately 20 to 30 minutes to complete a full regeneration. During regeneration, the exhaust gases reach temperatures above 1000°F (550°C). If a regeneration event is interrupted for any reason, it will continue where it left off (including the next drive cycle) when the conditions are met for regeneration. Active regeneration is for the most part transparent to the customer. There are times when regeneration is required, but the operating conditions do not meet the ECM's requirements, such as on a delivery vehicle that is driven on frequent short trips or subjected to extended idling conditions. In such cases, the ECM turns on a "regeneration required" indicator to notify the vehicle operator that the filter requires cleaning.

FREQUENTLY ASKED QUESTION ???

Will the Post-Injection Pulses Reduce Fuel Economy?

Maybe. Due to the added fuel injection pulses and late fuel injection timing, an increase in fuel consumption may be noticed on the Driver Information Center (DIC) during the regeneration time period. A drop in overall fuel economy should not be noticeable.

DPF Service Regeneration Another active regeneration method, the "DPF Service Regeneration" is a useful tool for the dealership technician. The procedure would typically be used to clean the DPF when vehicle operating conditions did not allow the DPF to regenerate normally while the vehicle is driven. A service regeneration procedure can also be run in order to clean the DPF when there is an unknown amount of soot present. This might result from engine or engine control errors caused by a Charge Air Cooler leak or low compression. In these cases, a DTC P2463 would normally set, and the DPF would have 80 grams or less of accumulated soot. If over 100 grams of soot are present, P244B sets and a service light comes on to warn the driver.

Conditions for Running a DPF Service Regeneration A service regeneration cannot be initiated if there are active diagnostic trouble codes (DTCs) present. Other conditions that the ECM checks are as follows:

- The battery voltage is greater than 10 volts.
- The engine speed is between 600 and 1250 RPM.
- The brake pedal is in the released position.
- The accelerator pedal is in the released position.
- The transmission must be in park or neutral.
- The engine coolant temperature (ECT) is between 158°F (70°C) and 239°F (115°C).
- The vehicle's fuel tank level must be between 15% and 85% capacity. For safety, refueling should never be performed during the regeneration process.
- The exhaust gas temperature (EGT Sensors 1 and 2) must be less than 752°F (400°C).

CAUTION: To avoid extremely elevated exhaust temperatures, inspect the exhaust cooler vent located at the tailpipe and remove any debris or mud that would impede its operation.

1. DO NOT connect any shop exhaust removal hoses to the vehicle's tailpipe.
2. Park the vehicle outdoors and keep people, other vehicles, and combustible material a safe distance away from the vehicle during Service Regeneration.
3. Do not leave the vehicle unattended during Service Regeneration.

WARNING: Tailpipe outlet exhaust temperature will be greater than 572°F (300°C) during service regeneration. To help prevent personal injury or property damage from fire or burns, keep vehicle exhaust away from any object and people.

ASH LOADING

Regeneration will not burn off ash. Only the particulate matter (PM) is burned off during regeneration. Ash is a noncombustible by-product from normal oil consumption. Ash accumulation in the DPF will eventually cause a restriction in the particulate filter. To service an ash loaded DPF, the DPF will need to be removed from the vehicle and cleaned or replaced. Low ash content engine oil (API CJ-4) is required for vehicles with the DPF system. The CJ-4 rated oil is limited to 1% ash content.

DIESEL EXHAUST SMOKE DIAGNOSIS

While some exhaust smoke is considered normal operation for many diesel engines, especially older units, the cause of excessive exhaust smoke should be diagnosed and repaired.

Black Smoke Black exhaust smoke is caused by incomplete combustion because of a lack of air or a fault in the injection system that could cause an excessive amount of fuel in the cylinders. Items that should be checked include the following:

- Check the fuel specific gravity (API gravity).
- Perform an injector balance test to locate faulty injectors using a scan tool.
- Check for proper operation of the engine coolant temperature (ECT) sensor.
- Check for proper operation of the fuel rail pressure (FRP) sensor.
- Check for restrictions in the intake or turbocharger.
- Check to see if the engine is using oil.

White Smoke White exhaust smoke occurs most often during cold engine starts because the smoke is usually condensed fuel droplets. White exhaust smoke is also an indication of cylinder misfire on a warm engine. The most common causes of white exhaust smoke include:

- Inoperative glow plugs
- Low engine compression
- Incorrect injector spray pattern
- A coolant leak into the combustion chamber

Gray or Blue Smoke Blue exhaust smoke is usually due to oil consumption caused by worn piston rings, scored cylinder walls, or defective valve stem seals. Gray or blue smoke can also be caused by a defective injector(s).

SCAN TOOL DIAGNOSIS

Diesel engines since the late 1980s have been computer controlled and are equipped with sensors and activators to control functions that were previously mechanically controlled. All light truck diesels since 1996 have also adhered to on-board diagnostic systems (second generation [OBD-II]). The use of a scan tool to check for diagnostic trouble codes (DTCs) and to monitor engine operation is one of the first diagnostic steps. See Figure 19–20.

COMPRESSION TESTING

A compression test, is fundamental for determining the mechanical condition of a diesel engine. Worn piston rings can cause low power and excessive exhaust smoke. A diesel engine should produce at least 300 PSI (2,068 kPa) of compression pressure and all cylinders should be within 50 PSI (345 kPa) of each other. See Figure 19–21.



Figure 19–20 A scan tool is used to retrieve diagnostic trouble codes and to perform injector balance tests.



Figure 19–21 A compression gauge designed for the higher compression rate of a diesel engine should be used when checking the compression.

GLOW PLUG RESISTANCE BALANCE TEST

Glow plugs increase in resistance as their temperature increases. All glow plugs should have about the same resistance when checked with an ohmmeter. A similar test of the resistance of the glow plugs can be used to detect a weak cylinder. This test is particularly helpful on a diesel engine that is not computer controlled. To test for even cylinder balance using glow plug resistance, perform the following on a warm engine.

1. Unplug, measure, and record the resistance of all of the glow plugs.
2. With the wires still removed from the glow plugs, start the engine.
3. Allow the engine to run for several minutes to allow the combustion inside the cylinder to warm the glow plugs.
4. Measure the plugs and record the resistance of all of the glow plugs.
5. The resistance of all of the glow plugs should be higher than at the beginning of the test. A glow plug that is in a cylinder that is not firing correctly will not increase in resistance as much as the others.
6. Another test is to measure exhaust manifold temperature at each exhaust port. Misfiring cylinders will run cold. This can be done with a contact or noncontact thermometer.

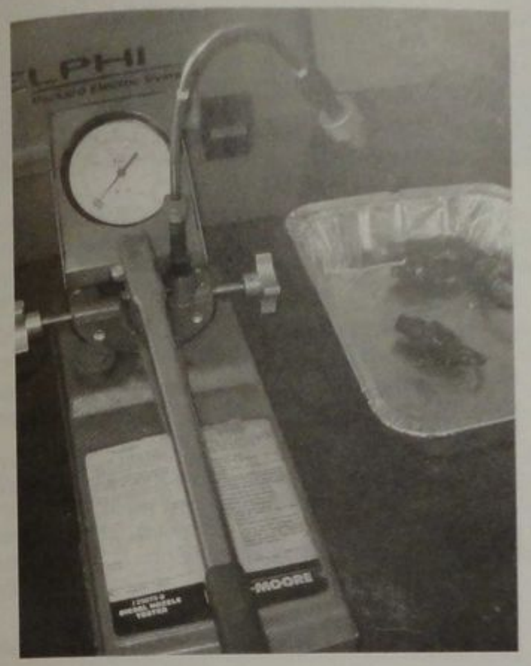


Figure 19–22 A typical pop tester used to check the spray pattern of a diesel engine injector.

INJECTOR POP TESTING

A **pop tester** is a device used for checking a diesel injector nozzle for proper spray pattern. The handle is depressed and pop off pressure is displayed on the gauge. See Figure 19–22.

The spray pattern should be a hollow cone. This will vary depending on design. The nozzle should also be tested for leakage—dripping of the nozzle while under pressure. If the spray pattern is not correct, cleaning, repairing, or replacing of the injector nozzle may be necessary.

TECH TIP ✔ **Always Use Cardboard to Check for High-Pressure Leaks**

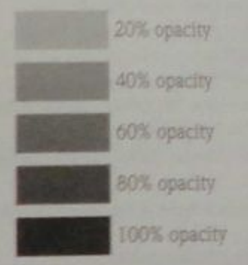
If diesel fuel is found on the engine, a high-pressure leak could be present. When checking for a high-pressure leak, wear protective clothing including safety glasses and face shield plus gloves and long-sleeved shirt. Then use a piece of cardboard to locate the high-pressure leak. When a diesel is running, the pressure in the common rail and injector tubes can reach over 20,000 PSI. At these pressures the diesel fuel is atomized and cannot be seen but can penetrate the skin and cause personal injury. A leak will be shown as a dark area on the cardboard. When a leak is found, shut off the engine and locate the exact location of the leak without the engine running.

CAUTION: Sometimes a leak can actually cut through the cardboard, so use extreme care.

DIESEL EMISSION TESTING

The most commonly used diesel exhaust emission test used in state or local testing programs is called the **opacity** test. Opacity means the percentage of light that is blocked by the exhaust smoke.

- A 0% opacity means that the exhaust has no visible smoke and does not block light from a beam projected through the exhaust smoke.
- A 100% opacity means that the exhaust is so dark that it completely blocks light from a beam projected through the exhaust smoke.
- A 50% opacity means that the exhaust blocks half of the light from a beam projected through the exhaust smoke.



Snap Acceleration Test In a snap acceleration test, the vehicle is held stationary with wheel chocks and brakes released as the engine is rapidly accelerated to high idle with the transmission in neutral while smoke emissions are measured. This test is conducted a minimum of six times and the three most consistent measurements are averaged together for a final score.

Rolling Acceleration Test Vehicles with a manual transmission are rapidly accelerated in low gear from an idle speed to a maximum governed RPM while the smoke emissions are measured.

Stall Acceleration Test Vehicles with automatic transmissions are held in a stationary position with the parking brake and service brakes applied while the transmission is placed in "drive." The accelerator is depressed and held momentarily while smoke emissions are measured.

The standards for diesels vary according to the type of vehicle and other factors, but usually include a 40% opacity or less.

TECH TIP ✔ **Do Not Switch Injectors**

In the past, it was common practice to switch diesel fuel injectors from one cylinder to another when diagnosing a dead cylinder problem. However, most high-pressure common rail systems used in new diesels use precisely calibrated injectors that should not be mixed up during service. Each injector has its own calibration number. See Figure 19–23.



Figure 19–23 The letters on the side of this injector on a Cummins 6.7-liter diesel indicate the calibration number for the injector.

SUMMARY

1. A diesel engine uses heat of compression to ignite the diesel fuel when it is injected into the compressed air in the combustion chamber.
2. There are two basic designs of combustion chambers used in diesel engines. Indirect injection (IDI) uses a precombustion chamber whereas a direct injection (DI) occurs directly into the combustion chamber.
3. The three phases of diesel combustion include:
   a. Ignition delay
   b. Rapid combustion
   c. Controlled combustion
4. The typical diesel engine fuel system consists of the fuel tank, lift pump, water-fuel separator, and fuel filter.
5. The engine-driven injection pump supplies high-pressure diesel fuel to the injectors.
6. The two most common types of fuel injection used in automotive diesel engines are:
   a. Distributor-type injection pump
   b. Common rail design where all of the injectors are fed from the same fuel supply from a rail under high pressure
7. Injector nozzles are either opened by the high-pressure pulse from the distributor pump or electrically by the computer on a common rail design.
8. Glow plugs are used to help start a cold diesel engine and help prevent excessive white smoke during warm-up.
9. The higher the cetane rating of diesel fuel, the more easily the fuel is ignited.
10. Most automotive diesel engines are designed to operate on grade #2 diesel fuel in moderate weather conditions.
11. The API specific gravity of diesel fuel should be 30 to 39 with a typical reading of 35 for #2 diesel fuel.
12. Diesel engines can be tested using a scan tool, as well as measuring the glow plug resistance or compression reading to determine a weak or nonfunctioning cylinder.

REVIEW QUESTIONS

1. What is the difference between direct injection and indirect injection?
2. What are the three phases of diesel ignition?
3. What are the two most commonly used types of automotive diesel injection systems?
4. Why are glow plugs kept working after the engine starts?
5. What is the advantage of using diesel fuel with a high cetane rating?
6. How is the specific gravity of diesel fuel tested?

CHAPTER QUIZ

1. How is diesel fuel ignited in a warm diesel engine?
   a. Glow plugs
   b. Heat of compression
   c. Spark plugs
   d. Distributorless ignition system
2. Which type of diesel injection produces less noise?
   a. Indirect injection (IDI)
   b. Common rail
   c. Direct injection
   d. Distributor injection
3. Which diesel injection system requires the use of a glow plug?
   a. Indirect injection (IDI)
   b. High-pressure common rail
   c. Direct injection
   d. Distributor injection
4. The three phases of diesel ignition include _____.
   a. Glow plug ignition, fast burn, slow burn
   b. Slow burn, fast burn, slow burn
   c. Ignition delay, rapid combustion, controlled combustion
   d. Glow plug ignition, ignition delay, controlled combustion
5. What fuel system component is used in a vehicle equipped with a diesel engine that is not usually used on the same vehicle when it is equipped with a gasoline engine?
   a. Fuel filter
   b. Fuel supply line
   c. Fuel return line
   d. Water-fuel separator
6. The diesel injection pump is usually driven by a _____.
   a. Gear off the camshaft
   b. Belt off the crankshaft
   c. Shaft drive off of the crankshaft
   d. Chain drive off of the camshaft
7. Which diesel system supplies high-pressure diesel fuel to all of the injectors all of the time?
   a. Distributor
   b. Inline
   c. High-pressure common rail
   d. Rotary
8. Glow plugs should have high resistance when _____ and lower resistance when _____.
   a. Cold/warm
   b. Warm/cold
   c. Wet/dry
   d. Dry/wet
9. Technician A says that glow plugs are used to help start a diesel engine and are shut off as soon as the engine starts. Technician B says that the glow plugs are turned off as soon as a flame is detected in the combustion chamber. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. What part should be removed to test cylinder compression on a diesel engine?
    a. An injector
    b. An intake valve rocker arm and stud
    c. An exhaust valve
    d. A glow plug

CHAPTER 20

Cooling System Operation and Diagnosis

OBJECTIVES: **After studying Chapter 20, the reader will be able to:** Prepare for Engine Repair (A1) ASE certification test content area "D" (Lubrication and Cooling Systems Diagnosis and Repair). • Describe how coolant flows through an engine. • Discuss the operation of the thermostat. • Explain the purpose and function of the radiator pressure cap. • Describe the various types of antifreeze and how to recycle and discard used coolant. • Discuss how to diagnose cooling system problems.

KEY TERMS: bar • bypass • cavitation • centrifugal pump • coolant recovery system • core tubes • ethylene glycol • fins • impeller • reverse cooling • scroll • silicone coupling • surge tank • thermostat • thermostatic spring

Satisfactory cooling system operation depends on the design and operating conditions of the system. The design is based on heat output of the engine, radiator size, type of coolant, size of water pump (coolant pump), type of fan, thermostat, and system pressure. Unfortunately, the cooling system is usually neglected until there is a problem. Proper routine maintenance can prevent problems.

COOLING SYSTEM PURPOSE AND FUNCTION

The cooling system must allow the engine to warm up to the required operating temperature as rapidly as possible and then maintain that temperature. It must be able to do this when the outside air temperature is as low as −30°F (−35°C) and as high as 110°F (45°C).

Peak combustion temperatures in the engine cycle run from 4000° to 6000°F (2200° to 3300°C). The combustion temperatures will *average* between 1200° and 1700°F (650° and 925°C). Continued temperatures as high as this would weaken engine parts, so heat must be removed from the engine. The cooling system keeps the head and cylinder walls at a temperature that is within the range for maximum efficiency. See Figure 20–1.

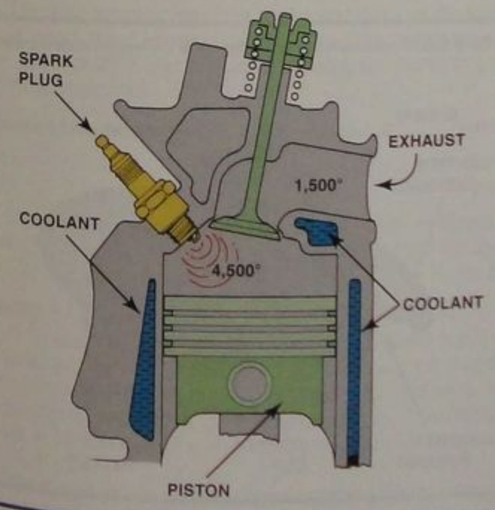


Figure 20–1 Typical combustion and exhaust temperatures.

TECH TIP ✓ **Overheating Can Be Expensive**

A faulty cooling system seems to be a major cause of engine failure. Engine rebuilders often have nightmares about seeing their rebuilt engine placed back in service in a vehicle with a clogged radiator. Most engine technicians routinely replace the water pump and all hoses after an engine overhaul or repair. The radiator should also be checked for leaks and proper flow whenever the engine is repaired or replaced. Overheating is one of the most common causes of engine failure.

LOW-TEMPERATURE ENGINE PROBLEMS

Engine operating temperatures must be above a minimum temperature for proper engine operation. Gasoline combustion is a rapid oxidation process that releases heat as the hydrocarbon fuel chemically combines with oxygen from the air. *For each gallon of fuel used, moisture equal to a gallon of water is produced.* It is a part of this moisture that condenses and gets into the oil pan, along with unburned fuel and soot, and causes sludge formation. The condensed moisture combines with unburned hydrocarbons and additives to form carbonic acid, sulfuric acid, nitric acid, hydrobromic acid, and hydrochloric acid. These acids are responsible for engine wear by causing corrosion and rust within the engine. Rust occurs rapidly when the coolant temperature is below 130°F (55°C). High cylinder wall wear rates occur whenever the coolant temperature is below 150°F (65°C).

To reduce cold-engine problems and to help start engines in cold climates, most manufacturers offer block heaters as an option. These block heaters are plugged into household current (110 volts AC) and the heating element warms the coolant.

HIGH-TEMPERATURE ENGINE PROBLEMS

Maximum temperature limits are required to protect the engine. High temperatures will oxidize the engine oil. This breaks the oil down, producing hard carbon and varnish. If high temperatures are allowed to continue, the carbon that is produced will plug piston rings. The varnish will cause the hydraulic valve lifter plungers to stick. High temperatures always thin the oil. Metal-to-metal contact within the engine will occur when the oil is too thin. This will cause high friction, loss of power, and rapid wear of the parts. Thinned oil will also get into the combustion chamber by going past the piston rings and through valve guides to cause excessive oil consumption.

High coolant temperatures raise the combustion temperatures to a point that may cause detonation and preignition to occur. These are common forms of abnormal combustion. If they are allowed to continue for any period of time, the engine will be damaged.

TECH TIP ✓ **Engine Temperature and Exhaust Emissions**

Many areas of the United States and Canada have exhaust emission testing. Hydrocarbon (HC) emissions are simply unburned gasoline. To help reduce HC emissions and be able to pass emission tests, be sure that the engine is at normal operating temperature. Vehicle manufacturers' definition of "normal operating temperature" includes the following:

1. Upper radiator hose is hot and pressurized.
2. Electric cooling fan(s) cycles twice.

Be sure that the engine is operating at normal operating temperature before testing for exhaust emissions. For best results, the vehicle should be driven about 20 miles (32 kilometers) to be certain that the catalytic converter and engine oil, as well as the coolant, are at normal temperature. This is particularly important in cold weather. Most drivers believe that their vehicle will "warm-up" if allowed to idle until heat starts flowing from the heater. The heat from the heater comes from the coolant. Most manufacturers recommend that idling be limited to a maximum of 5 minutes and that the vehicle should be warmed up by driving slowly after just a minute or two to allow the oil pressure to build.

COOLING SYSTEM DESIGN

Coolant flows through the engine, where it picks up heat. It then flows to the radiator, where the heat is given up to the outside air. The coolant continually recirculates through the cooling system, as illustrated in Figures 20–2 and 20–3.

Its temperature rises as much as 15°F (8°C) as it goes through the engine; then it recools as it goes through the radiator. *The coolant flow rate may be as high as 1 gallon (4 liters) per minute for each horsepower the engine produces.*

Hot coolant comes out of the thermostat housing on the top of the engine. The engine coolant outlet is connected to the top of the radiator by the upper hose and clamps. The coolant in the radiator is cooled by air flowing through the radiator. As it cools, it moves from the top to the bottom of the radiator. Cool coolant leaves the lower radiator area through an outlet and lower hose, going into the inlet side of the water pump, where it is recirculated through the engine.

NOTE: Some newer engine designs such as Chrysler's 4.7-L, V-8 and General Motors 4.8-, 5.3-, 5.7-, and 6.0-L V-8s place the thermostat on the inlet side of the water pump. As the cooled coolant hits the thermostat, the thermostat closes until the coolant temperature again causes it to open. Placing the thermostat in the inlet side of the water pump therefore reduces thermal cycling by reducing the rapid temperature changes that could cause stress in the engine, especially if aluminum heads are used with a cast-iron block.

Much of the cooling capacity of the cooling system is based on the functioning of the radiator. Radiators are designed for the maximum rate of heat transfer using minimum space. Cooling airflow through the radiator is aided by a belt- or electric motor-driven cooling fan.

THERMOSTAT TEMPERATURE CONTROL

There is a normal operating temperature range between low-temperature and high-temperature extremes. The thermostat controls the minimum normal temperature. The **thermostat** is a temperature-controlled valve placed at the engine coolant outlet. An encapsulated, wax-based, plastic-pellet heat sensor is located on the engine side of the thermostatic valve. As the engine warms, heat swells the heat sensor. See Figure 20–4.

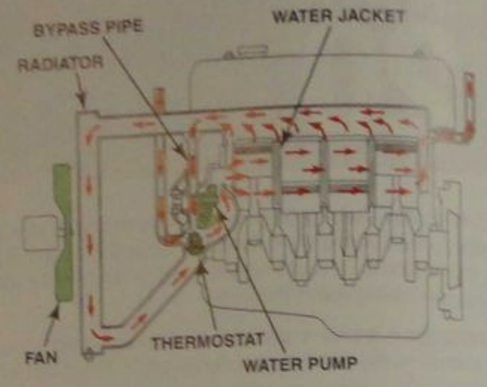


Figure 20–2 Coolant flow through a typical engine cooling system.

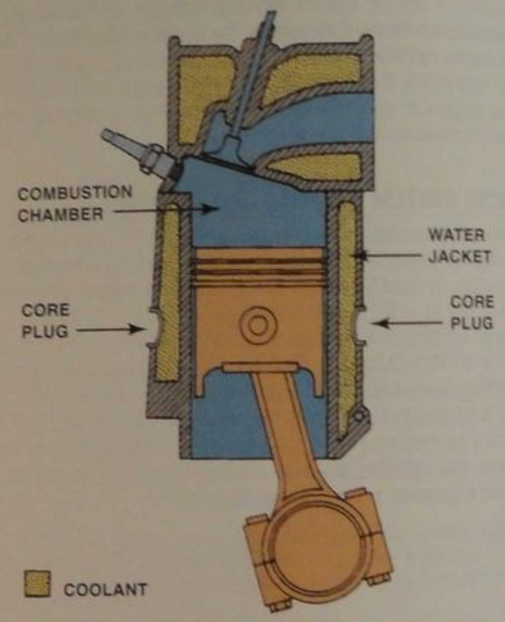


Figure 20–3 Coolant circulates through the water jackets in the engine block and cylinder head.

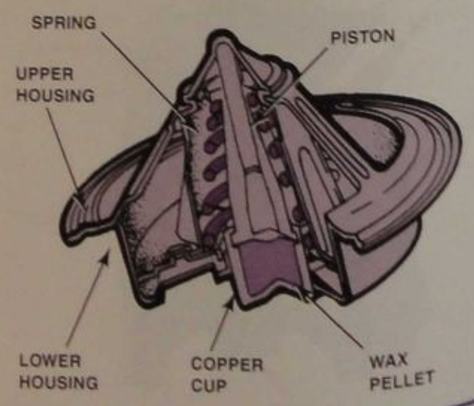


Figure 20–4 A cross-section of a typical wax-actuated thermostat showing the position of the wax pellet and spring.

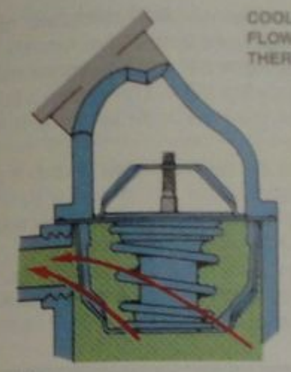


Figure 20–5 (a) When the engine is cold, the coolant flows through the bypass. (b) When the thermostat opens, the coolant can flow to the radiator.

A mechanical link, connected to the heat sensor, opens the thermostat valve. As the thermostat begins to open, it allows some coolant to flow to the radiator, where it is cooled. The remaining part of the coolant continues to flow through the bypass, thereby bypassing the thermostat and flowing back through the engine. See Figure 20–5.

The rated temperature of the thermostat indicates the temperature at which the thermostat starts to open. The thermostat is fully open at about 20°F higher than its opening temperature. See the following examples.

Thermostat Temperature Rating	Starts to Open	Fully Open
180°F	180°F	200°F
195°F	195°F	215°F

If the radiator, water pump, and coolant passages are functioning correctly, the engine should always be operating within the opening and fully open temperature range of the thermostat. See Figure 20–6.

Bypass A **bypass** around the closed thermostat allows a small part of the coolant to circulate within the engine during warm-up. It is a small passage that leads from the engine side of the thermostat to the inlet side of the water pump. It allows some coolant to bypass the thermostat even when the thermostat is open. The bypass may be cast or drilled into the engine and pump parts. See Figures 20–7 and 20–8.

The bypass aids in uniform engine warm-up. Its operation eliminates hot spots and prevents the buildup of excessive coolant pressure in the engine when the thermostat is closed.



Figure 20–6 A thermostat stuck in the open position caused the engine to operate too cold. The vehicle failed an exhaust emission test because of this defect.

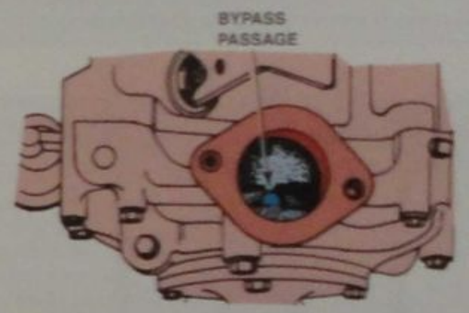


Figure 20–7 This internal bypass passage in the thermostat housing directs cold coolant to the water pump.

TECH TIP ✓ **Do Not Take Out the Thermostat!**

Some vehicle owners and technicians remove the thermostat in the cooling system to "cure" an overheating problem. In some cases, removing the thermostat can *cause* overheating—not stop overheating. This is true for three reasons:

1. Without a thermostat the coolant can flow more quickly through the radiator. The thermostat adds some restriction to the coolant flow, and therefore keeps the coolant in the radiator longer. The presence of the thermostat thus ensures a greater reduction in the coolant temperature before it returns to the engine.
2. Heat transfer is greater with a greater difference between the coolant temperature and air temperature. Therefore, when coolant flow rate is increased (no thermostat), the temperature difference is reduced.
3. Without the restriction of the thermostat, much of the coolant flow often bypasses the radiator entirely and returns directly to the engine.

If overheating is a problem, removing the thermostat will usually not solve the problem. Remember, the thermostat controls the temperature of the engine coolant by opening at a certain temperature and closing when the temperature falls below the minimum rated temperature of the thermostat. If overheating occurs, two basic problems could be the cause:

1. The engine is producing too much heat for the cooling system to handle. For example, if the engine is running too lean or if the ignition timing is either excessively advanced or excessively retarded, overheating of the engine can result.
2. The cooling system has a malfunction or defect that prevents it from getting rid of its heat.



Figure 20–8 A cutaway of a small block Chevrolet V-8 showing the passage from the cylinder head through the front of the intake manifold to the thermostat.



Figure 20–9 Setup used to check the opening temperature of a thermostat.

TESTING THE THERMOSTAT

There are three basic methods that can be used to check the operation of the thermostat.

1. **Hot-water method.** If the thermostat is removed from the vehicle and is closed, insert a 0.015-inch (0.4-millimeter) feeler gauge in the opening so that the thermostat will hang on the feeler gauge. The thermostat should then be suspended by the feeler gauge in a bath along with a thermometer. See Figure 20–9. The bath should be heated until the thermostat opens enough to release and fall from the feeler gauge. The temperature of the bath when the thermostat falls is the opening temperature of the thermostat. If it is within 5°F (4°C) of the temperature stamped on the thermostat, the thermostat is satisfactory for use. If the temperature difference is greater, the thermostat should be replaced.
2. **Infrared pyrometer method.** An infrared pyrometer can be used to measure the temperature of the coolant near the thermostat. The area on the engine side of the thermostat should be at the highest temperature that exists in the engine. A properly operating cooling system should cause the pyrometer to read as follows:
   A. As the engine warms, the temperature reaches near thermostat-opening temperature.
   B. As the thermostat opens, the temperature drops just as the thermostat opens, sending coolant to the radiator.
   C. As the thermostat cycles, the temperature should range between the opening temperature of the thermostat and 20°F (11°C) above the opening temperature.

NOTE: If the temperature rises higher than 20°F (11°C) above the opening temperature of the thermostat, inspect the cooling system for a restriction or low coolant flow. A clogged radiator could also cause the excessive temperature rise.

3. **Scan tool method.** A scan tool can be used on many vehicles to read the actual temperature of the coolant as detected by the engine coolant temperature (ECT) sensor. Although the sensor or the wiring to and from the sensor may be defective, at least the scan tool can indicate what the computer "thinks" the engine coolant temperature is.

THERMOSTAT REPLACEMENT

An overheating engine may result from a faulty thermostat. An engine that does not get warm enough always indicates a faulty thermostat.

To replace the thermostat, coolant will have to be drained from the radiator drain petcock to lower the coolant level below the thermostat. It is not necessary to completely drain the system. The upper hose should be removed from the thermostat housing neck; then the housing must be removed to expose the thermostat. See Figure 20–10.

The gasket flanges of the engine and thermostat housing should be cleaned, and the gasket surface of the housing must be flat. The thermostat should be placed in the engine with the sensing pellet *toward* the engine. Make sure that the thermostat position is correct, and install the thermostat housing with a new gasket.



Figure 20–10 Some thermostats are an integral part of the housing. This thermostat and radiator hose housing is serviced as an assembly. Some thermostats simply snap into the engine radiator fill tube underneath the pressure cap.

CAUTION: Failure to set the thermostat into the recessed groove will cause the housing to become tilted when tightened. If this happens and the housing bolts are tightened, the housing will usually crack, creating a leak.

The upper hose should then be installed and the system refilled. Install the proper size of radiator hose clamp.

ANTIFREEZE/COOLANT

Coolant is a mixture of antifreeze and water. Water is able to absorb more heat per gallon than any other liquid coolant. Under standard conditions, water boils at 212°F (100°C) and freezes at 32°F (0°C). *When water freezes, it increases in volume about 9%.* The expansion of the freezing water can easily crack engine blocks, cylinder heads, and radiators. All manufacturers recommend the use of **ethylene glycol**-based antifreeze mixtures for protection against this problem.

A curve depicting freezing point as compared with the percentage of antifreeze mixture is shown in Figure 20–11.

It should be noted that the freezing point increases as the antifreeze concentration is increased above 60%. The normal mixture is 50% antifreeze and 50% water. Ethylene glycol antifreezes contain anticorrosion additives, rust inhibitors, and water pump lubricants.

At the maximum level of protection, an ethylene glycol concentration of 60% will absorb about 85% as much heat as will water. Ethylene glycol-based antifreeze also has a higher boiling point than water. See Figure 20–12.

If the coolant boils, it vaporizes and does not act as a cooling agent because it is not in liquid form and in contact with the cooling surfaces.

All coolants have rust and corrosion inhibitors to help protect the metals in the engine and cooling systems. Most conventional green antifreeze contains inorganic salts such as sodium silicate and phosphates. Organic additive technology (OAT) coolant contains inorganic acid salts (carboxylates) additives that are not abrasive to water pumps. Hybrid organic additive technology (HOAT) coolant contains inorganic acids and some silicate but is phosphate free.

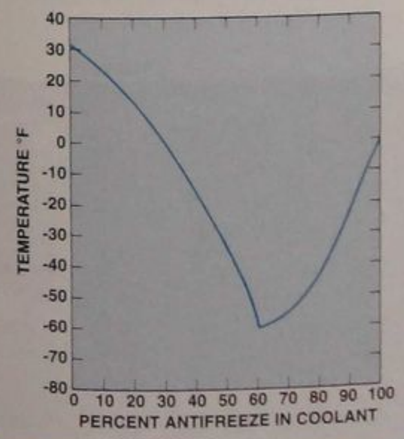


Figure 20–11 Graph showing the relationship of the freezing point of the coolant to the percentage of antifreeze used in the coolant.

FREQUENTLY ASKED QUESTION ???

What Is "Pet Friendly" Coolant?

Similar to ethylene glycol, propylene glycol is a type of coolant that is less harmful to pets and animals because it is not sweet tasting, although it is still harmful if swallowed. This type of coolant should not be mixed with ethylene glycol coolant.

NOTE: Some vehicle manufacturers do not recommend the use of propylene glycol coolant. Check the recommendations in the owner's manual or service manual before using it in a vehicle.

REAL WORLD FIX **If 50% Is Good, 100% Must Be Better**

A vehicle owner said that the cooling system of his vehicle would never freeze or rust. He said that he used 100% antifreeze (ethylene glycol) instead of a 50/50 mixture with water.

However, after the temperature dropped to −20°F (−29°C), the radiator froze and cracked. [Pure antifreeze freezes at about 0°F (−18°C)]. After thawing, the radiator had to be repaired. The owner was lucky that the engine block did not also crack.

For best freeze protection with good heat transfer, use a 50/50 mixture of antifreeze and water. A 50/50 mixture of antifreeze and water is the best compromise between temperature protection and the heat transfer that is necessary for cooling system operation. Do not exceed 70% antifreeze (30% water). As the percentage of antifreeze increases, the boiling temperature increases, and freezing protection increases (up to 70% antifreeze), but the heat transfer performance of the mixture decreases.

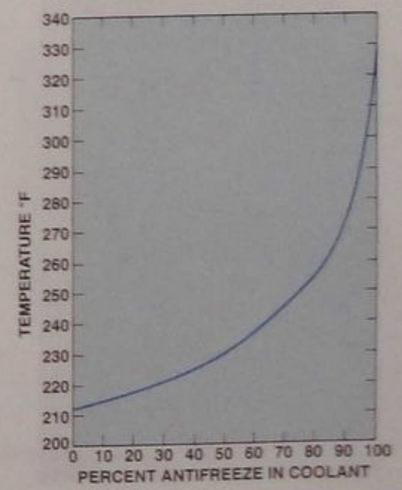


Figure 20–12 Graph showing how the boiling point of the coolant increases as the percentage of antifreeze in the coolant increases.

ANTIFREEZE CAN FREEZE

An antifreeze and water mixture is an example wherein the freezing point differs from the freezing point of either pure antifreeze or pure water.

	Freezing Point
Pure water	32°F (0°C)
Pure antifreeze*	0°F (−18°C)
50/50 mixture	−34°F (−37°C)
70% antifreeze/30% water	−84°F (−64°C)

* Pure antifreeze is usually 95% ethylene glycol, 2% to 3% water, and 2% to 3% additives.

Depending on the exact percentage of water used, antifreeze, as sold in containers, freezes between −8°F and +8°F (−13°C and −22°C). Therefore, it is easiest just to remember that most antifreeze freezes at about 0°F (−18°C).

The boiling point of antifreeze and water is also a factor of mixture concentrations.

	Boiling Point at Sea Level	Boiling Point with 15 PSI Pressure Cap
Pure water	212°F (100°C)	257°F (125°C)
50/50 mixture	218°F (103°C)	265°F (130°C)
70/30 mixture	225°F (107°C)	276°F (136°C)

HYDROMETER TESTING

Coolant can be checked using a coolant hydrometer. The hydrometer measures the density of the coolant. The higher the density, the more concentration of antifreeze in the water. Most coolant hydrometers read the freezing point and boiling point of the coolant. See Figure 20–13.

If the engine is overheating and the hydrometer reading is near −50°F (−45.555°C), suspect that pure 100% antifreeze is present. For best results, the coolant should have a freezing point lower than −20°F and a boiling point above 234°F.



Figure 20–13 Checking the freezing and boiling protection levels of the coolant using a hydrometer.

TECH TIP ✓ **Ignore the Windchill Factor**

The windchill factor is a temperature that combines the actual temperature and the wind speed to determine the overall heat loss effect on exposed skin. Because it is the heat loss factor for exposed skin, the windchill temperature is not to be considered when determining antifreeze protection levels.

Although moving air does make it feel colder, the actual temperature is not changed by the wind and the engine coolant will not be affected by the windchill. Not convinced? Try this. Place a thermometer in a room and wait until a stable reading is obtained. Now turn on a fan and have the air blow across the thermometer. The temperature will not change.

RECYCLING COOLANT

Coolant (antifreeze and water) should be recycled. Used coolant may contain heavy metals, such as lead, aluminum, and iron, which are absorbed by the coolant during its use in the engine.

Recycle machines filter out these metals and dirt and reinstall the depleted additives. The recycled coolant, restored to be like new, can be reinstalled into the vehicle.

CAUTION: Most vehicle manufacturers warn that antifreeze coolant should not be reused unless it is recycled and the additives restored.

DISPOSING OF USED COOLANT

Used coolant drained from vehicles can usually be disposed of by combining it with used engine oil. The equipment used for recycling the used engine oil can easily separate the coolant from the waste oil. Check with recycling companies authorized by local or state governments for the exact method recommended for disposal in your area.

RADIATOR DESIGN AND FUNCTION

Two types of radiator cores are in common use in domestic vehicles—the serpentine fin core and the plate fin core. In each of these types the coolant flows through oval-shaped **core tubes.** Heat is transferred through the tube wall and soldered joint to **fins.** The fins are exposed to airflow, which removes heat from the radiator and carries it away. See Figures 20–14 through 20–16.

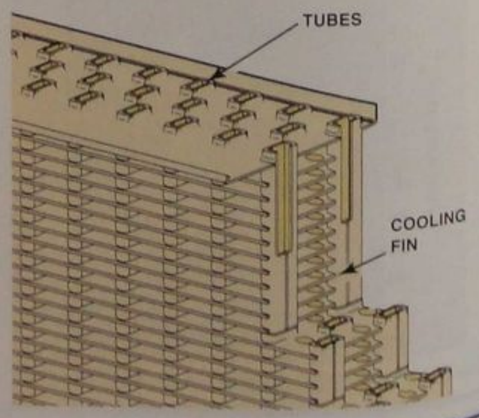


Figure 20–14 The tubes and fins of the radiator core.

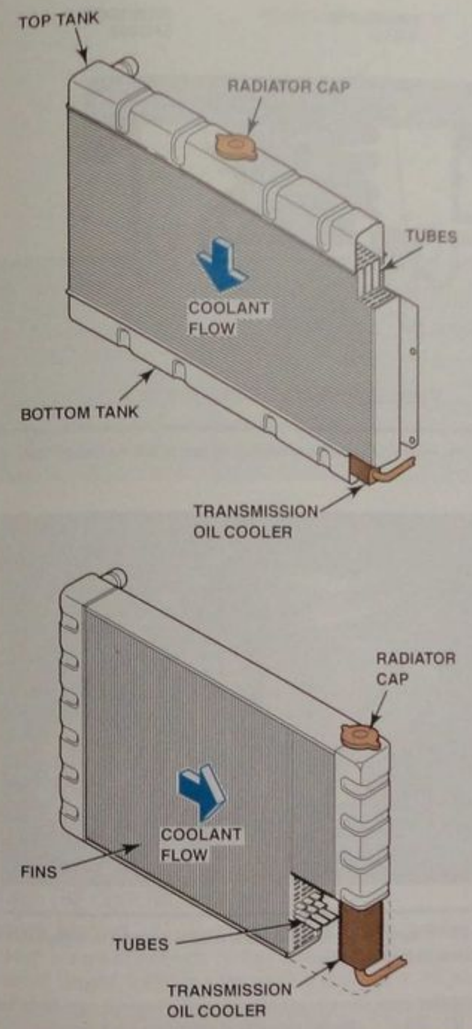


Figure 20–15 A radiator may be either a down-flow or a cross-flow type.



Figure 20–16 Cutaway of a typical radiator showing restriction of tubes. Changing antifreeze frequently helps prevent this type of problem.

Older automobile radiators were made from yellow brass. Since the 1980s, most radiators have been made from aluminum. These materials are corrosion resistant, have good heat-transferring ability, and are easily formed.

Core tubes are made from 0.0045- to 0.012-inch (0.1 to 0.3-millimeter) sheet brass or aluminum, using the thinnest possible materials for each application. The metal is rolled into round tubes and the joints are sealed with a locking seam.

The main limitation of heat transfer in a cooling system is in the transfer from the radiator to the air. Heat transfers from the water to the fins as much as seven times faster than heat transfers from the fins to the air, assuming equal surface exposure. The radiator must be capable of removing an amount of heat energy approximately equal to the heat energy of the power produced by the engine. *Each horsepower is equivalent to 42 Btu (10,800 calories) per minute.* As the engine power is increased, the heat-removing requirement of the cooling system is also increased.

With a given frontal area, radiator capacity may be increased by increasing the core thickness, packing more material into the same volume, or both. The radiator capacity may also be increased by placing a shroud around the fan so that more air will be pulled through the radiator.

NOTE: The lower air dam in the front of the vehicle is used to help direct the air through the radiator. If this air dam is broken or missing, the engine may overheat, especially during highway driving due to the reduced airflow through the radiator.

Radiator headers and tanks that close off the ends of the core were made of sheet brass 0.020 to 0.050 inch (0.5 to 1.25 millimeters) thick and now are made of molded plastic. When a transmission oil cooler is used in the radiator, it is placed in the outlet tank, where the coolant has the lowest temperature. See Figure 20–17.

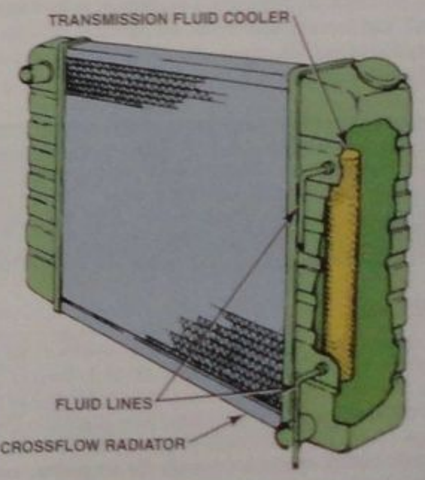


Figure 20–17 Many vehicles equipped with an automatic transmission use a transmission fluid cooler installed in one of the radiator tanks.

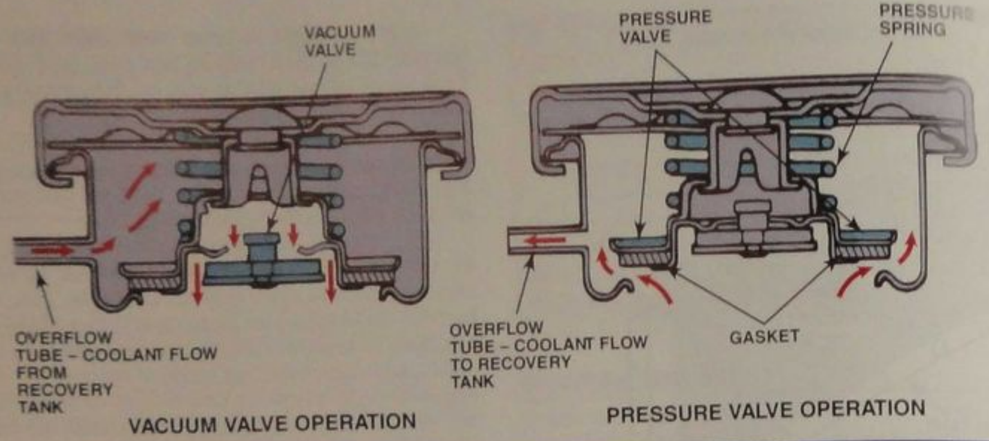


Figure 20–18 The pressure valve maintains the system pressure and allows excess pressure to vent. The vacuum valve allows coolant to return to the system from the recovery tank.

PRESSURE CAP

The filler neck is fitted with a pressure cap. The cap has a spring-loaded valve that closes the cooling system vent. This causes cooling pressure to build up to the pressure setting of the cap. At this point, the valve will release the excess pressure to prevent system damage. See Figure 20–18.

Engine cooling systems are pressurized to raise the boiling temperature of the coolant. *The boiling temperature will increase by approximately 3°F (1.6°C) for each pound of increase in pressure.* At standard atmospheric pressure, water will boil at 212°F (100°C). With a 15 PSI (100 kPa) pressure cap, water will boil at 257°F (125°C), which is a maximum operating temperature for an engine.

The high coolant system temperature serves two functions:

1. It allows the engine to run at an efficient temperature, close to 200°F (93°C), with no danger of boiling the coolant.
2. The higher the coolant temperature, the more heat the cooling system can transfer. The heat transferred by the cooling system is proportional to the temperature difference between the coolant and the outside air. This characteristic has led to the design of small, high-pressure radiators that are capable of handling large quantities of heat. For proper cooling, the system must have the right pressure cap correctly installed.

NOTE: The proper operation of the pressure cap is especially important at high altitudes. The boiling point of water is lowered by about 1°F for every 550-foot increase in altitude. Therefore in Denver, Colorado (altitude 5,280 feet), the boiling point of water is about 202°F, and at the top of Pike's Peak in Colorado (14,110 feet) water boils at 186°F.

SURGE TANK

Some vehicles use a **surge tank,** which is located at the highest level of the cooling system and holds about 1 quart (1 liter) of coolant. A hose attaches to the bottom of the surge tank to the inlet side of the water pump. A smaller bleed hose attaches to the side of the surge tank to the highest point of the radiator. The bleed line allows some coolant circulation through the surge tank, and air in the system will rise below the radiator cap and be forced from the system if the pressure in the system exceeds the rating of the radiator cap. See Figure 20–19.



Figure 20–19 Some vehicles use a surge tank, which is located at the highest level of the cooling system, with a radiator cap.

TECH TIP ✔ **Working Better Under Pressure**

A problem that sometimes occurs with a high-pressure cooling system involves the water pump. For the pump to function, the inlet side of the pump must have a lower pressure than its outlet side. If inlet pressure is lowered too much, the coolant at the pump inlet can boil, producing vapor. The pump will then spin the coolant vapors and not pump coolant. This condition is called pump **cavitation.** Therefore, a radiator cap could be the cause of an overheating problem. A pump will not pump enough coolant if not kept under the proper pressure for preventing vaporization of the coolant.

METRIC RADIATOR CAPS

According to the *SAE Handbook*, all radiator caps must indicate their nominal (normal) pressure rating. Most original equipment radiator caps are rated at about 14 to 16 PSI (97 to 110 kPa).

However, many vehicles manufactured in Japan or Europe have the radiator pressure indicated in a unit called a **bar.** One bar is the pressure of the atmosphere at sea level, or about 14.7 PSI. The following conversion can be used when replacing a radiator cap to make certain it matches the pressure rating of the original.

Bar or Atmospheres	Pounds per Square Inch (PSI)
1.1	16
1.0	15
0.9	13
0.8	12
0.7	10
0.6	9
0.5	7

NOTE: Many radiator repair shops use a 7-PSI (0.5-bar) radiator cap on a repaired radiator. A 7-PSI cap can still provide boil protection of 21°F (3°F × 7 PSI = 21°F) above the boiling point of the coolant. For example, if the boiling point of the antifreeze coolant is 223°F, 21°F is added for the pressure cap, and boil over will not occur until about 244°F (223°F + 21°F = 244°F). Even though this lower-pressure radiator cap does provide some protection and will also help protect the radiator repair, the coolant can still boil *before* the "hot" dash warning light comes on and therefore, should not be used.

COOLANT RECOVERY SYSTEM

Excess pressure usually forces some coolant from the system through an overflow. Most cooling systems connect the overflow to a plastic reservoir to hold excess coolant while the system is hot. See Figure 20–20.

When the system cools, the pressure in the cooling system is reduced and a partial vacuum forms. This pulls the coolant from the plastic container back into the cooling system, keeping the system full. Because of this action, this system is called a **coolant recovery system.** The filler cap used on a coolant system without a coolant saver is fitted with a vacuum valve. This valve allows air to reenter the system as the system cools so that the radiator parts will not collapse under the partial vacuum.

TESTING THE COOLING SYSTEM

Pressure Testing Pressure testing using a hand-operated pressure tester is a quick and easy cooling system test. The radiator cap is removed (engine cold!) and the tester is attached in the place of the radiator cap. By operating the plunger on the pump, the entire cooling system is pressurized. See Figure 20–21.

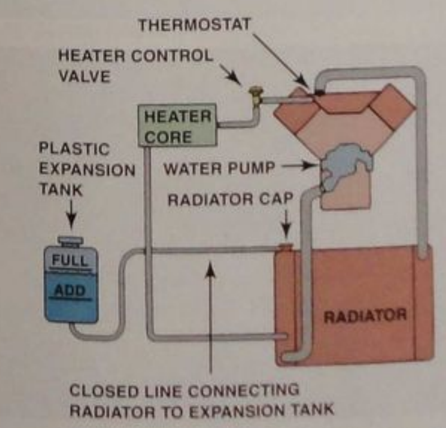


Figure 20–20 The level in the coolant recovery system raises and lowers with engine temperature.



Figure 20–21 Pressure testing the cooling system. A typical hand-operated pressure tester applies pressure equal to the radiator cap pressure. The pressure should hold; if it drops, this indicates a leak somewhere in the cooling system. An adapter is used to attach the pump to the cap to determine if the radiator can hold pressure, and release it when pressure rises above its maximum rated pressure setting.

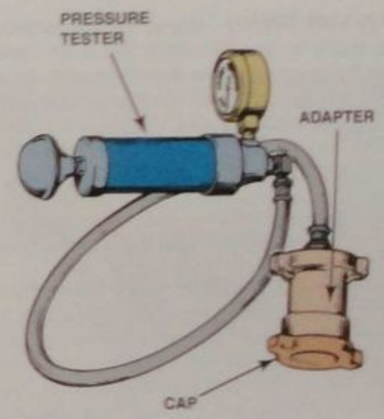


Figure 20–22 The pressure cap should be checked for proper operation using a pressure tester as part of the cooling system diagnosis.

CAUTION: Do not pump up the pressure beyond that specified by the vehicle manufacturer. Most systems should not be pressurized beyond 14 PSI (100 kPa). If a greater pressure is used, it may cause the water pump, radiator, heater core, or hoses to fail.

If the cooling system is free from leaks, the pressure should stay and not drop. If the pressure drops, look for evidence of leaks anywhere in the cooling system including:

1. Heater hoses
2. Radiator hoses
3. Radiator
4. Heat core
5. Cylinder head
6. Core plugs in the side of the block or cylinder head

Pressure testing should be performed whenever there is a leak or suspected leak. The pressure tester can also be used to test the radiator cap. An adapter is used to connect the pressure tester to the radiator cap. Replace any cap that will not hold pressure. See Figure 20–22.



Figure 20–23 Use dye specifically made for coolant when checking for leaks using a black light.

Coolant Dye Leak Testing One of the best methods to check for a coolant leak is to use a fluorescent dye in the coolant. Use a dye designed for coolant. Operate the vehicle with the dye in the coolant until the engine reaches normal operating temperature. Use a black light to inspect all areas of the cooling system. When there is a leak, it will be easy to spot because the dye in the coolant will be seen as bright green. See Figure 20–23.

TECH TIP ✓ **Use Distilled Water in the Cooling System**

Two technicians are discussing refilling the radiator after changing antifreeze. One technician says that distilled water is best to use because it does not contain minerals that can coat the passages of the cooling system. The other technician says that any water that is suitable to drink can be used in a cooling system. Both technicians are correct. If water contains minerals, however, it can leave deposits in the cooling system that could prevent proper heat transfer. Because the mineral content of most water is unknown, distilled water, which has no minerals, is better to use. Although the cost of distilled water must be considered, the amount of water required [usually about 2 gallons (8 liters) or less of water] makes the expense minor in comparison with the cost of radiator or cooling system failure.

WATER PUMP

Operation The water pump (also called a coolant pump) is driven by a belt from the crankshaft or driven by the camshaft. Coolant recirculates from the radiator to the engine and back to the radiator. Low-temperature coolant leaves the radiator by the bottom outlet. It is pumped into the warm engine block, where it picks up some heat. From the block, the warm coolant flows to the hot cylinder head, where it picks up more heat.

NOTE: Some engines use **reverse cooling.** This means that the coolant flows from the radiator to the cylinder head(s) before flowing to the engine block.

Water pumps are not positive displacement pumps. The water pump is a **centrifugal pump** that can move a large volume of coolant without increasing the pressure of the coolant. The pump pulls coolant in at the center of the **impeller.** Centrifugal force

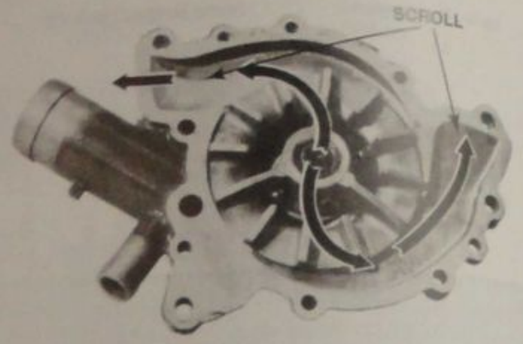


Figure 20–24 Coolant flow through the impeller and scroll of a coolant pump for a V-type engine.

throws the coolant outward so that it is discharged at the impeller tips. This can be seen in Figure 20–24.

As engine speeds increase, more heat is produced by the engine and more cooling capacity is required. The pump impeller speed increases as the engine speed increases to provide extra coolant flow at the very time it is needed.

Coolant leaving the pump impeller is fed through a **scroll.** The scroll is a smoothly curved passage that changes the fluid flow direction with minimum loss in velocity. The scroll is connected to the front of the engine so as to direct the coolant into the engine block. On V-type engines, two outlets are usually used, one for each cylinder bank. Occasionally, diverters are necessary in the water pump scroll to equalize coolant flow between the cylinder banks of a V-type engine to equalize the cooling.

FREQUENTLY ASKED QUESTION ???

How Much Coolant Can a Water Pump Pump?

A typical water pump can move a maximum of about 7,500 gallons (28,000 liters) of coolant per hour, or recirculate the coolant in the engine over 20 times per minute. This means that a water pump could be used to empty a typical private swimming pool in an hour! The slower the engine speed, the less power is consumed by the water pump. However, even at 35 miles per hour (56 kilometers per hour), the typical water pump still moves about 2,000 gallons (7,500 liters per hour or 1/2 gallon (2 liters) per second! See Figure 20–25.



Figure 20–25 A demonstration engine showing the amount of water that can be circulated through the cooling system.



Figure 20–26 This severely corroded water pump could not circulate enough coolant to keep the engine cool. As a result, the engine overheated and blew a head gasket.



Figure 20–27 The bleed weep hole in the water pump allows coolant to leak out of the pump and not be forced into the bearing. If the bearing failed, more serious damage could result.

Service A worn impeller on a water pump can reduce the amount of coolant flow through the engine. See Figure 20–26. If the seal of the water pump fails, coolant will leak out of the hole as seen in Figure 20–27. The hole allows coolant to escape without getting trapped and forced into the water pump bearing assembly.

If the bearing is defective, the pump will usually be noisy and will have to be replaced. Before replacing a water pump that has failed because of a loose or noisy bearing, be sure to do all of the following:

1. Check belt tension
2. Check for bent fan
3. Check fan for balance

If the water pump drive belt is too tight, excessive force may be exerted against the pump bearing. If the cooling fan is bent or out of balance, the resulting vibration can damage the water pump bearing. See Figure 20–28.

COOLING FANS

Air is forced across the radiator core by a cooling fan. On older engines used in rear-wheel-drive vehicles, it is attached to a fan hub that is pressed on the water pump shaft. See Figure 20–29.

Many installations with rear-wheel drive and all transverse engines drive the fan with an electric motor. See Figure 20–30.



Figure 20–28 A cutaway of a typical water pump showing the long bearing assembly and the seal. The weep hole is located between the seal and the bearing. If the seal fails, then coolant flows out of the weep hole to prevent the coolant from damaging the bearing.

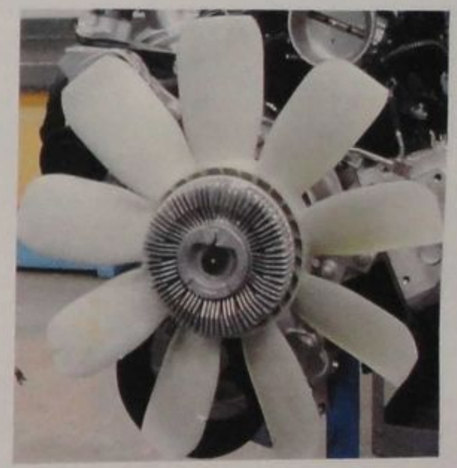


Figure 20–29 A typical engine-driven cooling fan.

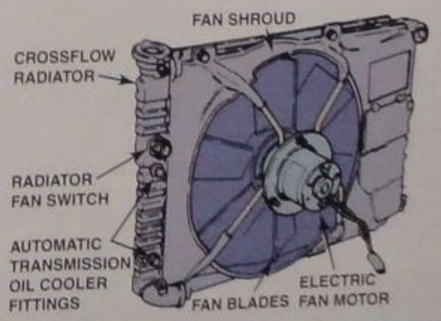


Figure 20–30 A typical electric cooling fan assembly showing the radiator and related components.

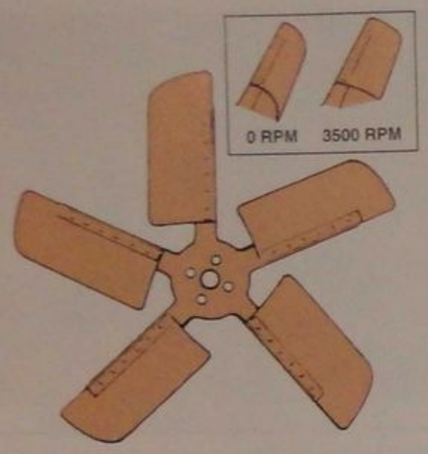


Figure 20–31 Flexible cooling fan blades change shape as the engine speed changes.

NOTE: Most electric cooling fans are computer controlled. To save energy, most cooling fans are turned off whenever the vehicle is traveling faster than 35 mph (55 km/h). The ram air from the vehicle's traveling at that speed should be enough to keep the radiator cool. Of course, if the computer senses that the temperature is still too high, the computer will turn on the cooling fan, to "high," if possible, in an attempt to cool the engine to avoid severe engine damage.

The fan is designed to move enough air at the lowest fan speed to cool the engine when it is at its highest coolant temperature. The fan shroud is used to increase the cooling system efficiency. The horsepower required to drive the fan increases at a much faster rate than the increase in fan speed. Higher fan speeds also increase fan noise. Fans with flexible plastic or flexible steel blades have been used. These fans have high blade angles that pull a high volume of air when turning at low speeds. As the fan speed increases, the fan blade angle flattens, reducing the horsepower required to rotate the blade at high speeds. See Figure 20–31.

THERMOSTATIC FANS

Since the early 1980s, most cooling fans have been computer-controlled electric motor units. On some rear-wheel-drive vehicles, a thermostatic cooling fan is driven by a belt from the crankshaft. It turns faster as the engine turns faster. Generally, the engine is required to produce more power at higher speeds. Therefore, the cooling system will also transfer more heat. Increased fan speed aids in the required cooling. Engine heat also becomes critical at low engine speeds in traffic where the vehicle moves slowly.

The thermal fan is designed so that it uses little power at high engine speeds and minimizes noise. The thermal fan has a **silicone coupling** fan drive mounted between the drive pulley and the fan.

HINT: Whenever diagnosing an overheating problem, look carefully at the cooling fan. If silicone is leaking, then the fan may not be able to function correctly and should be replaced.

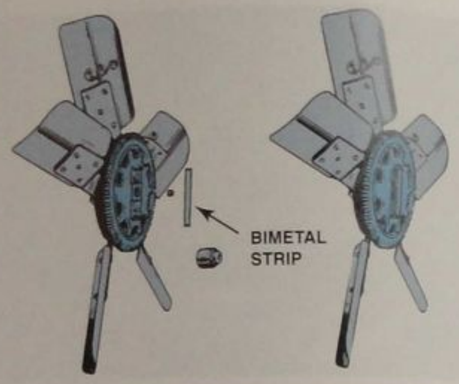


Figure 20–32 The bimetallic temperature sensor spring controls the amount of silicone that is allowed into the drive unit, which controls the speed of the fan.



Figure 20–33 A typical electric cooling fan assembly after being removed from them the vehicle.

A second type of thermal fan has a **thermostatic spring** added to the silicone coupling fan drive. The thermostatic spring operates a valve that allows the fan to freewheel when the radiator is cold. As the radiator warms to about 150°F (65°C), the air hitting the thermostatic spring will cause the spring to change its shape. The new shape of the spring opens a valve that allows the drive to operate like the silicone coupling drive. When the engine is very cold, the fan may operate at high speeds for a short time until the drive fluid warms slightly. The silicone fluid will then flow into a reservoir to let the fan speed drop to idle. See Figure 20–32.

ELECTRIC COOLING FANS

Air is forced across the radiator core by a cooling fan. On older engines used in rear-wheel-drive vehicles, it is attached to a fan hub that is pressed on the water pump shaft. Many installations with rear-wheel drive and all transverse engines drive the fan with an electric motor. See Figure 20–33.

A typical engine cooling fan system consists of one cooling fan and two relays or two separate fans. If only one fan is used, the cooling fan has two windings in the motor. One winding is for low speed and the other winding is for high speed. When the cooling fan 1 relay is energized, voltage is sent to the cooling fan low-speed winding. The ECM controls the high-speed fan operation by grounding the cool fan 2 relay control circuit. When the cooling fan 2 relay is energized, voltage is sent to the cooling fan high-speed winding. The cooling fan motor has its own ground circuit.

The ECM commands Low Speed Fans ON under the following conditions:

- Engine coolant temperature (ECT) exceeds approximately 223°F (106°C).
- A/C refrigerant pressure exceeds 190 PSI (1, 310 kPa).

After the vehicle is shut off, the ECT at key-off is greater than 284°F (140°C) and system voltage is more than 12 volts. The fans will stay on for approximately 3 minutes.

The ECM commands High Speed Fans ON under the following conditions:

- ECT reaches 230°F (110°C).
- A/C refrigerant pressure exceeds 240 PSI (1, 655 kPa).
- When certain diagnostic trouble codes (DTCs) set.

To prevent a fan from cycling ON and OFF excessively at idle, the fan may not turn OFF until the ignition switch is moved to the OFF position or the vehicle speed exceeds approximately 10 mph.

NOTE: To save energy and to improve fuel economy, most cooling fans are turned off whenever the vehicle is traveling faster than 35mph (55 km/h). The ram air from the vehicle's traveling at that speed should be enough to keep the radiator cool. Of course, if the computer senses that the temperature is still too high, the computer will turn on the cooling fan, to "high," if possible, in an attempt to cool the engine to avoid severe engine damage. Some engines, such as the General Motors NorthStar engine, can disable four of the eight cylinders from firing to air cool the engine in the event of a severe overheating condition.

TECH TIP ✔ **Cause and Effect**

A common cause of overheating is an inoperative cooling fan. Most front-wheel-drive vehicles and many rear-wheel-drive vehicles use electric motor-driven cooling fans. A fault in the cooling fan circuit often causes overheating during slow city-type driving.

Even slight overheating can soften or destroy rubber vacuum hoses and gaskets. The gaskets most prone to overheating damage are rocker cover (valve cover) and intake manifold gaskets. Gasket and/or vacuum hose failure often results in an air (vacuum) leak that leans the air–fuel mixture. The resulting lean mixture burns hotter in the cylinders and contributes to the overheating problem.

The vehicle computer can often compensate for a minor air leak (vacuum leak), but more severe leaks can lead to driveability problems; especially idle quality problems. If the leak is severe enough, a lean diagnostic trouble code (DTC) may be present. If a lean code is not set, the vehicle's computer may indicate a defective or out-of-range MAP sensor code in diagnostics.

Therefore, a typical severe engine problem can often be traced back to a simple, easily repaired, cooling system-related problem.

COOLANT TEMPERATURE WARNING LIGHT

Most vehicles are equipped with a heat sensor for the engine operating temperature. If the "hot" light comes on during driving (or the temperature gauge goes into the red danger zone), then the coolant temperature is about 250° to 258°F (120° to 126°C), which is still *below* the boiling point of the coolant (assuming a properly operating pressure cap and system). If this happens, follow these steps:

Step #1 Shut off the air conditioning and turn on the heater. The heater will help rid the engine of extra heat. Set the blower speed to high.

Step #2 If possible, shut the engine off and let it cool. (This may take over an hour.)

Step #3 Never remove the radiator cap when the engine is hot.

Step #4 Do not continue to drive with the hot light on, or serious damage to your engine could result.

Step #5 If the engine does not feel or smell hot, it is possible that the problem is a faulty hot light sensor or gauge. Continue to drive, but to be safe, stop occasionally and check for any evidence of overheating or coolant loss.

COMMON CAUSES OF OVERHEATING

Overheating can be caused by defects in the cooling system. Some common causes of overheating include:

1. Low coolant level
2. Plugged, dirty, or blocked radiator
3. Defective fan clutch or electric fan
4. Incorrect ignition timing
5. Low engine oil level
6. Broken fan belt
7. Defective radiator cap
8. Dragging brakes
9. Frozen coolant (in freezing weather)
10. Defective thermostat
11. Defective water pump (the impeller slipping on the shaft internally)

REAL WORLD FIX **Highway Overheating**

A vehicle owner complained of an overheating vehicle, but the problem occurred only while driving at highway speeds. The vehicle, see Figure 20–34, would run in a perfectly normal manner in city-driving situations.

The technician flushed the cooling system and replaced the radiator cap and the water pump, thinking that restricted coolant flow was the cause of the problem. Further testing revealed coolant spray out of one cylinder when the engine was turned over by the starter with the spark plugs removed.

A new head gasket solved the problem. Obviously, the head gasket leak was not great enough to cause any problems until the engine speed and load created enough flow and heat to cause the coolant temperature to soar.

The technician also replaced the oxygen (O_2) sensor, because some coolant contains phosphates and silicates that often contaminate the sensor. The deteriorated oxygen sensor could have contributed to the problem.



Figure 20–34 When an engine overheats, often the coolant overflow container boils.

COOLING SYSTEM MAINTENANCE

The cooling system is one of the most maintenance-free systems in the engine. Normal maintenance involves an occasional check on the coolant level. It should also include a visual inspection for signs of coolant system leaks and for the condition of the coolant hoses and fan drive belts.

CAUTION: The coolant level should only be checked when the engine is cool. Removing the pressure cap from a hot engine will release the cooling system pressure while the coolant temperature is above its atmospheric boiling temperature. When the cap is removed, the pressure will instantly drop to atmospheric pressure level, causing the coolant to boil immediately. Vapors from the boiling liquid will blow coolant from the system. Coolant will be lost, and someone may be injured or burned by the high-temperature coolant that is blown out of the filler opening.

The coolant-antifreeze mixture is renewed at periodic intervals. Some vehicle manufacturers recommend that coolant system stop-leak pellets be installed whenever the coolant is changed.

CAUTION: General Motors recommends the use of these stop-leak pellets in only certain engines. Using these pellets in some engines could cause a restriction in the cooling system and an overheating condition.

Drive belt condition and proper installation are important for the proper operation of the cooling system.

FLUSH AND REFILL

Manufacturers recommend that a cooling system be flushed and that the antifreeze be replaced at specified intervals. Draining coolant when the engine is cool eliminates the danger of being injured by hot coolant. The radiator is drained by opening a petcock in the bottom tank, and the coolant in the block is drained into a suitable container by opening plugs located in the lower part of the cooling passage.

Water should be run into the filler opening while the drains remain open. Flushing should be continued until only clear water comes from the system.

The volume of the cooling system must be determined. It is specified in the owner's manual and in the engine service manual. The antifreeze quantity needed for the protection desired is shown on a chart that comes with the antifreeze. Open the bleeder valves and add the correct amount of the specified type of antifreeze followed by enough water to completely fill the system. See Figure 20–35. The coolant recovery reservoir should be filled to the "level-cold" mark with the correct antifreeze mixture.

BURPING THE SYSTEM

In most systems, small air pockets can occur. The engine must be thoroughly warmed to open the thermostat. This allows full coolant flow to remove the air pockets. The heater must also be turned to full heat.



(a)



(b)

Figure 20–35 (a) Chrysler recommends that the bleeder valve be opened whenever refilling the cooling system. (b) Chrysler also recommends that a clear plastic hose (1/4" ID) be attached to the bleeder valve and directed into a suitable container to keep from spilling coolant onto the ground and on the engine and to allow the technician to observe the flow of coolant for any remaining oil bubbles.

HINT: The cooling system will not function correctly if air is not released (burped) from the system after a refill. An easy method involves replacing the radiator cap after the refill, but only to the first locked position. Drive the vehicle for several minutes and check the radiator level. Without the radiator cap tightly sealed, no pressure will build in the cooling system. Driving the vehicle helps circulate the coolant enough to force all air pockets up and out of the radiator filler. Top off the radiator after burping and replace the radiator cap to the fully locked position. Failure to burp the cooling system to remove all the air will often result in lack of heat from the heater and may result in engine overheating.

HOSES

Coolant system hoses are critical to engine cooling. As the hoses get old, they become either soft or brittle and sometimes swell in diameter. Their condition depends on their material and on the engine service conditions. If a hose breaks while the engine is running, all coolant will be lost. A hose should be replaced anytime it appears to be abnormal. See Figure 20–36.

HINT: To make hose removal easier and to avoid possible damage to the radiator, use a utility knife and slit the hose lengthwise. Then simply peel the hose off.

Care should be taken to avoid bending the soft metal hose neck on the radiator. The hose neck should be cleaned before a new hose is slipped in place. The clamp is placed on the hose; then the hose is pushed fully over the neck. The hose should be cut so that the clamp is close to the bead on the neck. This is especially important on aluminum hose necks to avoid corrosion. When the hoses are in place and the drain petcock is closed, the cooling system can be refilled with the correct coolant mixture.

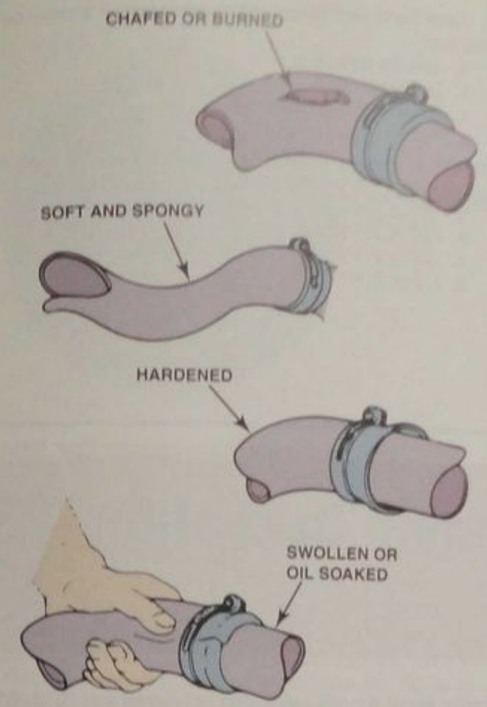


Figure 20–36 All cooling system hoses should be checked for wear or damage.

CLEANING THE RADIATOR EXTERIOR

Overheating can result from exterior radiator plugging as well as internal plugging. External plugging is caused by dirt and insects. This type of plugging can be seen if you look straight through the radiator while a light is held behind it. It is most likely to occur on off-road vehicles. The plugged exterior of the radiator core can usually be cleaned with water pressure from a hose. The water is aimed at the *engine side* of the radiator. The water should flow freely through the core at all locations. If this does not clean the core, the radiator should be removed for cleaning at a radiator shop.

TECH TIP ✓ **Quick and Easy Cooling System Problem Diagnosis**

If overheating occurs in slow, stop-and-go traffic, the usual cause is low airflow through the radiator. Check for airflow blockages or cooling fan malfunction. If overheating occurs at highway speeds, the cause is usually a radiator or coolant circulation problem. Check for a restricted or clogged radiator.

SUMMARY

1. The purpose and function of the cooling system is to maintain proper engine operating temperature.
2. The thermostat controls engine coolant temperature by opening at its rated opening temperature to allow coolant to flow through the radiator.
3. Most antifreeze coolant is ethylene glycol-based.
4. Used coolant should be recycled whenever possible.
5. Coolant fans are designed to draw air through the radiator to aid in the heat transfer process, drawing the heat from the coolant and transferring it to the outside air through the radiator.
6. The cooling system should be tested for leaks using a hand-operated pressure pump.
7. The freezing and boiling temperature of the coolant can be tested using a hydrometer.

REVIEW QUESTIONS

1. Explain why the normal operating coolant temperature is about 200° to 220°F (93° to 104°C).
2. Explain why a 50/50 mixture of antifreeze and water is commonly used as a coolant.
3. Explain the flow of coolant through the engine and radiator.
4. Why is a cooling system pressurized?
5. Describe the difference between a series and a parallel coolant flow system.
6. Explain the purpose of the coolant system bypass.
7. Describe how to perform a drain, flush, and refill procedure on a cooling system.
8. Explain the operation of a thermostatic cooling fan.
9. List five common causes of overheating.

CHAPTER QUIZ

1. Permanent antifreeze is mostly _____.
   a. Methanol
   b. Glycerin
   c. Kerosene
   d. Ethylene glycol
2. As the percentage of antifreeze in the coolant increases, _____.
   a. The freeze point decreases (up to a point)
   b. The boiling point decreases
   c. The heat transfer increases
   d. All of the above occurs
3. Heat transfer is improved from the coolant to the air when _____.
   a. The temperature difference is great
   b. The temperature difference is small
   c. The coolant is 95% antifreeze
   d. Both a and c
4. A water pump is a positive displacement-type pump.
   a. True
   b. False
5. Engine-driven water pumps _____.
   a. Only work at idle and low speeds; the pump is disengaged at higher speeds
   b. Use engine oil as a lubricant and coolant
   c. Rotate at about the same speed as the engine
   d. Disengage during freezing weather to prevent radiator failure
6. The procedure that should be used when refilling an empty cooling system includes the following _____.
   a. Determine capacity, then fill the cooling system halfway with antifreeze and the rest of the way with water
   b. Fill completely with antifreeze, but mix a 50/50 solution for the overflow bottle
   c. Fill the block and one-half of the radiator with 100% pure antifreeze and fill the rest of the radiator with water
   d. Fill the radiator with antifreeze, start the engine, drain the radiator, and refill with a 50/50 mixture of antifreeze and water

7. Which statement is *true* about thermostats?
   a. The temperature marked on the thermostat is the temperature at which the thermostat should be fully open.
   b. Thermostats often cause overheating.
   c. The temperature marked on the thermostat is the temperature at which the thermostat should start to open.
   d. Both a and b.
8. Technician A says that the radiator should always be inspected for leaks and proper flow before installing a rebuilt engine. Technician B says that overheating during slow city driving can only be due to a defective electric cooling fan. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. An engine fails to reach normal operating temperature. Which is the most likely fault?
   a. Defective thermostat
   b. Low coolant level
   c. Wrong antifreeze coolant
   d. Partially clogged radiator
10. The normal operating temperature (coolant temperature) of an engine equipped with a 195°F thermostat is _____.
   a. 175° to 195°F
   b. 185° to 205°F
   c. 195° to 215°F
   d. 175° to 215°F

CHAPTER 21

Lubrication System Operation and Diagnosis

OBJECTIVES: After studying Chapter 21, the reader will be able to: Prepare for Engine Repair (A1) ASE certification test content area "D" (Lubrication and Cooling Systems Diagnosis and Repair). • Explain engine oil ratings. • Describe how an oil pump and engine lubrication work. • Discuss how and when to change the oil and filter. • Explain how to inspect an oil pump for wear.

KEY TERMS: boundary lubrication • hydrodynamic lubrication • longitudinal header • oil gallery • positive displacement pump • pressure regulating valve • viscosity • windage tray

Engine oil is the lifeblood of any engine. The purposes of engine oil include the following:

1. *Lubricating* all moving parts to prevent wear
2. Helping to *cool* the engine
3. Helping to *seal* piston rings
4. *Cleaning*, and holding dirt in suspension in the oil until it can be drained from the engine
5. *Neutralizing* acids that are formed as the result of the combustion process
6. *Reducing* friction
7. *Preventing* rust and corrosion

LUBRICATION PRINCIPLES

Lubrication between two moving surfaces results from an oil film that separates the surfaces and supports the load. See Figure 21–1.

Although oil does not compress, it does leak out around the oil clearance between the shaft and the bearing. In some cases, the oil film is thick enough to keep the surfaces from seizing, but can allow some contact to occur. This condition is called **boundary lubrication.** The specified oil viscosity and oil clearances must be adhered to during service to help prevent boundary lubrication and wear from occurring, which usually happens when the engine is under a heavy load and low speeds. The movement of the shaft helps prevent contact with the bearing. If oil were put on a flat surface and a heavy block were pushed across the surface, the block would slide more easily than if it were pushed across a dry surface. The reason for this is that a wedge-shaped oil film is built up between the moving block and the surface, as illustrated in Figure 21–2. This wedging action is called **hydrodynamic**

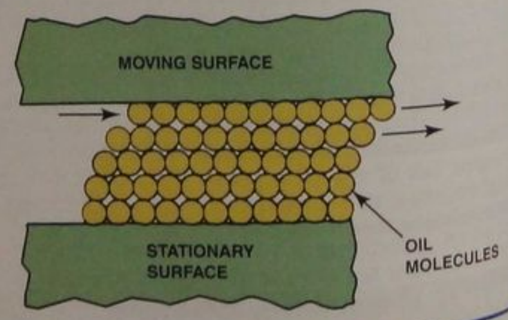


Figure 21–1 Oil molecules cling to metal surfaces but easily slide against each other.

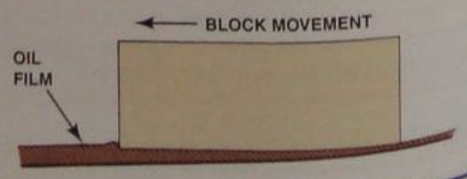


Figure 21–2 Wedge-shaped oil film developed below a moving block.

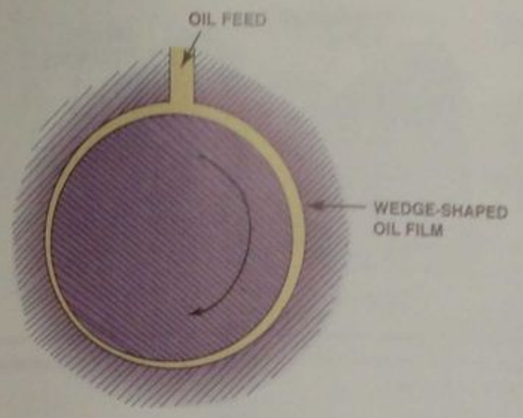


Figure 21–3 Wedge-shaped oil film curved around a bearing journal.

lubrication and depends on the force applied to how fast the speed between the objects and the thickness of the oil. Thickness of oil is called the **viscosity** and is defined as the ability of the oil to resist flow. High-viscosity oil is thick and low-viscosity oil is thin. The prefix *hydro-* refers to liquids, as in hydraulics, and *dynamic* refers to moving materials. Hydrodynamic lubrication occurs when a wedge-shaped film of lubricating oil develops between two surfaces that have relative motion between them. See Figure 21–3.

The engine oil pressure system feeds a continuous supply of oil into the lightly loaded part of the bearing oil clearance. Hydrodynamic lubrication takes over as the shaft rotates in the bearing to produce a wedge-shaped hydrodynamic oil film that is curved around the bearing. This film supports the bearing and reduces the turning effort to a minimum when oil of the correct viscosity is used.

Most bearing wear occurs during the initial start-up. Wear continues until a hydrodynamic film is established.

ENGINE LUBRICATION SYSTEMS

The primary function of the engine lubrication system is to maintain a positive and continuous oil supply to the bearings. Engine oil pressure must be high enough to get the oil to the bearings with enough force to cause the oil flow that is required for proper cooling. The normal engine oil pressure range is from 10 to 60 PSI (200 to 400 kPa) (10 PSI per 1000 engine RPM). However, hydrodynamic film pressures developed in the high-pressure areas of the engine bearings may be over 1,000 PSI (6,900 kPa). The relatively low engine oil pressures obviously could not support these high bearing loads without hydrodynamic lubrication.

OIL PUMPS

All production automobile engines have a full-pressure oil system. The oil is drawn from the bottom of the oil pan and is forced into the lubrication system under pressure.

NOTE: The oil pump is the only engine component that uses unfiltered oil.

In most engines that use a distributor, the distributor drive gear meshes with a gear on the camshaft, as shown in Figures 21–4 and 21–5. The oil pump is driven from the end of the distributor

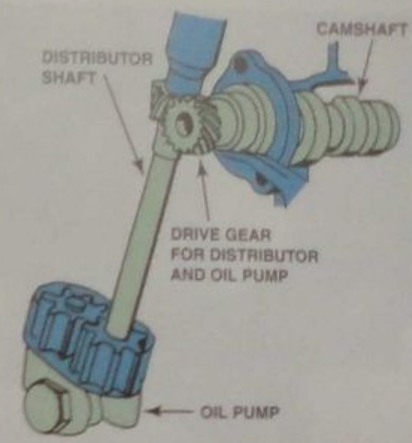


Figure 21–4 An oil pump driven by the camshaft.

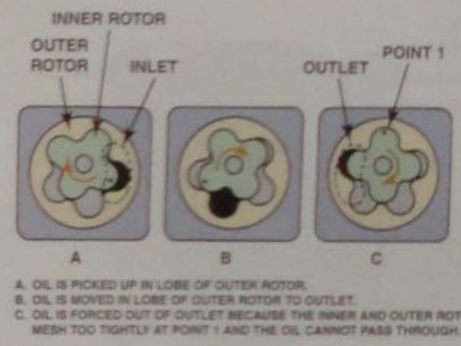


Figure 21–5 The operation of a rotor-type oil pump.

shaft, often with a hexagon-shaped shaft. Some engines have a short shaft gear that meshes with the cam gear to drive both the distributor and oil pump. With these drive methods, the pump turns at one-half engine speed. In other engines, the oil pump is driven by the front of the crankshaft, in a setup similar to that of an automatic transmission pump, so that it turns at the same speed as the crankshaft. Examples of a crankshaft-driven oil pump are shown in Figures 21–6 and 21–7.

Most automotive engines use one of two types of oil pumps: *gear* or *rotor*. All oil pumps are called **positive displacement pumps,** and each rotation of the pump delivers the same volume of oil; thus, everything that enters must exit. The gear-type oil pump consists of two spur gears in a close-fitting housing—one gear is driven while the other idles. As the gear teeth come out of mesh, they tend to leave a space, which is filled by oil drawn through the pump inlet. When the pump is pumping, oil is carried around the *outside* of each gear in the space between the gear teeth and the housing, as shown in Figure 21–8.

As the teeth mesh in the center, oil is forced from the teeth into an oil passage, thus producing oil pressure. The rotor-type oil pump consists essentially of a special lobe-shape gear meshing with the inside of a lobed rotor. The center lobed section is driven and the outer section idles. As the lobes separate, oil is drawn in just as it is drawn into gear-type pumps. As the pump rotates, it carries oil



Figure 21–6 A typical oil pump mounted in the front cover of the engine that is driven by the crankshaft.

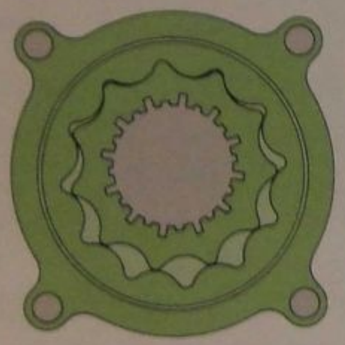


Figure 21–7 Gerotor-type oil pump driven by the crankshaft.

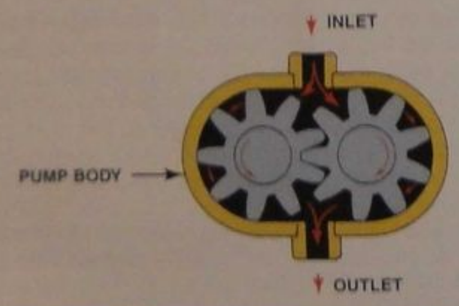


Figure 21–8 In a gear-type oil pump, the oil flows through the pump around the outside of each gear. This is an example of a positive displacement pump, wherein everything entering the pump must leave the pump.

around and between the lobes. As the lobes mesh, they force the oil out from between them under pressure in the same manner as the gear-type pump. The pump is sized so that it will maintain a pressure of at least 10 PSI (70 kPa) in the oil gallery when the engine is hot and idling. Pressure will increase by about 10 PSI for each 1000 RPM as the engine speed increases, because the engine-driven pump also rotates faster.

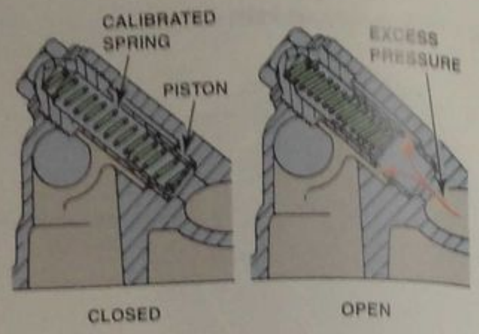


Figure 21–9 Oil pressure relief valves are spring loaded. The stronger the spring tension, the higher the oil pressure.

OIL PRESSURE REGULATION

In engines with a full-pressure lubricating system, maximum pressure is limited with a pressure relief valve. The relief valve (sometimes called the **pressure regulating valve**) is located at the outlet of the pump. The relief valve controls maximum pressure by bleeding off oil to the inlet side of the pump. See Figure 21–9.

The relief valve spring tension determines the maximum oil pressure. If a pressure relief valve is not used, the engine oil pressure will continue to increase as the engine speed increases. Maximum pressure is usually limited to the lowest pressure that will deliver enough lubricating oil to all engine parts that need to be lubricated. *Three to 6 gallons per minute are required to lubricate the engine.* The oil pump is made so that it is large enough to provide pressure at low engine speeds and small enough so that cavitation will not occur at high speed. Cavitation occurs when the pump tries to pull oil faster than it can flow from the pan to the pickup. When it cannot get enough oil, it will pull air. This puts air pockets or cavities in the oil stream. A pump is cavitating when it is pulling air or vapors.

NOTE: The reason for sheet-metal covers over the pickup screen is to prevent cavitation. Oil is trapped under the cover, which helps prevent the oil pump from drawing in air, especially during sudden stops or during rapid acceleration.

After the oil leaves the pump, it is delivered to the oil filter and then to the moving parts through drilled oil passages. See Figure 21–10. It needs no pressure after it reaches the parts that are to be lubricated. The oil film between the parts is developed and maintained by hydrodynamic lubrication. Excessive oil pressure requires more horsepower and provides no better lubrication than the minimum effective pressure.

FACTORS AFFECTING OIL PRESSURE

Oil pressure can only be produced when the oil pump has a capacity larger than all the "leaks" in the engine. The leaks are the clearances at end points of the lubrication system. The end points are the edges of bearings, the rocker arms, the connecting rod holes, and so on. These clearances are designed into the engine as are necessary for its proper operation. As the engine parts wear and clearance becomes greater, more oil will leak out. The oil pump *capacity* must be great enough to supply extra oil for these leaks. The capacity of the oil pump results from its size, rotating speed, and physical condition. If the pump is rotating slowly as the engine

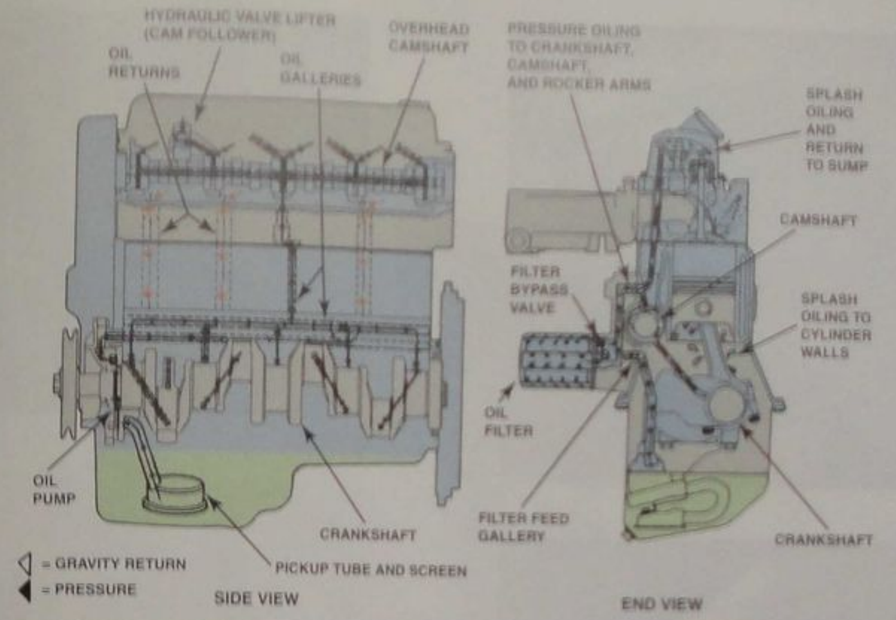


Figure 21–10 A typical engine design that uses both pressure and splash lubrication. Oil travels under pressure through the galleries (passages) to reach the top of the engine. Other parts are lubricated as the oil flows back down into the oil pan or is splashed onto parts.

is idling, oil pump capacity is low. *If the leaks are greater than the pump capacity, engine oil pressure is low.* As the engine speed increases, the pump capacity increases and the pump tries to force more oil out of the leaks. This causes the pressure to rise until it reaches the regulated maximum pressure.

The viscosity of the engine oil affects both the pump capacity and the oil leakage. Thin oil or oil of very low viscosity slips past the edges of the pump and flows freely from the leaks. Hot oil has a low viscosity, and therefore, a hot engine often has low oil pressure. Cold oil is more viscous (thicker) than hot oil. This results in higher pressures, even with the cold engine idling. High oil pressure occurs with a cold engine, because the oil relief valve must open further to release excess oil than is necessary with a hot engine. This larger opening increases the spring compression force, which in turn increases the oil pressure. Putting higher-viscosity oil in an engine will raise the engine oil pressure to the regulated setting of the relief valve at a lower engine speed.

OIL PUMP CHECKS

The cover is removed to check the condition of the oil pump. The gears and housing are examined for scoring. If the gears and housing are heavily scored, the entire pump should be replaced. If they are lightly scored, the clearances in the pump should be measured. These clearances include the space between the gears and housing, the space between the teeth of the two gears, and the space between the side of the gear and the pump cover. A feeler gauge is often used to make these measurements. Gauging plastic can be used to measure the space between the side of the gears and the cover. The oil pump should be replaced when excessive clearance or scoring is found. See Figure 21–11.

On most engines, the oil pump should be replaced as part of any engine work, especially if the cause for the repair is lack of lubrication.

NOTE: The oil pump is the "garbage pit" of the entire engine. Any and all debris is often forced through the gears and housing of an oil pump. See Figure 21–12.

Always refer to the manufacturer's specifications when checking the oil pump for wear. Typical oil pump clearances include the following:

1. End plate clearance: 0.0015 inch (0.04 millimeter)
2. Side (rotor) clearance: 0.012 inch (0.30 millimeter)
3. Rotor tip clearance: 0.010 inch (0.25 millimeter)
4. Gear end play clearance: 0.004 inch (0.10 millimeter)

All parts should also be inspected closely for wear. Check the relief valve for scoring and check the condition of the spring. When installing the oil pump, coat the sealing surfaces with engine assembly lubricant. This lubricant helps draw oil from the oil pan on initial start-up.

OIL PASSAGES IN THE BLOCK

From the filter, oil goes through a drilled hole that intersects with a drilled main **oil gallery** or **longitudinal header.** This is a long hole drilled from the front of the block to the back. Inline engines use one oil gallery; V-type engines may use two or three galleries. Passages drilled through the block bulkheads allow the oil to go from the main oil gallery to the main and cam bearings. See Figure 21–13 on page 183. In some engines, oil goes to the cam bearings first, and then to the main bearings.

It is important that the oil holes in the bearings match with the drilled passages in the bearing saddles so that the bearing can be properly lubricated. Over a long period of use, bearings will wear. This wear causes excess clearance. The excess clearance will allow too



(a)



(b)

Figure 21–11 (a) A visual inspection indicated that this pump cover was worn. (b) An embedded particle of something was found on one of the gears, making this pump worthless except for scrap metal.

much oil to leak from the side of the bearing. When this happens, there will be little or no oil left for bearings located farther downstream in the lubricating system. This is a major cause of bearing failure. If a new bearing were installed in place of the oil-starved bearing, it, too, would fail unless the bearing having the excess clearance was also replaced.

VALVE TRAIN LUBRICATION

The valve train components are the last parts to get oil from the oil pump. The oil gallery may intersect or have drilled passages to the valve lifter bores to lubricate the lifters. When hydraulic lifters are used, the oil pressure in the gallery keeps refilling them. On some engines, oil from the lifters goes up the center of a hollow pushrod to lubricate the pushrod ends, the rocker arm pivot, and the valve stem tip. See Figure 21–14. In other engines, an oil passage is drilled from either the gallery or a cam bearing to the block deck, where it matches with a gasket hole and a hole drilled in the head to carry



(a)



(b)

Figure 21–12 (a) The oil pump is the only part in an engine that gets unfiltered engine oil. The oil is drawn up from the bottom of the oil pan and is pressurized before flowing to the oil filter. (b) If debris gets into an oil pump, the drive or distributor shaft can twist and/or break. When this occurs, the engine will lose all oil pressure.

the oil to a rocker arm shaft. Some engines use an enlarged hole to carry lubrication oil around the rocker shaft cap screw to the rocker arm shaft. Holes in the bottom of the rocker arm shaft allow lubrication of the rocker arm pivot. Mechanical loads on the valve train hold the rocker arm against the passage in the rocker arm shaft. This prevents excessive oil leakage from the rocker arm shaft. Often, holes are drilled in cast rocker arms to carry oil to the pushrod end and to the valve tip. Rocker arm assemblies need only a surface coating of oil, so the oil flow to the rocker assembly is minimized using restrictions or metered openings. The restriction or metering disk is in the lifter when the rocker assembly is lubricated

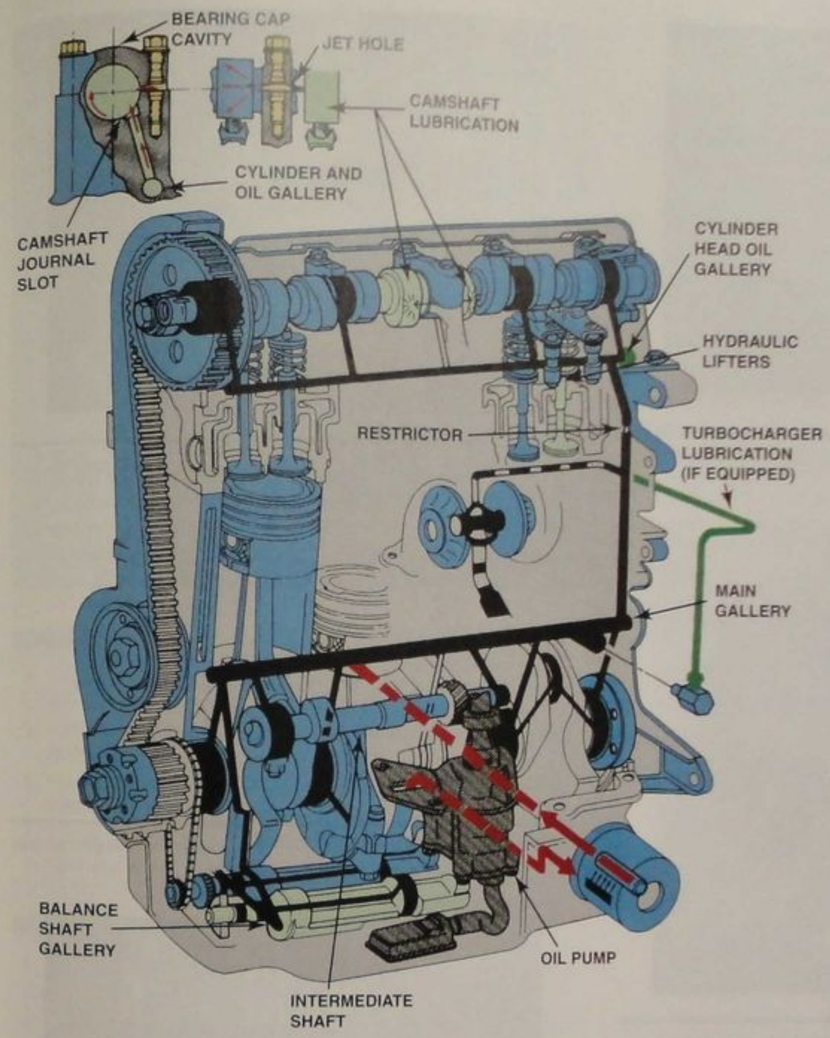


Figure 21–13 An intermediate shaft drives the oil pump on this overhead camshaft engine. Note the main gallery and other drilled passages in the block and cylinder head.



Figure 21–14 Oil is sent to the rocker arms on this Chevrolet V-8 engine through the hollow pushrods. The oil returns to the oil pan through the oil drainback holes in the cylinder head.

through the pushrod. Cam journal holes that line up with oil passages are often used to meter oil to the rocker shafts.

Oil that seeps from the rocker assemblies is returned to the oil pan through drain holes. These oil drain holes are often placed so that the oil drains on the camshaft or cam drive gears to lubricate them.

Some engines have means of directing a positive oil flow to the cam drive gears or chain. This may be a nozzle or a chamfer on a bearing parting surface that allows oil to spray on the loaded portion of the cam drive mechanism.

OIL PANS

As the vehicle accelerates, brakes, or turns rapidly, the oil tends to move around in the pan. Pan baffles and oil pan shapes are often used to keep the oil inlet under the oil at all times. As the crankshaft rotates, it acts like a fan and causes air within the crankcase to rotate with it. This can cause a strong draft on the oil, churning it so that air bubbles enter the oil, which then causes oil foaming. Oil with air will not lubricate like liquid oil, so oil foaming can cause bearings to fail. A baffle or **windage tray** is sometimes installed in engines to

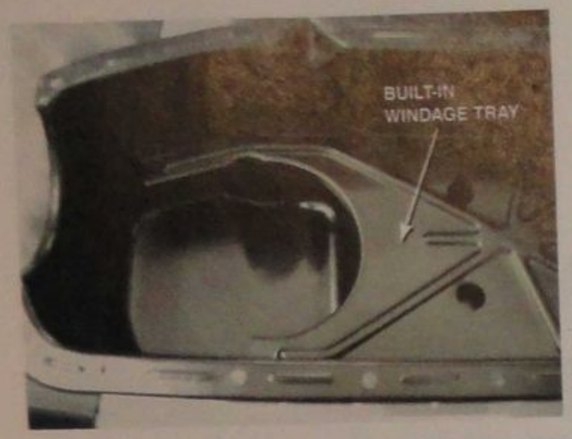


Figure 21–15 A typical oil pan with a built-in windage tray used to keep oil from being churned up by the rotating crankshaft.



Figure 21–16 A straightedge and a feeler gauge are being used to check that the oil pan has been correctly installed on the 5.7-liter Chevrolet V-8 engine. The oil pan is part of the engine itself and must be properly installed to ensure that other parts attached to the engine are not being placed in a bind.

eliminate the oil churning problem. This may be an added part, as shown in Figure 21–15, or it may be a part of the oil pan. Windage trays have the good side effect of reducing the amount of air disturbed by the crankshaft, so that less power is drained from the engine at high crankshaft speeds. Oil pans on many engines are a structural part of the engine. See Figure 21–16.

OIL COOLERS

Oil temperature must also be controlled on many high-performance or turbocharged engines. See Figure 21–17 for an example of an engine oil cooler used on a production high-performance engine. A larger-capacity oil pan also helps to control oil temperature. Coolant flows through the oil cooler to help warm the oil when the engine is cold and cool the oil when the engine is hot. Oil temperature should be above 212°F (100°C) to boil off any accumulated moisture, but it should not exceed about 280° to 300°F (138° to 148°C).

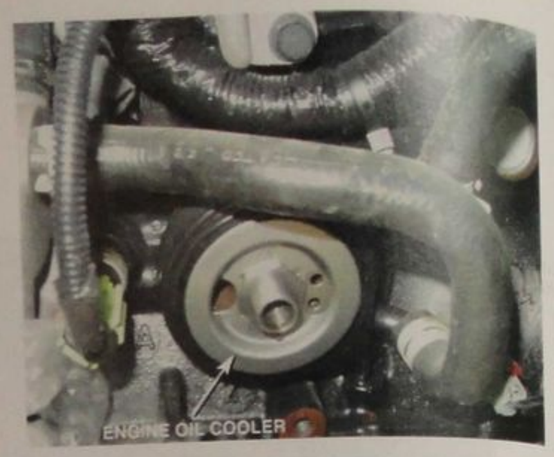


Figure 21–17 A typical engine oil cooler. Engine coolant flows through the cooler adapter that fits between the engine block and the oil filter.

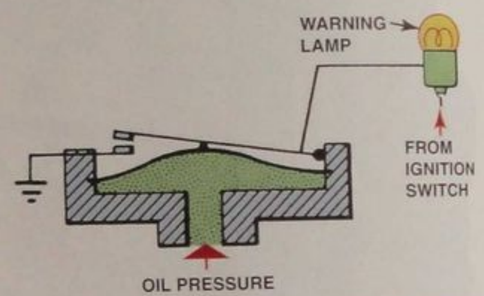


Figure 21–18 The oil pressure switch is connected to a warning lamp that alerts the driver of low oil pressure.



Figure 21–19 A typical oil pressure sending unit on a Ford V-8.

OIL PRESSURE WARNING LAMP

All vehicles are equipped with an oil pressure gauge or a warning lamp. The warning lamp comes on whenever the engine oil pressure has dropped to 3 to 7 PSI. Normal oil pressure is considered to be 10 PSI per 1000 RPM. An electrical switch is used to convert the ground circuit of the oil pressure warning lamp if the oil pressure is below the rating of the sending unit. See Figures 21–18 and 21–

FREQUENTLY ASKED QUESTION ???

What Is Acceptable Oil Consumption?

There are a number of opinions regarding what is acceptable oil consumption. Most vehicle owners do not want their engine to use any oil between oil changes even if they do not change it more often than every 7,500 miles (12,000 kilometers). Engineers have improved machining operations and piston ring designs to help eliminate oil consumption.

Many stationary or industrial engines are not driven on the road; therefore, they do not accumulate miles, yet they still may consume excessive oil.

A general rule for "acceptable" oil consumption is that it should be about 0.002 to 0.004 pounds per horsepower per hour. To figure, use the following:

$$\frac{1.82 \times \text{quarts used}}{\text{Operating hp} \times \text{total hours}} = \text{lb/hp/hr}$$

Therefore, oil consumption is based on the amount of work an engine performs. Although the formula may not be usable for vehicle engines used for daily transportation, it may be usable by the marine or industrial engine builder. Generally, oil consumption that is greater than 1 quart for every 600 miles (1,000 kilometers per liter) is considered to be excessive with a motor vehicle.

SUMMARY

1. Normal engine oil pump pressure ranges from 10 to 60 PSI (200 to 400 kPa) or 10 PSI for every 1000 engine RPM.
2. Hydrodynamic oil pressure around engine bearings is usually over 1,000 PSI (6,900 kPa).
3. The oil pump is driven directly by the crankshaft or by a gear or shaft from the camshaft.
4. The last components to get oil from the oil pump are the valve train parts.
5. Some engines use an oil cooler.

REVIEW QUESTIONS

1. What causes a wedge-shaped film to form in the oil?
2. What is hydrodynamic lubrication?
3. Explain why the oil filter is bypassed when the engine oil is cold and thick.
4. Explain why internal engine leakage affects oil pressure.
5. Explain the operation of the bypass valve located in the oil filter or oil filter adapter.
6. Describe how the oil flows from the oil pump, through the filter and main engine bearings, to the valve train.
7. What is the purpose of a windage tray?

CHAPTER QUIZ

1. Normal oil pump pressure in an engine is _____.
   a. 3 to 7 PSI
   b. 10 to 60 PSI
   c. 100 to 150 PSI
   d. 180 to 210 PSI
2. Hydrodynamic oil pressure can be as high as _____ PSI.
   a. 10 to 60
   b. 100 to 150
   c. 200 to 450
   d. over 1,000
3. A typical oil pump is what type of pump?
   a. Positive displacement
   b. Centrifugal
   c. Piston-type
   d. Hydraulically driven
4. Engine oil passages in an engine block are called _____.
   a. Oil passages
   b. Oil galleries
   c. Weep holes
   d. Oil holes
5. Technician A says that the oil pump draws unfiltered oil from the bottom of the oil pan. Technician B says that the oil pump is driven from the front of the crankshaft in some engines. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Technician A says that oil pressure is affected by the amount of main and rod bearing clearance. Technician B says that the oil pressure is lower when the oil gets hot than when it is cold. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Technician A says that many engines use a windage tray in the oil pan. Technician B says that some engines are equipped with an oil cooler. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. The oil pressure warning light normally comes on to warn the driver if the oil pressure drops below _____.
   a. 50 PSI
   b. 30 PSI
   c. 10 PSI
   d. 3 to 7 PSI
9. A typical oil pump can pump how many gallons per minute?
   a. 3 to 6 gallons
   b. 6 to 10 gallons
   c. 10 to 60 gallons
   d. 50 to 100 gallons
10. In typical engine lubrication systems, what components are the last to receive oil and the first to suffer from a lack of oil or oil pressure?
    a. Main bearings
    b. Rod bearings
    c. Valve train components
    d. Oil filters

CHAPTER 22

Intake and Exhaust Systems

OBJECTIVES: After studying Chapter 22, the reader will be able to: Prepare for ASE Engine Performance (A8) certification test content area "C" (Air Induction and Exhaust Systems Diagnosis and Repair). • Discuss the purpose and function of intake manifolds. • Explain the differences between throttle fuel-injection manifolds and port fuel-injection manifolds. • Describe the operation of the exhaust gas recirculation system in the intake manifold. • List the materials used in exhaust manifolds and exhaust systems.

KEY TERMS: annealing • exhaust gas recirculation (EGR) • hangers • helmholtz resonator • micron • plenum

AIR INTAKE FILTRATION

Gasoline must be mixed with air to form a combustible mixture. Air movement into an engine occurs due to low pressure (vacuum) being created in the engine. See Figure 22–1.

Like gasoline, air contains dirt and other materials which cannot be allowed to reach the engine. Just as fuel filters are used to clean impurities from gasoline, an air cleaner and filter are used to remove contaminants from the air. The three main jobs of the air cleaner and filter are to:

- Clean the air before it is mixed with fuel
- Silence intake noise
- Act as a flame arrester in case of a backfire

The automotive engine uses about 9,000 gallons (34,069 liters) of air for every gallon of gasoline burned at an air–fuel ratio of 14.7 to 1. Without proper filtering of the air before intake, dust and dirt in the air seriously damage engine parts and shorten engine life.

While abrasive particles can cause wear any place inside the engine where two surfaces move against each other, they first attack piston rings and cylinder walls. Contained in the blowby gases, they pass by the piston rings and into the crankcase. From the crankcase, the particles circulate throughout the engine in the oil. Large amounts of abrasive particles in the oil can damage other moving engine parts.

The filter that cleans the intake air is in a two-piece air cleaner housing made either of stamped steel or composite materials. The air cleaner housing is located on top of the throttle-body injection (TBI) unit or is positioned to one side of the engine. See Figure 22–2.

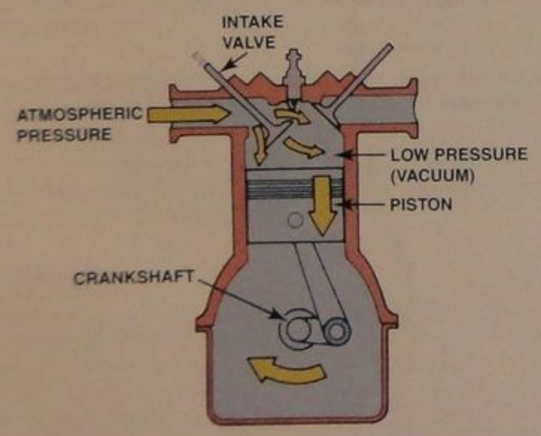


Figure 22–1 Downward movement of the piston lowers the air pressure inside the combustion chamber. The pressure differential between the atmosphere and the inside of the engine forces air into the engine.

Filter Replacement Manufacturers recommend cleaning or replacing the air filter element at periodic intervals, usually listed in terms of distance driven or months of service. The distance and time intervals are based on so-called normal driving. More frequent air filter replacement is necessary when the vehicle is driven under dusty, dirty, or other severe conditions.

It is best to replace a filter element before it becomes too dirty to be effective. A dirty air filter passes contaminants that cause engine wear.

Air Filter Elements The paper air filter element is the most common type of filter. It is made of a chemically treated paper stock that contains tiny passages in the fibers. These passages form an irregular path for the airflow to follow. The airflow passes through several fiber surfaces, each of which traps microscopic particles of dust, dirt, and carbon. Most air filters are capable of trapping dirt and other particles larger than 10 to 25 microns in size. One **micron** is equal to 0.000039 in.

NOTE: A person can only see objects that are 40 microns or larger in size. A human hair is about 50 microns in diameter.



Figure 22–2 Dust and dirt in the air are trapped in the air filter so they do not enter the engine.

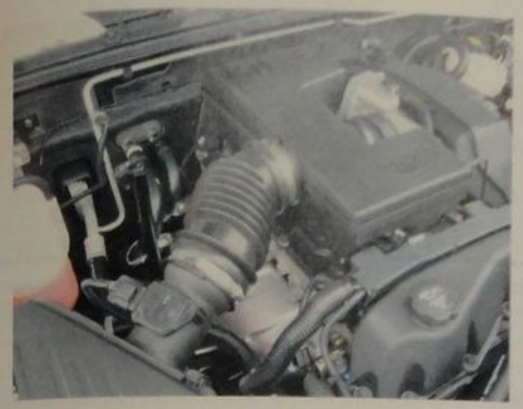


Figure 22–3 Most air filter housings are located on the side of the engine compartment and use flexible rubber hose to direct the airflow into the throttle body of the engine.

NOTE: Do not attempt to clean a paper element filter by rapping it on a sharp object to dislodge the dirt, or blowing compressed air through the filter. This tends to clog the paper pores and further reduce the airflow capability of the filter.

Remotely Mounted Air Filters and Ducts Air cleaner and duct design depend on a number of factors such as the size, shape, and location of other engine compartment components, as well as the vehicle body structure.

Port fuel-injection systems generally use a horizontally mounted throttle body. Some systems also have a mass airflow (MAF) sensor between the throttle body and the air cleaner. See Figure 22–3. Because placing the air cleaner housing next to the throttle body would cause engine and vehicle design problems, it is more efficient to use this remote air cleaner placement.

Turbocharged engines present a similar problem. The air cleaner connects to the air inlet elbow at the turbocharger. However, the tremendous heat generated by the turbocharger makes it impractical to place the air cleaner housing too close to the turbocharger. For better protection, the MAF sensor is installed between the turbocharger and the air cleaner in some vehicles. Remote air cleaners are connected to the turbocharger air inlet elbow or fuel-injection throttle body by composite ducting, which is usually retained by clamps. The ducting used may be rigid or flexible, but all connections must be airtight.

ENGINE AIR TEMPERATURE REQUIREMENTS

Some form of thermostatic control has been used on vehicles equipped with a throttle-body fuel injection to control intake air temperature for improved driveability. In a throttle-body fuel injection system, the fuel and air are combined above the throttle plate and must travel through the intake manifold before reaching the cylinders. Air temperature control is needed under these conditions to help keep the gas and air mixture combined.

Heat radiating from the exhaust manifold is retained by the heat stove and sent to the air cleaner inlet to provide heated air to the throttle body.

An air control valve or damper permits the air intake of:

- Heated air from the heat stove
- Cooler air from the snorkel or cold-air duct
- A combination of both

While the air control valve generally is located in the air cleaner snorkel, it may be in the air intake housing or ducting of remote air cleaners. Most fuel-injection systems do not use temperature control.

TECH TIP ✓ **Always Check the Air Filter**

Always inspect the air filter and the air intake system carefully during routine service. Debris or objects deposited by animals can cause a restriction to the airflow and can reduce engine performance. See Figure 22–4.

FREQUENTLY ASKED QUESTION ???

What Does This Tube Do?

What is the purpose of the odd-shaped tube attached to the inlet duct between the air filter and the throttle body, as seen in Figure 22–5?

The tube shape is designed to dampen out certain resonant frequencies that can occur at certain engine speeds. The length and shape of this tube are designed to absorb shock waves that are created in the air intake system and to provide a reservoir for the air that will then be released into the airstream during cycles of lower pressure. This resonance tube is often called a **Helmholtz resonator,** named for the discoverer of the relationship between shape and value of frequency Herman L. F. von Helmholtz (1821–1894) of the University of Hönizsberg in East Prussia. The overall effect of these resonance tubes is to reduce the noise of the air entering the engine.



(a)



(b)

Figure 22–4 (a) Note the discovery as the air filter housing was opened during service on a Pontiac Bonneville. The nuts were obviously deposited by squirrels (or some other animal). (b) Not only was the housing filled with nuts, but also this air filter was extremely dirty, indicating that this vehicle had not been serviced for a long time.



Figure 22–5 A resonance tube, called a Helmholtz resonator, is used on the intake duct between the air filter and the throttle body to reduce air intake noise during engine acceleration.



Figure 22–6 A throttle-body injection (TBI) unit used on a GM V-6 engine.

THROTTLE-BODY INJECTION INTAKE MANIFOLDS

The *intake manifold* is also called the *inlet manifold*. Smooth operation can only occur when each combustion chamber produces the same pressure as every other chamber in the engine. For this to be achieved, each cylinder must receive a charge exactly like the charge going into the other cylinders in quality and quantity. The charges must have the same physical properties and the same air–fuel mixture.

A throttle-body fuel injector forces finely divided droplets of liquid fuel into the incoming air to form a combustible air–fuel mixture. See Figure 22–6 for an example of a typical throttle-body injection (TBI) unit. These droplets start to evaporate as soon as they leave the throttle-body injector nozzles. *The droplets stay in the charge as long as the charge flows at high velocities.* At maximum horsepower, these velocities may reach 300 feet per second. Separation of the droplets from the charge as it passes through the manifold occurs when the velocity drops below 50 feet per second. Intake charge velocities at idle speeds are often below this value. When separation occurs—at low engine speeds—extra fuel must be supplied to the charge in order to have a combustible mixture reach the combustion chamber.

Manifold sizes represent a compromise. They must have a cross-section large enough to allow charge flow for maximum power. The cross-section must be small enough that the flow velocities of the charge will be high enough to keep the fuel droplets in suspension. This is required so that equal mixtures reach each cylinder. Manifold cross-sectional size is one reason why engines designed especially for racing will not run at low engine speeds. Racing manifolds must be large enough to reach maximum horsepower. This size, however, allows the charge to move slowly, and the fuel will separate from the charge at low engine speeds. Fuel separation leads to poor accelerator response. See Figure 22–7. Standard passenger vehicle engines are primarily designed for economy during light-load, partial-throttle operation. Their manifolds, therefore, have a much smaller cross-sectional area than do those of racing engines. This small size will help keep flow velocities of the charge high throughout the normal operating speed range of the engine.

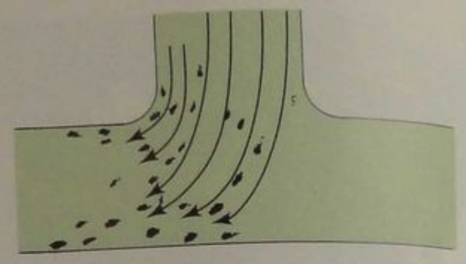


Figure 22–7 Heavy fuel droplets separate as they flow around an abrupt bend in an intake manifold.

TECH TIP ✔ **Check the Intake If an Exhaust Noise**

Because many V-type engines equipped with a throttle-body injection and/or EGR valve use a crossover exhaust passage, a leak around this passage will create an exhaust leak and noise. Always check for evidence of an exhaust leak around the intake manifold whenever diagnosing an exhaust sound.

PORT FUEL-INJECTION INTAKE MANIFOLDS

The size and shape of port fuel-injected engine intake manifolds can be optimized because the only thing in the manifold is air. The fuel injection is located in the intake manifold about 3 to 4 inches (70 to 100 mm) from the intake valve. Therefore, the runner length and shape are designed for tuning only. There is no need to keep an air–fuel mixture homogenized throughout the trip from the TBI unit to the intake valve. Typically, long runners build low-RPM torque while shorter runners provide maximum high-RPM power. See Figures 22–8 and 22–9. Some engines with four valve heads utilize a dual or variable intake runner design. At lower engine speeds, long intake runners provide low-speed torque. At higher engine speeds, shorter intake runners are opened by means of a computer-controlled valve to increase high-speed power.

VARIABLE INTAKES

Many intake manifolds are designed to provide both short runners best for higher engine speed power, and longer runners, best for lower engine speed torque. The valve(s) that control the flow of air through the passages of the intake manifold are computer controlled. See Figure 22–10.

PLASTIC INTAKE MANIFOLDS

Most thermoplastic intake manifolds are molded from fiberglass-reinforced nylon. The plastic manifolds can be cast or injection molded. Some manifolds are molded in two parts and bonded together. Plastic intake manifolds are lighter than aluminum manifolds and can better insulate engine heat from the fuel injectors.

Plastic intake manifolds have smoother interior surfaces than do other types of manifolds, resulting in greater airflow. See Figure 22–11.

EXHAUST GAS RECIRCULATION PASSAGES

To reduce the emission of oxides of nitrogen (NO_x), engines have been equipped with **exhaust gas recirculation (EGR)** valves. From 1973 until recently, they were used on almost all vehicles. Because of the efficiency of computer-controlled fuel injection, some newer engines do not require an EGR system to meet emission standards. Some engines use intake and exhaust valve overlap as a means of trapping some exhaust in the cylinder as an alternative to using an EGR valve.

The EGR valve opens at speeds above idle on a warm engine. When open, the valve allows a small portion of the exhaust gas (5% to 10%) to enter the intake manifold. Here, the exhaust gas mixes with and takes the place of some of the intake charge. This leaves less room for the intake charge to enter the combustion chamber. The recirculated exhaust gas is inert and does *not* enter into the combustion process. The result is a lower peak combustion temperature. As the combustion temperature is lowered, the production of oxides of nitrogen is also reduced.

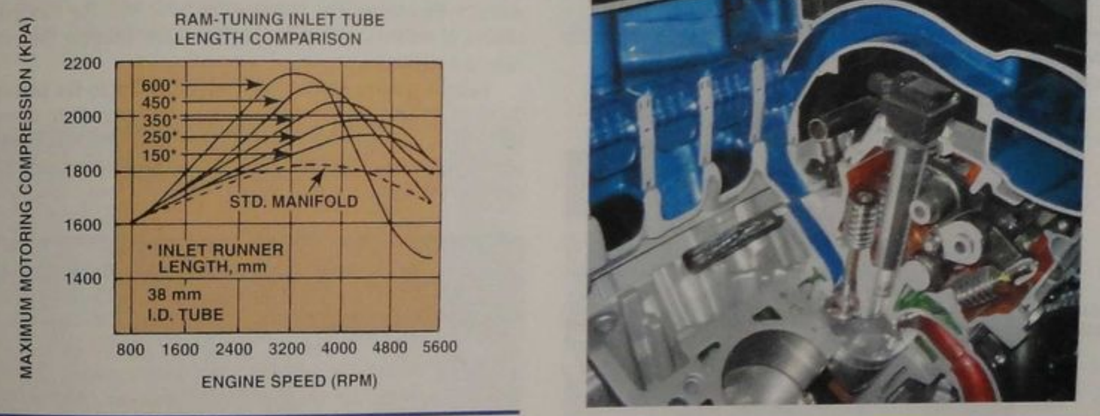


Figure 22–8 The graph shows the effect of sonic tuning of the intake manifold runners. The longer runners increase the torque peak and move it to a lower RPM. The 600-mm-long intake runner is about 24 inches long.

Figure 22–10 The air flowing into the engine can be directed through long or short runners for best performance and fuel economy.

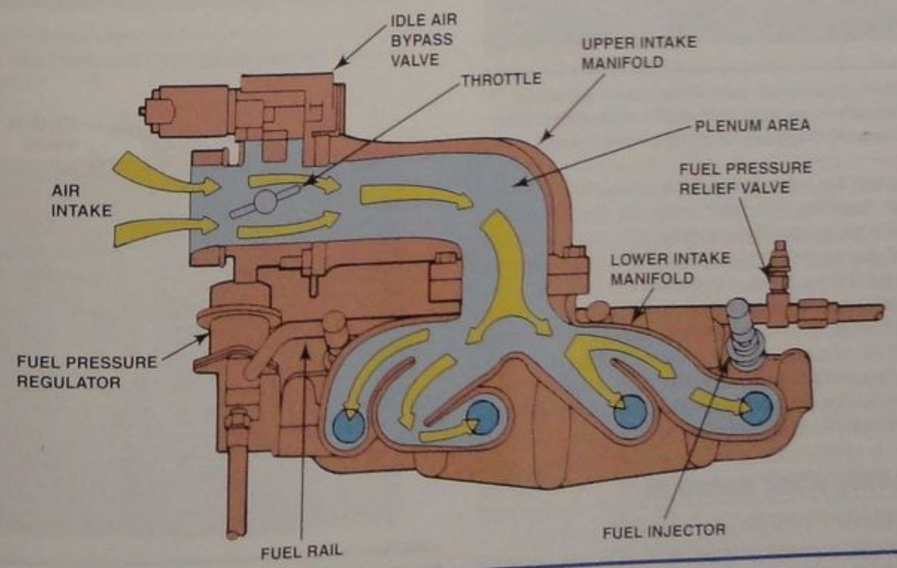


Figure 22–9 Airflow through the large diameter upper intake manifold is distributed to smaller diameter individual runners in the lower manifold in this two-piece manifold design.



Figure 22–11 Many plastic intake manifolds are constructed using many parts glued together to form complex passages for airflow into the engine.

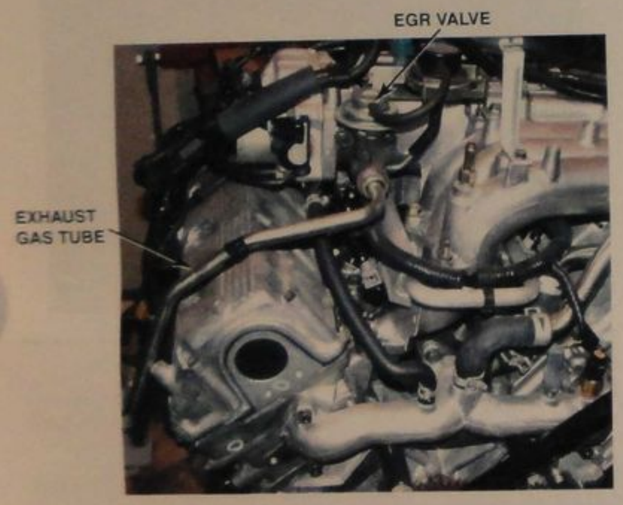


Figure 22–12 The exhaust gas recirculation system is more efficient at controlling NO_x emissions if the exhaust gases are cooled. A long metal tube between the exhaust manifold and the intake manifold allows the exhaust gases to cool before entering the engine.

The EGR system has some means of interconnecting the exhaust and intake manifolds. The interconnecting passage is controlled by the EGR valve. On V-type engines, the intake manifold crossover is used as a source of exhaust gas for the EGR system. A cast passage connects the exhaust crossover to the EGR valve. On inline-type engines, an external tube is generally used to carry exhaust gas to the EGR valve. The exhaust gases are more effective in reducing oxides of nitrogen (NO_x) emissions if the exhaust is cooled before being drawn into the cylinders. This tube is often designed to be long so that the exhaust gas is cooled before it enters the EGR valve. Figure 22–12 shows a typical long EGR tube.

UPPER AND LOWER INTAKE MANIFOLDS

Many intake manifolds are constructed in two parts.

- A lower section, usually called the **plenum,** attaches to the cylinder heads and includes passages from the intake ports.
- An upper manifold connects to the lower unit and includes the long passages needed to help provide the ram effect that helps the engine deliver maximum torque at low engine speeds. The throttle body attaches to the upper intake.

The use of a two-part intake manifold allows for easier manufacturing as well as assembly, but can create additional locations for leaks. If the lower intake manifold gasket leaks, not only could a vacuum leak occur affecting the operation of the engine, but a coolant leak or an oil leak can also occur. A leak at the gasket(s) of the upper intake manifold usually results in a vacuum (air) leak only.

EXHAUST MANIFOLD DESIGN

The exhaust manifold is designed to collect high-temperature spent gases from the head exhaust ports. See Figure 22–13. The hot gases are sent to an exhaust pipe, then to a catalytic converter, to the muffler, to a resonator, and on to the tailpipe, where they are vented to the atmosphere. This must be done with the least-possible amount of restriction or back pressure while keeping the exhaust noise at a minimum.

Exhaust gas temperature will vary according to the power produced by the engine. The manifold must be designed to operate at both engine idle and continuous full power. Under full-power conditions, the exhaust manifold will become red-hot, causing a great deal of expansion.

NOTE: The temperature of an exhaust manifold can exceed 1500°F (815°C).

At idle, the exhaust manifold is just warm, causing little expansion. After casting, the manifold may be annealed. **Annealing** is a heat-treating process that takes out the brittle hardening of the casting to reduce the chance of cracking from the temperature changes. During vehicle operation, manifold temperatures usually reach the high-temperature extremes. Most exhaust manifolds are made from cast iron to withstand extreme and rapid temperature changes. The manifold is bolted to the head in a way that will allow expansion and contraction. In some cases, hollow-headed bolts are used to maintain a gas-tight seal while still allowing normal expansion and contraction.

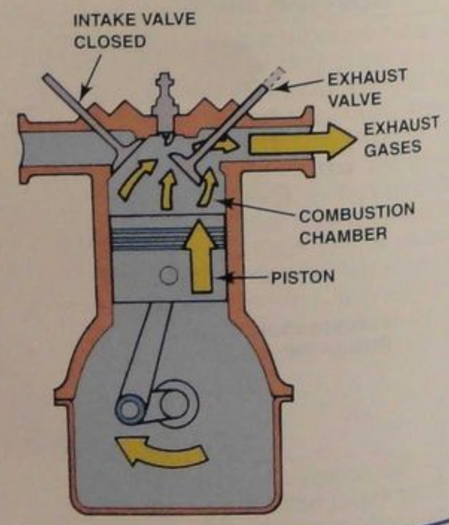


Figure 22–13 The exhaust gases are pushed out of the cylinder by the piston on the exhaust stroke.

The exhaust manifold is designed to allow the free flow of exhaust gas. Some manifolds use internal cast-rib deflectors or dividers to guide the exhaust gases toward the outlet as smoothly as possible.

Some exhaust manifolds are designed to go above the spark plug, whereas others are designed to go below. The spark plug and carefully routed ignition wires are usually shielded from the exhaust heat with sheet-metal deflectors. Many exhaust manifolds have heat shields as seen in Figure 22–14.

Exhaust systems are especially designed for the engine-chassis combination. The exhaust system length, pipe size, and silencer are designed, where possible, to make use of the tuning effect of the gas column resonating within the exhaust system. Tuning occurs when the exhaust pulses from the cylinders are emptied into the manifold between the pulses of other cylinders. See Figure 22–15.



Figure 22–14 This exhaust manifold has a heat shield to help retain the heat and help reduce exhaust emissions.



Figure 22–15 Many exhaust manifolds are constructed of pressed steel and are free flowing to improve engine performance.

FREQUENTLY ASKED QUESTION ???

How Can a Cracked Exhaust Manifold Affect Engine Performance?

A crack in an exhaust manifold will not only allow exhaust gases to escape and cause noise but the crack can also allow air to enter the exhaust manifold. See Figure 22–16.

Exhaust flows from the cylinders as individual puffs or pressure pulses. Behind each of these pressure pulses, a low pressure (below atmospheric pressure) is created. Outside air at atmospheric pressure is then drawn into the exhaust manifold through the crack. This outside air contains 21% oxygen and is measured by the oxygen sensor (02S). The air passing the 02S signals the engine computer that the engine is operating too lean (excess oxygen) and the computer, not knowing that the lean indicator is false, adds additional fuel to the engine. The result is that the engine will be operating richer (more fuel than normal) and spark plugs could become fouled causing poor engine operation.



Figure 22–16 A crack in an exhaust manifold is often not this visible. A crack in the exhaust manifold upstream of the oxygen sensor can fool the sensor and affect engine operation.

EXHAUST MANIFOLD GASKETS

Exhaust heat will expand the manifold more than it will expand the head. It causes the exhaust manifold to slide on the sealing surface of the head. The heat also causes thermal stress. When the manifold is removed from the engine for service, the stress is relieved and this may cause the manifold to warp slightly. Exhaust manifold gaskets are included in gasket sets to seal slightly warped exhaust manifolds. These gaskets *should* be used, even if the engine did not originally use exhaust manifold gaskets. When a perforated core exhaust manifold gasket has facing on one side only, put the facing side against the head and put the manifold against the perforated metal core. The manifold can slide on the metal of the gasket just as it slid on the sealing surface of the head.

Gaskets are used on new engines with tubing- or header-type exhaust manifolds. The gaskets often include heat shields to keep exhaust heat from the spark plugs and spark plug cables. They may have several layers of steel for high-temperature sealing. The layers are spot-welded together. Some are embossed where special sealing is needed. See Figure 22–17.

Many new engines do not use gaskets with cast exhaust manifolds. The flat surface of the new cast-iron exhaust manifold fits tightly against the flat surface of the new head.



Figure 22–17 Typical exhaust manifold gaskets. Note how they are laminated to allow the exhaust manifold to expand and contract due to heating and cooling.

TECH TIP ✔ **The Correct Tools Save Time**

When cast-iron exhaust manifolds are removed, the stresses built up in the manifolds often cause the manifolds to twist or bend. This distortion even occurs when the exhaust manifolds have been allowed to cool before removal. Attempting to reinstall distorted exhaust manifolds is often a time-consuming and frustrating exercise.

However, special spreading jacks can be used to force the manifold back into position so that the fasteners can be lined up with the cylinder head. See Figure 22–18.



Figure 22–18 An exhaust manifold spreader tool is a tool that is absolutely necessary to use when reinstalling exhaust manifolds. When they are removed from the engine, they tend to warp slightly even though the engine is allowed to cool before being removed. The spreader tool allows the technician to line up the bolt holes without doing any harm to the manifold.

MUFFLERS

When the exhaust valve opens, it rapidly releases high-pressure gas. This sends a strong air pressure wave through the atmosphere, which produces a sound we call an explosion. It is the same sound produced when the high-pressure gases from burned gunpowder are released from a gun. In an engine, the pulses are released one after another. The explosions come so fast that they blend together in a steady roar.

Sound is air vibration. When the vibrations are large, the sound is loud. The muffler catches the large bursts of high-pressure exhaust gas from the cylinder, smoothing out the pressure pulses and allowing them to be released at an even and constant rate. It does this through the use of perforated tubes within the muffler chamber. The smooth-flowing gases are released to the tailpipe. In this way, the muffler silences engine exhaust noise. Sometimes resonators are used in the exhaust system and the catalytic converter also acts as a muffler. They provide additional expansion space at critical points in the exhaust system to smooth out the exhaust gas flow. See Figure 22–19.

Most mufflers have a larger inlet diameter than outlet diameter. As the exhaust enters the muffler, it expands and cools. The cooler exhaust is more dense and occupies less volume. The diameter of the outlet of the muffler and the diameter of the tailpipe can be reduced with no decrease in efficiency.

The tailpipe carries the exhaust gases from the muffler to the air, away from the vehicle. In most cases, the tailpipe exit is at the rear of the vehicle, below the rear bumper. In some cases, the exhaust is released at the side of the vehicle, just ahead of or just behind the rear wheel.

The muffler and tailpipe are supported with brackets called **hangers.** The hangers are made of rubberized fabric with metal ends that hold the muffler and tailpipe in position so that they do not touch any metal part. This helps to isolate the exhaust noise from the rest of the vehicle.

FREQUENTLY ASKED QUESTION ???

Why Is There a Hole in My Muffler?

Many mufflers are equipped with a small hole in the lower rear part to drain accumulated water. About 1 gallon of water is produced in the form of steam for each gallon of gasoline burned. The water vapor often condenses on the cooler surfaces of the exhaust system unless the vehicle has been driven long enough to fully warm the muffler above the boiling point of water (212°F [100°C]). See Figure 22–20.

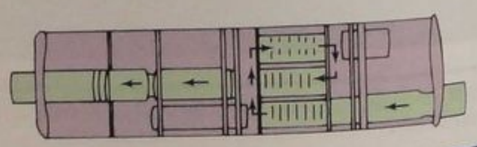


Figure 22–19 Exhaust gases expand and cool as they travel through the passages in the muffler.



Figure 22–20 A hole in the muffler allows condensed water to escape.

HIGH-PERFORMANCE TIP

More Airflow = More Power

One of the most popular high-performance modifications is to replace the factory exhaust system with a low-restriction design and to replace the original air filter and air filter housing with a low-restriction unit as shown in Figure 22–21.

The installation of an aftermarket air filter not only increases power, but also increases air induction noise, which many drivers prefer. The aftermarket filter housing, however, may not be able to effectively prevent water from being drawn into the engine if the vehicle is traveling through deep water.

Almost every modification that increases performance has a negative effect on some other part of the vehicle, or else the manufacturer would include the change at the factory.



Figure 22–21 A high-performance aftermarket air filter often can increase airflow into the engine for more power.

SUMMARY

1. All air entering an engine must be filtered.
2. Engines that use throttle-body injection units are equipped with intake manifolds that keep the airflow speed through the manifold at 50 to 300 feet per second.
3. Most intake manifolds have an EGR valve that regulates the amount of recirculated exhaust that enters the engine to reduce NO_x emissions.
4. Exhaust manifolds can be made from cast iron or stainless steel.
5. The exhaust system also contains a catalytic converter, exhaust pipes, and muffler. The entire exhaust system is supported by rubber hangers that isolate the noise and vibration of the exhaust from the rest of the vehicle.

REVIEW QUESTIONS

1. Why is it necessary to have intake charge velocities of about 50 feet per second?
2. Why can fuel-injected engines use larger (and longer) intake manifolds and still operate at low engine speed?
3. What is a tuned runner in an intake manifold?
4. How does a muffler quiet exhaust noise?

CHAPTER QUIZ

1. Intake charge velocity has to be _____ to prevent fuel droplet separation.
   a. 25 feet per second
   b. 50 feet per second
   c. 100 feet per second
   d. 300 feet per second
2. The intake manifold of a port fuel-injected engine _____.
   a. Uses a dual heat riser
   b. Contains a leaner air–fuel mixture than does the intake manifold of a TBI system
   c. Contains only fuel (gasoline)
   d. Contains only air
3. Why are the EGR gases cooled before entering the engine on some engines?
   a. Cool exhaust gas is more effective at controlling NO_x emissions
   b. To help prevent the exhaust from slowing down
   c. To prevent damage to the intake valve
   d. To prevent heating the air–fuel mixture in the cylinder
4. A heated air intake system is usually necessary for proper cold-engine driveability on _____.
   a. Port fuel-injection systems
   b. Throttle-body fuel-injection systems
   c. Both a port-injected and throttle-body injected engine
   d. Any fuel-injected engine
5. Air filters can remove particles and dirt as small as _____.
   a. 5 to 10 microns
   b. 10 to 25 microns
   c. 30 to 40 microns
   d. 40 to 50 microns
6. Why do many port fuel-injected engines use long intake manifold runners?
   a. To reduce exhaust emissions
   b. To heat the incoming air
   c. To increase high-RPM power
   d. To increase low-RPM torque
7. Exhaust passages are included in some intake manifolds. Technician A says that the exhaust passages are used for exhaust gas recirculation (EGR) systems. Technician B says that the exhaust heat is used to warm the intake charge on some engines equipped with a throttle-body-type fuel-injection system. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. The lower portion of a two-part intake manifold is often called the _____.
   a. Housing
   b. Lower part
   c. Plenum
   d. Vacuum chamber
9. Technician A says that a cracked exhaust manifold can affect engine operation. Technician B says that a leaking lower intake manifold gasket could cause a vacuum leak. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Technician A says that some intake manifolds are plastic. Technician B says that some intake manifolds are constructed in two parts or sections: upper and lower. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 23

Turbocharging and Supercharging

OBJECTIVES: After studying Chapter 23, the reader will be able to: Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Explain the difference between a turbocharger and a supercharger. • Describe how the boost levels are controlled. • Discuss maintenance procedures for turbochargers and superchargers.

KEY TERMS: bar • boost • bypass valve • compressor bypass valve (CBV) • dump valve • intercooler • naturally (normally) aspirated • positive displacement • relief valve • roots-type • supercharger • turbo lag • turbocharger • vent valve • volumetric efficiency • wastegate

AIRFLOW REQUIREMENTS

Naturally aspirated engines with throttle bodies rely on atmospheric pressure to push an air–fuel mixture into the combustion chamber vacuum created by the downstroke of a piston. The mixture is then compressed before ignition to increase the force of the burning, expanding gases. The greater the mixture compression, the greater the power resulting from combustion.

All gasoline automobile engines share certain air–fuel requirements. For example, a four-stroke engine can take in only so much air, and how much fuel it consumes depends on how much air it takes in. Engineers calculate engine airflow requirements using these three factors:

- Engine displacement
- Engine revolutions per minute (RPM)
- Volumetric efficiency

Volumetric Efficiency **Volumetric efficiency** is a comparison of the actual volume of air–fuel mixture drawn into an engine to the theoretical maximum volume that could be drawn in. Volumetric efficiency is expressed as a percentage, and changes with engine speed. For example, an engine might have 75% volumetric efficiency at 1000 RPM. The same engine might be rated at 85% at 2000 RPM and 60% at 3000 RPM.

If the engine takes in the airflow volume slowly, a cylinder might fill to capacity. It takes a definite amount of time for the airflow to pass through all the curves of the intake manifold and valve port. Therefore, volumetric efficiency decreases as engine speed increases. At high speed, it may drop to as low as 50%.

The average street engine never reaches 100% volumetric efficiency. With a street engine, the volumetric efficiency is about 75% at maximum speed, or 80% at the torque peak. A high-performance street engine is about 85% efficient, or a bit more efficient at peak torque. A race engine usually has 95% or better volumetric efficiency. These figures apply only to naturally aspirated engines, however, and turbocharged and supercharged engines easily achieve more than 100% volumetric efficiency. Many vehicles are equipped with a supercharger or a turbocharger to increase power. See Figures 23–1 and 23–2.

Engine Compression Higher compression increases the thermal efficiency of the engine because it raises compression temperatures, resulting in hotter, more complete combustion. However, a higher compression can cause an increase in NO_x emissions and would require the use of high-octane gasoline with effective antiknock additives.

SUPERCHARGING PRINCIPLES

The amount of force an air–fuel charge produces when it is ignited is largely a function of the charge density. Density is the mass of a substance in a given amount of space. See Figure 23–3.



Figure 23–1 A supercharger on a Ford V-8.



Figure 23–2 A turbocharger on a Toyota engine.

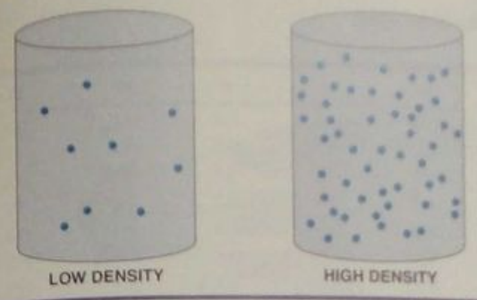


Figure 23–3 The more air and fuel that can be packed in a cylinder, the greater the density of the air–fuel charge.

The greater the density of an air–fuel charge forced into a cylinder, the greater the force it produces when ignited, and the greater the engine power.

An engine that uses atmospheric pressure for intake is called a **naturally (normally) aspirated** engine. A better way to increase air density in the cylinder is to use a pump.

When air is pumped into the cylinder, the combustion chamber receives an increase of air pressure known as **boost** and is measured in pounds per square inch (PSI), atmospheres (ATM), or bar. While boost pressure increases air density, friction heats air in motion and causes an increase in temperature. This increase in temperature works in the opposite direction, decreasing air density. Because of these and other variables, an increase in pressure does not always result in greater air density.

Another way to achieve an increase in mixture compression is called **supercharging.** This method uses a pump to pack a denser air–fuel charge into the cylinders. Since the density of the air–fuel charge is greater, so is its weight—and power is directly related to the weight of an air–fuel charge consumed within a given time period. The result is similar to that of a high-compression ratio, but the effect can be controlled during idle and deceleration to avoid high emissions.

Air is drawn into a naturally aspirated engine by atmospheric pressure forcing it into the low-pressure area of the intake manifold. The low pressure or vacuum in the manifold results from the reciprocating motion of the pistons. When a piston moves downward during its intake stroke, it creates an empty space, or vacuum, in the cylinder. Although atmospheric pressure pushes air to fill up as much of this empty space as possible, it has a difficult path to travel. The air must pass through the air filter, the throttle body, the manifold, and the intake port before entering the cylinder. Bends and restrictions in this pathway limit the amount of air reaching the cylinder before the intake valve closes; therefore, the volumetric efficiency is less than 100%.

Pumping air into the intake system under pressure forces it through the bends and restrictions at a greater speed than it would travel under normal atmospheric pressure, allowing more air to enter the intake port before it closes. By increasing the airflow into the intake, more fuel can be mixed with the air while still maintaining the same air–fuel ratio. The denser the air–fuel charge entering the engine during its intake stroke, the greater the potential energy released during combustion. In addition to the increased power resulting from combustion, there are several other advantages of supercharging an engine including:

- It increases the air–fuel charge density to provide high-compression pressure when power is required, but allows the engine to run on lower pressures when additional power is not required.
- The pumped air pushes the remaining exhaust from the combustion chamber during intake and exhaust valve overlap.
- The forced airflow and removal of hot exhaust gases lowers the temperature of the cylinder head, pistons, and valves, and helps extend the life of the engine.

A supercharger pressurizes air to greater than atmospheric pressure. The pressurization above atmospheric pressure, or boost, can be measured in the same way as atmospheric pressure. Atmospheric pressure drops as altitude increases, but boost pressure remains the same. If a supercharger develops 12 PSI (83 kPa) boost at sea level, it will develop the same amount at a 5,000-foot altitude because boost pressure is measured inside the intake manifold. See Figure 23–4.

Boost and Compression Ratios Boost increases the amount of air drawn into the cylinder during the intake stroke. This extra air causes the effective compression ratio to be greater than the mechanical compression ratio designed into the engine. The higher the boost

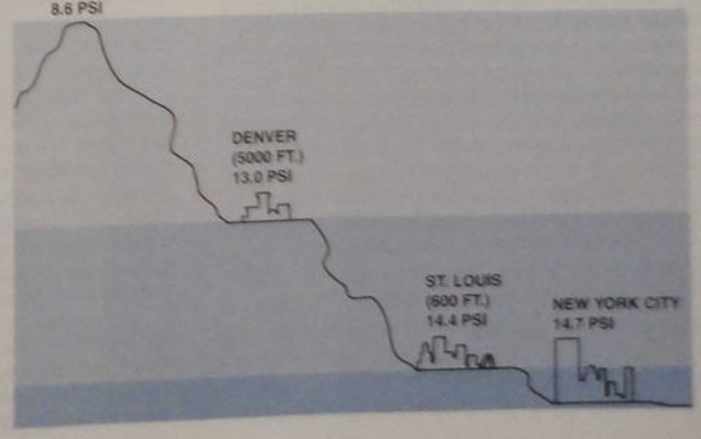


Figure 23–4 Atmospheric pressure decreases with increases in altitude.

Final Compression Ratio Chart at Various Boost Levels

Comp Ratio	Blower Boost (PSI) 2	4	6	8	10	12	14	16	18	20
6.5	7.4	8.3	9.2	10	10.9	11.8	12.7	13.6	14.5	15.3
7	8	8.9	9.9	10.8	11.8	12.7	13.6	14.5	15.3	16.2
7.5	8.5	9.5	10.6	11.6	12.6	13.6	14.6	15.7	16.7	17.8
8	9.1	10.2	11.3	12.4	13.4	14.5	15.6	16.7	17.8	18.9
8.5	9.7	10.8	12	13.1	14.3	15.4	16.6	17.8	18.9	19.8
9	10.2	11.4	12.7	13.9	15.1	16.3	17.6	18.8	20	21.2
9.5	10.8	12.1	13.4	14.7	16	17.3	18.5	19.8	21.1	22.4
10	11.4	12.7	14.1	15.4	16.8	18.2	19.5	20.9	22.2	23.6

pressure, the greater the compression ratio. See the following table for an example of how much the effective compression ratio is increased compared to the boost pressure.

SUPERCHARGERS

A supercharger is an engine-driven air pump that supplies more than the normal amount of air into the intake manifold and boosts engine torque and power. A supercharger provides an instantaneous increase in power without the delay or lag often associated with turbochargers. However, a supercharger, because it is driven by the engine, does require horsepower to operate and is not as efficient as a turbocharger.

In basic concept, a supercharger is nothing more than an air pump mechanically driven by the engine itself. Gears, shafts, chains, or belts from the crankshaft can be used to turn the pump. This means that the air pump or supercharger pumps air in direct relation to engine speed.

There are two general types of superchargers:

- **Roots-type supercharger.** Named for Philander and Francis Roots, two brothers from Connersville, Indiana, who patented the design in 1860 as a type of water pump to be used in mines. Later it was used to move air and is used today on two-stroke cycle Detroit diesel engines and other supercharged engines. The **roots-type supercharger** is called a **positive displacement** design because all of the air that enters is forced through the unit. Examples of a roots-type supercharger include the GMC 6-71 (used originally on GMC diesel engines that had six cylinders each with 71 cu. in.) and Eaton used on supercharged 3800 V-6 General Motors engines. See Figure 23–5.
- **Centrifugal supercharger.** A centrifugal supercharger is similar to a turbocharger but is mechanically driven by the engine instead of being powered by the hot exhaust gases. A centrifugal supercharger is not a positive displacement pump and all of the air that enters is not forced through the unit. Air enters a centrifugal supercharger housing in the center and exits at the outer edges of the compressor wheels at a much higher speed due to centrifugal force. The speed of the blades has to be higher than engine speed so a smaller pulley is used on the supercharger and the crankshaft overdrives the impeller through an internal gear box achieving about seven times the speed of the engine. Examples of centrifugal superchargers include Vortech and Paxton.

Supercharger Boost Control Many factory-installed superchargers are equipped with a **bypass valve** that allows intake air to flow directly into the intake manifold bypassing the supercharger. The computer controls the bypass valve actuator. See Figure 23–6.



Figure 23–5 A roots-type supercharger uses two lobes to force the air around the outside of the housing and forces it into the intake manifold.

The airflow is directed around the supercharger whenever any of the following conditions occur:

- The boost pressure, as measured by the MAP sensor, indicates that the intake manifold pressure is reaching the predetermined boost level.
- During deceleration.
- Whenever reverse gear is selected.

Supercharger Service Superchargers are usually lubricated with synthetic engine oil inside the unit. This oil level should be checked and replaced as specified by the vehicle or supercharger manufacturer. The drive belt should also be inspected and replaced as necessary.

TURBOCHARGERS

The major disadvantage of a supercharger is its reliance on engine power to drive the unit. In some installations, as much as 20% of the engine's power is used by a mechanical supercharger. However, by connecting a centrifugal supercharger to a turbine driven wheel and installing it in the exhaust path, the lost engine horsepower is regained to perform other work and the combustion heat energy lost in the engine exhaust (as much as 40% to 50%) can be harnessed to do useful work. This is the concept of a **turbocharger**.

The turbocharger's main advantage over a mechanically driven supercharger is that the turbocharger does not drain power from the engine. In a naturally aspirated engine, about half of the heat energy contained in the fuel goes out the exhaust system. See Figure 23–7. Another 25% is lost through radiator cooling. Only about 25% is actually converted to mechanical power. A mechanically driven pump uses some of this mechanical output, but a turbocharger gets its energy from the exhaust gases, converting more of the fuel's heat energy into mechanical energy.

A turbocharger turbine looks much like a typical centrifugal pump used for supercharging. See Figure 23–8. Hot exhaust gases flow from the combustion chamber to the turbine wheel. The gases are heated and expanded as they leave the engine. It is not the speed of force of the exhaust gases that forces the turbine wheel to

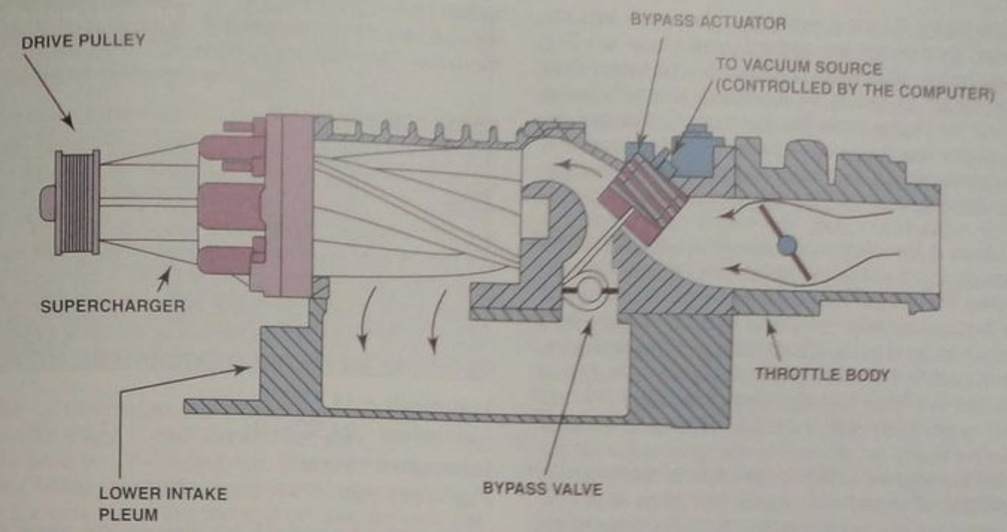


Figure 23–6 The bypass actuator opens the bypass valve to control boost pressure.

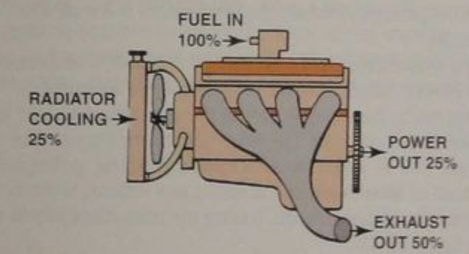


Figure 23–7 A turbocharger uses some of the heat energy that would normally be wasted.

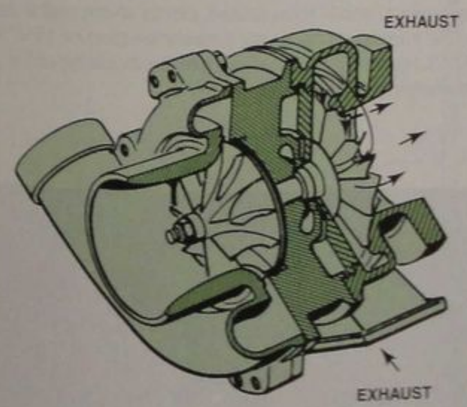


Figure 23–8 A turbine wheel is turned by the expanding exhaust gases.

turn, as is commonly thought, but the expansion of hot gases against the turbine wheel's blades.

Turbocharger Design and Operation A turbocharger consists of two chambers connected by a center housing. The two chambers contain a turbine wheel and a compressor wheel connected by a shaft which passes through the center housing.



Figure 23–9 The exhaust drives the turbine wheel on the left, which is connected to the impeller wheel on the right through a shaft. The bushings that support the shaft are lubricated with engine oil under pressure.

To take full advantage of the exhaust heat which provides the rotating force, a turbocharger must be positioned as close as possible to the exhaust manifold. This allows the hot exhaust to pass directly into the unit with a minimum of heat loss. As exhaust gas enters the turbocharger, it rotates the turbine blades. The turbine wheel and compressor wheel are on the same shaft so that they turn at the same speed. Rotation of the compressor wheel draws air in through a central inlet and centrifugal force pumps it through an outlet at the edge of the housing. A pair of bearings in the center housing support the turbine and compressor wheel shaft, and are lubricated by engine oil. See Figure 23–9.

Both the turbine and compressor wheels must operate with extremely close clearances to minimize possible leakage around their blades. Any leakage around the turbine blades causes a diminution of the heat energy required for compressor rotation. Leakage around the compressor blades prevents the turbocharger from developing its full boost pressure.

When the engine is started and runs at low speed, both exhaust heat and pressure are low and the turbine runs at a low speed (approximately 1000 RPM). Because the compressor does not turn fast enough to develop boost pressure, air simply passes through it and the engine works like any naturally aspirated engine. As the engine runs faster or load increases, both exhaust heat and flow increases, causing the turbine and compressor wheels to rotate faster. Since there is no brake and very little rotating resistance on the turbocharger shaft, the turbine and compressor wheels accelerate as the exhaust heat energy increases. When an engine is running at full power, the typical turbocharger rotates at speeds between 100,000 and 150,000 RPM.

Engine deceleration from full power to idle requires only a second or two because of its internal friction, pumping resistance, and drivetrain load. The turbocharger, however, has no such load on its shaft, and is already turning many times faster than the engine at top speed. As a result, it can take as much as a minute or more after the engine has returned to idle speed before the turbocharger also has returned to idle. If the engine is decelerated to idle and then shut off immediately, engine lubrication stops flowing to the center housing bearings while the turbocharger is still spinning at thousands of RPM. The oil in the center housing is then subjected to extreme heat and can gradually "coke" or oxidize. The coked oil can clog passages and will reduce the life of the turbocharger.

The high rotating speeds and extremely close clearances of the turbine and compressor wheels in their housings require equally critical bearing clearances. The bearings must keep radial clearances of 0.003 to 0.006 inch (0.08 to 0.15 mm). Axial clearance (end play) must be maintained at 0.001 to 0.003 inch (0.025 to 0.08 mm). If properly maintained, the turbocharger also is a trouble-free device. However, to prevent problems, the following conditions must be met:

- The turbocharger bearings must be constantly lubricated with clean engine oil—turbocharged engines should have regular oil changes at half the time or mileage intervals specified for nonturbocharged engines.
- Dirt particles and other contamination must be kept out of the intake and exhaust housings.
- Whenever a basic engine bearing (crankshaft or camshaft) has been damaged, the turbocharger must be flushed with clean engine oil after the bearing has been replaced.
- If the turbocharger is damaged, the engine oil must be drained and flushed and the oil filter replaced as part of the repair procedure.

Late-model turbochargers all have liquid-cooled center bearings to prevent heat damage. In a liquid-cooled turbocharger, engine coolant is circulated through passages cast in the center housing to draw off the excess heat. This allows the bearings to run cooler and minimize the probability of oil coking when the engine is shut down.

Turbocharger Size and Response Time A time lag occurs between an increase in engine speed and the increase in the speed of the turbocharger. This delay between acceleration and turbo boost is called **turbo lag.** Like any material, moving exhaust gas has inertia. Inertia also is present in the turbine and compressor wheels, as well as the intake airflow. Unlike a supercharger, the turbocharger cannot supply an adequate amount of boost at low speed.

Turbocharger response time is directly related to the size of the turbine and compressor wheels. Small wheels accelerate rapidly; large wheels accelerate slowly. While small wheels would seem to have an advantage over larger ones, they may not have enough airflow capacity for an engine. To minimize turbo lag, the intake and exhaust breathing capacities of an engine must be matched to the exhaust and intake airflow capabilities of the turbocharger.

BOOST CONTROL

Both supercharged and turbocharged systems are designed to provide a pressure greater than atmospheric pressure in the intake manifold. This increased pressure forces additional amounts of air into the combustion chamber over what would normally be forced in by atmospheric pressure. This increased charge increases engine power. The amount of "boost" (or pressure in the intake manifold) is measured in pounds per square inch (PSI), in inches of mercury (in. Hg), in bar's, or in atmospheres. The following values will vary due to altitude and weather conditions (barometric pressure).

1 atmosphere = 14.7 PSI

1 atmosphere = 29.50 in. Hg

1 atmosphere = 1.0 bar

1 bar = 14.7 PSI

The higher the level of boost (pressure), the greater the horsepower potential. However, other factors must be considered when increasing boost pressure:

1. As boost pressure increases, the temperature of the air also increases.
2. As the temperature of the air increases, combustion temperatures also increase, which increases the possibility of detonation.
3. Power can be increased by cooling the compressed air after it leaves the turbocharger. *The power can be increased about 1% per 10°F by which the air is cooled.* A typical cooling device is called an **intercooler** and is similar to a radiator, wherein outside air can pass through, cooling the pressurized heated air. See Figure 23–10.

   Some intercoolers use engine coolant to cool the hot compressed air that flows from the turbocharger to the intake.
4. As boost pressure increases, combustion temperature and pressures increase, which, if not limited, can do severe engine damage. The maximum exhaust gas temperature must be 1550°F (840°C). Higher temperatures decrease the durability of the turbocharger *and* the engine.

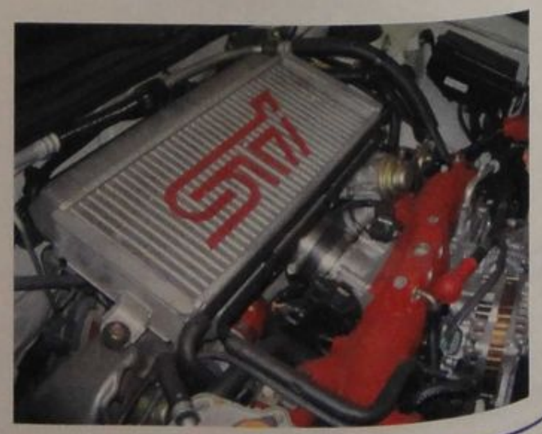


Figure 23–10 The unit on top of this Subaru that looks like a radiator is the intercooler which cools the air after it has been compressed by the turbocharger.

HIGH-PERFORMANCE TIP

Boost Is the Result of Restriction

The boost pressure of a turbocharger (or supercharger) is commonly measured in pounds per square inch. If a cylinder head is restricted because of small valves and ports, the turbocharger will quickly provide boost. Boost results when the air being forced into the cylinder heads cannot flow into the cylinders fast enough and "piles up" in the intake manifold, increasing boost pressure. If an engine had large valves and ports, the turbocharger could provide a much greater *amount* of air into the engine at the same boost pressure as an identical engine with smaller valves and ports. Therefore, by increasing the size of the valves, a turbocharged or supercharged engine will be capable of producing much greater power.

Wastegate A turbocharger uses exhaust gases to increase boost, which causes the engine to make more exhaust gases, which in turn increases the boost from the turbocharger. To prevent overboost and severe engine damage, most turbocharger systems use a wastegate. A **wastegate** is a valve similar to a door that can open and close. The wastegate is a bypass valve at the exhaust inlet to the turbine. It allows all of the exhaust into the turbine, or it can route part of the exhaust past the turbine to the exhaust system. If the valve is closed, all of the exhaust travels to the turbocharger. When a predetermined amount of boost pressure develops in the intake manifold, the wastegate valve is opened. As the valve opens, most of the exhaust flows directly out the exhaust system, bypassing the turbocharger. With less exhaust flowing across the vanes of the turbocharger, the turbocharger decreases in speed and boost pressure is reduced. When the boost pressure drops, the wastegate valve closes to direct the exhaust over the turbocharger vanes and again allow the boost pressure to rise. Wastegate operation is a continuous process to control boost pressure.

The wastegate is the pressure control valve of a turbocharger system. The wastegate is usually controlled by the onboard computer through a boost control solenoid. See Figure 23–11.

Relief Valves A wastegate controls the exhaust side of the turbocharger. A relief valve controls the intake side. A **relief valve** vents pressurized air from the connecting pipe between the outlet of the turbocharger and the throttle whenever the throttle is closed during boost, such as during shifts. If the pressure is not released, the turbocharger turbine wheel will slow down, creating a lag when the throttle is opened again after a shift has been completed. There are two basic types of relief valves including:

- **Compressor bypass valve or CBV** This type of relief valve routes the pressurized air to the inlet side of the turbocharger for reuse and is quiet during operation.
- **Blow-off valve or BOV** This is also called a **dump valve** or **vent valve** and features an adjustable spring design that keeps the valve closed until a sudden release of the throttle. The resulting pressure increase opens the valve and vents the pressurized air directly into the atmosphere. This type of relief valve is noisy in operation and creates a whooshing sound when the valve opens. See Figure 23–12.

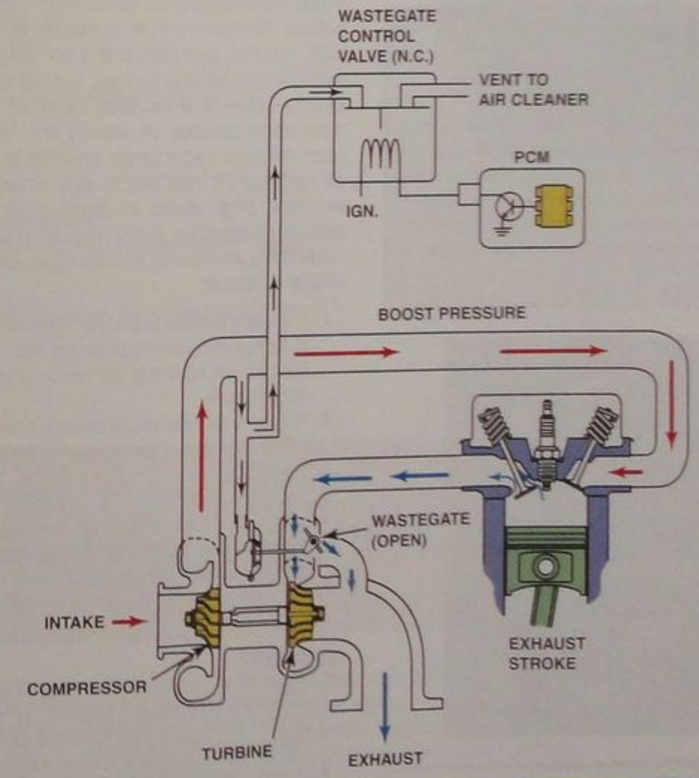


Figure 23–11 A wastegate is used on the first-generation Duramax diesel to control maximum boost pressure.

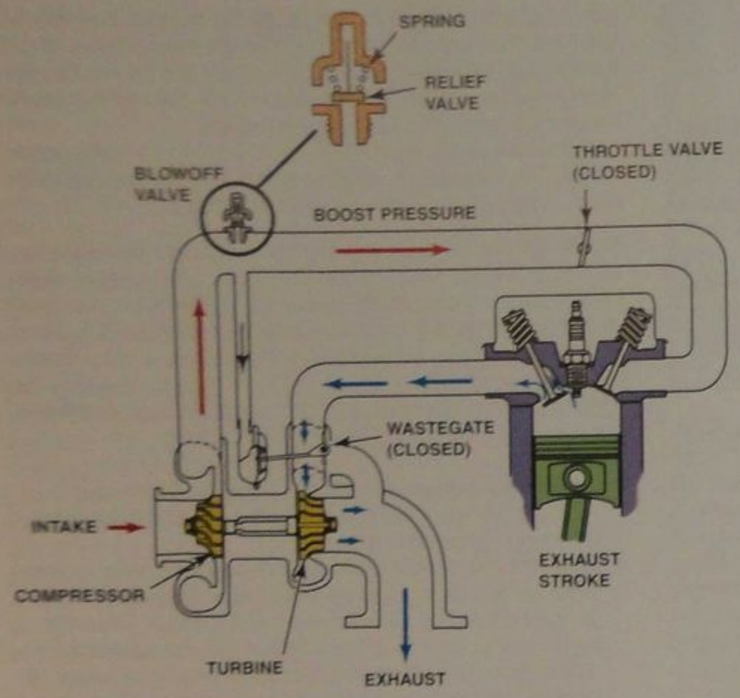


Figure 23–12 A blow-off valve is used in some turbocharged systems to relieve boost pressure during deceleration.

HIGH-PERFORMANCE TIP

If One Is Good, Two Are Better

A turbocharger uses the exhaust from the engine to spin a turbine, which is connected to an impeller inside a turbocharger. This impeller then forces air into the engine under pressure higher than is normally achieved without a turbocharger. The more air that can be forced into an engine, the greater the power potential. A V-type engine has two exhaust manifolds and so two small turbochargers can be used to help force greater quantities of air into an engine, as shown in Figure 23–13.



Figure 23–13 A dual turbocharger system installed on a small block Chevrolet V-8 engine.

TURBOCHARGER FAILURES

When turbochargers fail to function correctly, a drop in power is noticed. To restore proper operation, the turbocharger must be rebuilt, repaired, or replaced. It is not possible to simply remove the turbocharger, seal any openings, and still maintain decent driveability. Bearing failure is a common cause of turbocharger failure, and replacement bearings are usually only available to rebuilders. Another common turbocharger problem is excessive and continuous oil consumption resulting in blue exhaust smoke. Turbochargers use small rings similar to piston rings on the shaft to prevent exhaust (combustion gases) from entering the central bearing. Because there are no seals to keep oil in, excessive oil consumption is usually caused by:

1. A plugged positive crankcase ventilation (PCV) system resulting in excessive crankcase pressures forcing oil into the air inlet. This failure is not related to the turbocharger, but the turbocharger is often blamed.
2. A clogged air filter, which causes a low-pressure area in the inlet, which can draw oil past the turbo shaft rings and into the intake manifold.
3. A clogged oil return (drain) line from the turbocharger to the oil pan (sump), which can cause the engine oil pressure to force oil past the turbocharger's shaft rings and into the intake *and* exhaust manifolds. Obviously, oil being forced into both the intake and exhaust would create lots of smoke.

SUMMARY

1. Volumetric efficiency is a comparison of the actual volume of air-fuel mixture drawn into the engine to the theoretical maximum volume that can be drawn into the cylinder.
2. A supercharger operates from the engine by a drive belt and, while it does consume some engine power, it forces a greater amount of air into the cylinders for even more power.
3. A turbocharger uses the normally wasted heat energy of the exhaust to turn an impeller at high speed. The impeller is linked to a turbine wheel on the same shaft and is used to force air into the engine.
4. There are two types of superchargers: roots-type and centrifugal.
5. A bypass valve is used to control the boost pressure on most factory-installed superchargers.
6. An intercooler is used on many turbocharged and some supercharged engines to reduce the temperature of air entering the engine for increased power.
7. A wastegate is used on most turbocharger systems to limit and control boost pressures, as well as a relief valve, to keep the speed of the turbine wheel from slowing down during engine deceleration.

REVIEW QUESTIONS

1. What are the reasons why supercharging increases engine power?
2. How does the bypass valve work on a supercharged engine?
3. What are the advantages and disadvantages of supercharging?
4. What are the advantages and disadvantages of turbocharging?
5. What turbocharger control valves are needed for proper engine operation?

CHAPTER QUIZ

1. Boost pressure is generally measured in _____.
   a. in. Hg
   b. PSI
   c. in. H_2O
   d. in. lb
2. Two types of superchargers include _____.
   a. Rotary and reciprocating
   b. Roots-type and centrifugal
   c. Double and single acting
   d. Turbine and piston
3. Which valve is used on a factory supercharger to limit boost?
   a. A bypass valve
   b. A wastegate
   c. A blow-off valve
   d. An air valve
4. How are most superchargers lubricated?
   a. By engine oil under pressure through lines from the engine
   b. By an internal oil reservoir
   c. By greased bearings
   d. No lubrication is needed because the incoming air cools the supercharger
5. How are most turbochargers lubricated?
   a. By engine oil under pressure through lines from the engine
   b. By an internal oil reservoir
   c. By greased bearings
   d. No lubrication is needed because the incoming air cools the supercharger
6. Two technicians are discussing the term "turbo lag." Technician A says that it refers to the delay between when the exhaust leaves the cylinder and when it contacts the turbine blades of the turbocharger. Technician B says that it refers to the delay in boost pressure that occurs when the throttle is first opened. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. What is the purpose of an intercooler?
   a. To reduce the temperature of the air entering the engine
   b. To cool the turbocharger
   c. To cool the engine oil on a turbocharged engine
   d. To cool the exhaust before it enters the turbocharger
8. Which type of relief valve used on a turbocharged engine is noisy?
   a. A bypass valve
   b. A BOV
   c. A dump valve
   d. Both b and c
9. Technician A says that a stuck-open wastegate can cause the engine to burn oil. Technician B says that a clogged PCV system can cause the engine to burn oil. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. What service operation is *most* important on engines equipped with a turbocharger?
    a. Replacing the air filter regularly
    b. Replacing the fuel filter regularly
    c. Regular oil changes
    d. Regular exhaust system maintenance

CHAPTER 24 Engine Condition Diagnosis

OBJECTIVES: **After studying Chapter 24, the reader will be able to:** Prepare for ASE Engine Performance (A8) certification test content area "A" (General Engine Diagnosis). • List the visual checks to determine engine condition. • Discuss engine noise and its relation to engine condition. • Describe how to perform a dry and a wet compression test. • Explain how to perform a cylinder leakage test. • Discuss how to measure the amount of timing chain slack. • Describe how an oil sample analysis can be used to determine engine condition.

KEY TERMS: back pressure • compression test • cranking vacuum test • cylinder leakage test • dynamic compression test • idle vacuum test • inches of mercury (in. Hg) • paper test • power balance test • restricted exhaust • running compression test • vacuum test • wet compression test

If there is an engine operation problem, then the cause could be any one of many items, including the engine itself. The condition of the engine should be tested anytime the operation of the engine is not satisfactory.

TYPICAL ENGINE-RELATED COMPLAINTS

Many driveability problems are *not* caused by engine mechanical problems. A thorough inspection and testing of the ignition and fuel systems should be performed before testing for mechanical engine problems.

Typical engine mechanical-related complaints include the following:

- Excessive oil consumption
- Engine misfiring
- Loss of power
- Smoke from the engine or exhaust
- Engine noise

ENGINE SMOKE DIAGNOSIS

The color of engine exhaust smoke can indicate what engine problem might exist.

Typical Exhaust Smoke Color	Possible Causes
Blue	Blue exhaust indicates that the engine is burning oil. Oil is getting into the combustion chamber either past the piston rings or past the valve stem seals. Blue smoke only after start-up is usually due to defective valve stem seals. See Figure 24–1.
Black	Black exhaust smoke is due to excessive fuel being burned in the combustion chamber. Typical causes include a defective or misadjusted throttle body, leaking fuel injector, or excessive fuel-pump pressure.
White (steam)	White smoke or steam from the exhaust is normal during cold weather and represents condensed steam. Every engine creates about 1 gallon of water for each gallon of gasoline burned. If the steam from the exhaust is excessive, then water (coolant) is getting into the combustion chamber. Typical causes include a defective cylinder head gasket, a cracked cylinder head, or in severe cases a cracked block. See Figure 24–2.

Note: White smoke can also be created when automatic transmission fluid (ATF) is burned. A common source of ATF getting into the engine is through a defective vacuum modulator valve on the automatic transmission.



Figure 24–1 Blowby gases coming out of the crankcase vent hose. Excessive amounts of combustion gases flow past the piston rings and into the crankcase.



Figure 24–2 White steam is usually an indication of a blown (defective) cylinder head gasket that allows engine coolant to flow into the combustion chamber where it is turned to steam.

THE DRIVER IS YOUR BEST RESOURCE

The driver of the vehicle knows a lot about the vehicle and how it is driven. *Before* diagnosis is started, always ask the following questions:

- When did the problem first occur?
- Under what conditions does it occur?
  1. Cold or hot?
  2. Acceleration, cruise, or deceleration?
  3. How far was it driven?

After the nature and scope of the problem are determined, the complaint should be verified before further diagnostic tests are performed.

VISUAL CHECKS

The first and most important "test" that can be performed is a careful visual inspection.

Oil Level and Condition The first area for visual inspection is oil level and condition.

1. Oil level—oil should be to the proper level
2. Oil condition
   a. Using a match or lighter, try to light the oil on the dipstick; if the oil flames up, gasoline is present in the engine oil.
   b. Drip some of the engine oil from the dipstick onto the hot exhaust manifold. If the oil bubbles or boils, there is coolant (water) in the oil.
   c. Check for grittiness by rubbing the oil between your fingers.

Coolant Level and Condition Most mechanical engine problems are caused by overheating. The proper operation of the cooling system is critical to the life of any engine.

NOTE: Check the coolant level in the radiator only if the radiator is cool. If the radiator is hot and the radiator cap is removed, the drop in pressure above the coolant will cause the coolant to boil immediately and can cause severe burns when the coolant explosively expands upward and outward from the radiator opening.

1. The coolant level in the coolant recovery container should be within the limits indicated on the overflow bottle. If this level is too low or the coolant recovery container is empty, then check the level of coolant in the radiator (only when cool) and also check the operation of the pressure cap.
2. The coolant should be checked with a hydrometer for boiling and freezing temperature. This test indicates if the concentration of the antifreeze is sufficient for proper protection.
3. Pressure test the cooling system and look for leakage. Coolant leakage can often be seen around hoses or cooling system components because it will often cause:
   a. A grayish white stain
   b. A rusty color stain
   c. Dye stains from antifreeze (greenish or yellowish depending on the type of coolant)
4. Check for cool areas of the radiator indicating clogged sections.
5. Check operation and condition of the fan clutch, fan, and coolant pump drive belt.

TECH TIP ✔ **What's Leaking?**

The color of the leaks observed under a vehicle can help the technician determine and correct the cause. Some leaks, such as condensate (water) from the air-conditioning system, are normal, whereas a brake fluid leak is very dangerous. The following are colors of common leaks:

Sooty black	Engine oil
Yellow, green, blue, or orange	Antifreeze (coolant)
Red	Automatic transmission fluid
Murky brown	Brake or power steering fluid or very neglected antifreeze (coolant)
Clear	Air-conditioning condensate (water) (normal)

Oil Leaks Oil leaks can lead to severe engine damage if the resulting low oil level is not corrected. Besides causing an oily mess where the vehicle is parked, the oil leak can cause blue smoke to occur under the hood as leaking oil drips on the exhaust system. *Finding* the location of the oil leak can often be difficult. See Figures 24–3 and 24–4. To help find the source of oil leaks follow these steps:

Step #1 Clean the engine or area around the suspected oil leak. Use a high-powered hot-water spray to wash the engine. While the engine is running, spray the entire engine and the engine compartment. Avoid letting the water come into direct contact with the air inlet and ignition distributor or ignition coil(s).

NOTE: If the engine starts to run rough or stalls when the engine gets wet, then the secondary ignition wires (spark plug wires) or distributor cap may be defective or have weak insulation. Be certain to wipe all wires and the distributor cap dry with a soft, dry cloth if the engine stalls.

An alternative method is to spray a degreaser on the engine, then start and run the engine until warm. Engine heat helps the degreaser penetrate the grease and dirt. Use a water hose to rinse off the engine and engine compartment.

Step #2 If the oil leak is not visible or oil seems to be coming from "everywhere," use a white talcum powder. The leaking oil will show as a dark area on the white powder. See the Tech Tip, "The Foot Powder Spray Trick."

Step #3 Fluorescent dye can be added to the engine oil. Add about 1/2 oz (15 cc) of dye per 5 quarts of engine oil. Start the engine and allow it to run about 10 minutes to thoroughly mix the dye throughout the engine. A black light can then be shown around every suspected oil leak location. The black light will easily show all oil leak locations because the dye will show as a bright yellow/green area. See Figure 24–5.



Figure 24–3 What looks like an oil pan gasket leak can be a rocker cover gasket leak. Always look up and look for the highest place you see oil leaking; that should be repaired first.



Figure 24–4 The transmission and flexplate (flywheel) were removed to check the exact location of this oil leak. The rear main seal and/or the oil pan gasket could be the cause of this leak.



Figure 24–5 Using a black light to spot leaks after adding dye to the oil.

NOTE: Fluorescent dye works best with clean oil.

TECH TIP ✔ **The Foot Powder Spray Trick**

The source of an oil or other fluid leak is often difficult to determine. A quick and easy method that works is the following. First, clean the entire area. This can best be done by using a commercially available degreaser to spray the entire area. Let it soak to loosen all accumulated oil and greasy dirt. Clean off the degreaser with a water hose. Let the area dry. Start the engine, and using spray foot powder or other aerosol powder product, spray the entire area. The leak will turn the white powder dark. The exact location of any leak can be quickly located.

NOTE: Most oil leaks appear at the bottom of the engine due to gravity. Look for the highest, most forward location for the source of the leak.

ENGINE NOISE DIAGNOSIS

An engine knocking noise is often difficult to diagnose. Several items that can cause a deep engine knock include:

- **Valves clicking.** This can happen because of lack of oil to the lifters. This noise is most noticeable at idle when the oil pressure is the lowest.
- **Torque converter.** The attaching bolts or nuts may be loose on the flex plate. This noise is most noticeable at idle or when there is no load on the engine.
- **Cracked flex plate.** The noise of a cracked flex plate is often mistaken for a rod-or main-bearing noise.
- **Loose or defective drive belts or tensioners.** If an accessory drive belt is loose or defective, the flopping noise often sounds similar to a bearing knock. See Figure 24–6.
- **Piston pin knock.** This knocking noise is usually not affected by load on the cylinder. If the clearance is too great, a double knock noise is heard when the engine idles. If all cylinders are grounded out one at a time and the noise does not change, a defective piston pin could be the cause.
- **Piston slap.** A piston slap is usually caused by an undersized or improperly shaped piston or oversized cylinder bore. A piston slap is most noticeable when the engine is cold and tends to decrease or stop making noise as the piston expands during engine operation.
- **Timing chain noise.** An excessively loose timing chain can cause a severe knocking noise when the chain hits the timing chain cover. This noise can often sound like a rod-bearing knock.
- **Rod-bearing noise.** The noise from a defective rod bearing is usually load sensitive and changes in intensity as the load on the engine increases and decreases. A rod-bearing failure can often be detected by grounding out the spark plugs one cylinder at a time. If the knocking noise decreases or is eliminated when a particular cylinder is grounded (disabled), then the grounded cylinder is the one from which the noise is originating.
- **Main-bearing knock.** A main-bearing knock often cannot be isolated to a particular cylinder. The sound can vary in intensity and may disappear at times depending on engine load.

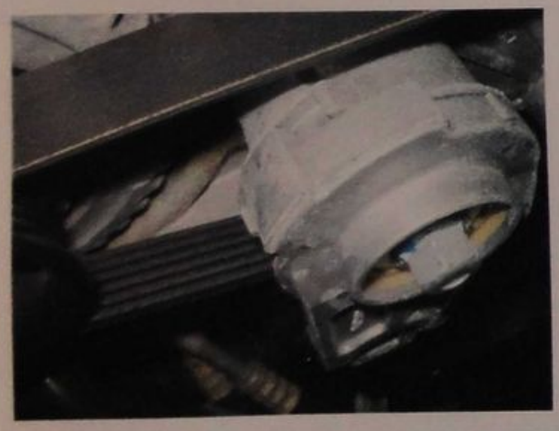


Figure 24–6 An accessory belt tensioner. Most tensioners have a mark that indicates normal operating location. If the belt has stretched, this indicator mark will be outside of the normal range. Anything wrong with the belt or tensioner can cause noise.

Regardless of the type of loud knocking noise, after the external causes of the knocking noise have been eliminated, the engine should be disassembled and carefully inspected to determine the exact cause.

Typical Noises	Possible Causes
Clicking noise—like the clicking of a ballpoint pen	1. Loose spark plug 2. Loose accessory mount (for air-conditioning compressor, alternator, power steering pump, etc.) 3. Loose rocker arm 4. Worn rocker arm pedestal 5. Fuel pump (broken mechanical fuel pump return spring 6. Worn camshaft 7. Exhaust leak. See Figure 24–7.
Clacking noise—like tapping on metal	1. Worn piston pin 2. Broken piston 3. Excessive valve clearance 4. Timing chain hitting cover
Knock—like knocking on a door	1. Rod bearing(s) 2. Main bearing(s) 3. Thrust bearing(s) 4. Loose torque converter 5. Cracked flex plate (drive plate)
Rattle—like a baby rattle	1. Manifold heat control valve 2. Broken harmonic balancer 3. Loose accessory mounts 4. Loose accessory drive belt or tensioner
Clatter—like rolling marbles	1. Rod bearings 2. Piston pin 3. Loose timing chain
Whine—like an electric motor running	1. Alternator bearing 2. Drive belt 3. Power steering 4. Belt noise (accessory or timing)
Clunk—like a door closing	1. Engine mount 2. Drive axle shaft U-joint or constant velocity (CV) joint

TECH TIP ✔ **Engine Noise and Cost**

A light ticking noise often heard at one-half engine speed and associated with valve train noise is a less serious problem than many deep-sounding knocking noises. Generally, the deeper the sound of the engine noise, the more the owner will have to pay for repairs. A light "tick tick tick," though often not cheap, is usually far less expensive than a deep "knock knock knock" from the engine.

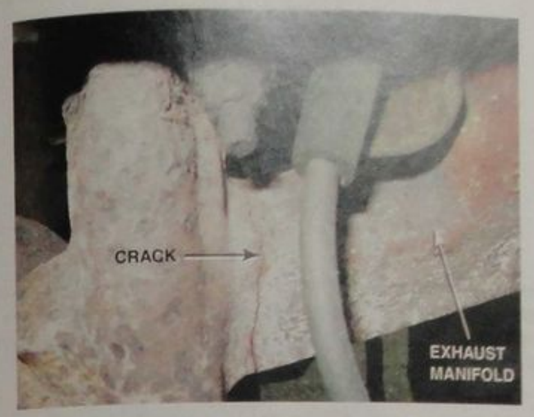


Figure 24–7 A cracked exhaust manifold on a Ford V-8.

OIL PRESSURE TESTING

Proper oil pressure is very important for the operation of any engine. *Low oil pressure can cause engine wear, and engine wear can cause low oil pressure.*

If main thrust or rod bearings are worn, oil pressure is reduced because of leakage of the oil around the bearings. Oil pressure testing is usually performed with the following steps:

Step #1 Operate the engine until normal operating temperature is achieved.

Step #2 With the engine off, remove the oil pressure sending unit or sender, usually located near the oil filter. Thread an oil pressure gauge into the threaded hole. See Figure 24–8.

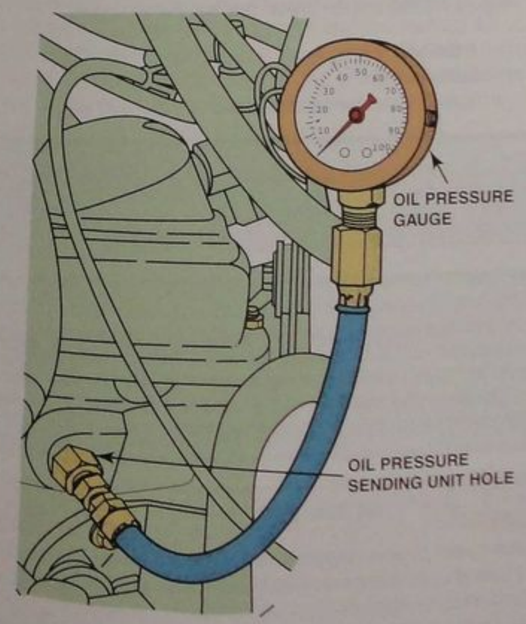


Figure 24–8 To measure engine oil pressure, remove the oil pressure sending (sender) unit usually located near the oil filter. Screw the pressure gauge into the oil pressure sending unit hole.

NOTE: An oil pressure gauge can be made from another gauge, such as an old air-conditioning gauge and a flexible brake hose. The threads are often the same as those used for the oil pressure sending unit.

Step #3 Start the engine and observe the gauge. Record the oil pressure at idle and at 2500 RPM. Most vehicle manufacturers recommend a minimum oil pressure of 10 PSI per 1000 RPM. Therefore, at 2500 RPM, the oil pressure should be at least 25 PSI. Always compare your test results with the manufacturer's recommended oil pressure.

Besides engine bearing wear, other possible causes for low oil pressure include:

- Low oil level
- Diluted oil
- Stuck oil pressure relief valve

OIL PRESSURE WARNING LAMP

The red oil pressure warning lamp in the dash usually lights when the oil pressure is less than 4 to 7 PSI, depending on vehicle and engine. The oil light should not be on during driving. If the oil warning lamp is on, stop the engine immediately. Always confirm oil pressure with a reliable mechanical gauge before performing engine repairs. The sending unit or circuit may be defective.

TECH TIP ✔ **Use the KISS Test Method**

Engine testing is done to find the cause of an engine problem. All the simple things should be tested first. Just remember KISS—"keep it simple, stupid." A loose alternator belt or loose bolts on a torque converter can sound just like a lifter or rod bearing. A loose spark plug can make the engine perform as if it had a burned valve. Some simple items that can cause serious problems include the following:

Oil Burning

- Low oil level
- Clogged PCV valve or system, causing blowby and oil to be blown into the air cleaner
- Clogged drainback passages in the cylinder head
- Dirty oil that has not been changed for a long time (Change the oil and drive for about 1,000 miles (1,600 kilometers) and change the oil and filter again.)

Noises

- Carbon on top of the piston(s) can sound like a bad rod bearing (often called a carbon knock)
- Loose torque-to-flex plate bolts (or nuts), causing a loud knocking noise

NOTE: Often this problem will cause noise only at idle; the noise tends to disappear during driving or when the engine is under load.

- A loose and/or defective drive belt, which may cause a rod- or main-bearing knocking noise (A loose or broken mount for the generator [alternator], power steering pump, or air-conditioning compressor can also cause a knocking noise.)

TECH TIP ✓ **The Paper Test**

A soundly running engine should produce even and steady exhaust at the tailpipe. You can test this with the **paper test.** Hold a piece of paper or a 3" × 5" index card (even a dollar bill works) within 1 inch (2.5 centimeters) of the tailpipe with the engine running at idle. See Figure 24–9.

The paper should blow out evenly without "puffing." If the paper is drawn toward the tailpipe at times, the exhaust valves in one or more cylinders could be burned. Other reasons why the paper might be sucked toward the tailpipe include the following:

1. The engine could be misfiring because of a lean condition that could occur normally when the engine is cold.
2. Pulsing of the paper toward the tailpipe could also be caused by a hole in the exhaust system. If exhaust escapes through a hole in the exhaust system, air could be drawn in during the intervals between the exhaust puffs from the tailpipe to the hole in the exhaust, causing the paper to be drawn toward the tailpipe.
3. Ignition fault causing misfire.

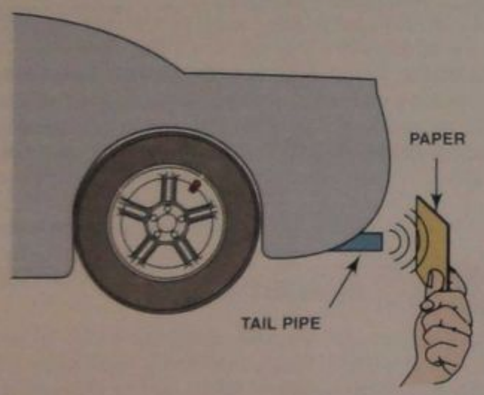


Figure 24–9 The paper test involves holding a piece of paper near the tailpipe of an idling engine. A good engine should produce even, outward puffs of exhaust. If the paper is sucked in toward the tailpipe, a burned valve is a possibility.

COMPRESSION TEST

An engine **compression test** is one of the fundamental engine diagnostic tests that can be performed. For smooth engine operation, all cylinders must have equal compression. An engine can lose compression by leakage of air through one or more of only three routes:

- Intake or exhaust valve
- Piston rings (or piston, if there is a hole)
- Cylinder head gasket

For best results, the engine should be warmed to normal operating temperature before testing. An accurate compression test should be performed as follows:

Step #1 Remove all spark plugs. This allows the engine to be cranked to an even speed. Be sure to label all spark plug wires.

CAUTION: Disable the ignition system by disconnecting the primary leads from the ignition coil or module or by grounding the coil wire after removing it from the center of the distributor cap. Also disable the fuel-injection system to prevent the squirting of fuel into the cylinder.



Figure 24–10 A two-piece compression gauge set. The threaded hose is screwed into the spark plug hole after removing the spark plug. The gauge part is then snapped onto the end of the hose.

Step #2 Block open the throttle. This permits the maximum amount of air to be drawn into the engine. This step also ensures consistent compression test results.

Step #3 Thread a compression gauge into one spark plug hole and crank the engine. See Figure 24–10.

Continue cranking the engine through *four* compression strokes. Each compression stroke makes a puffing sound.

NOTE: Note the reading on the compression gauge after the first puff. This reading should be at least one-half the final reading. For example, if the final, highest reading is 150 PSI, then the reading after the first puff should be higher than 75 PSI. A low first-puff reading indicates possible weak piston rings. Release the pressure on the gauge and repeat for the other cylinders.

Step #4 Record the highest readings and compare the results. Most vehicle manufacturers specify the minimum compression reading and the maximum allowable variation among cylinders. Most manufacturers specify a maximum difference of 20% between the highest reading and the lowest reading. For example:

If the high reading is	150 PSI
Subtract 20%	−30 PSI
Lowest allowable compression is	120 PSI

NOTE: To make the math quick and easy, think of 10% of 150, which is 15 (move the decimal point to the left one place). Now double it: 15 × 2 = 30. This represents 20%.

NOTE: During cranking, the oil pump cannot maintain normal oil pressure. Extended engine cranking, such as that which occurs during a compression test, can cause hydraulic lifters to collapse. When the engine starts, loud valve clicking noises may be heard. This should be considered normal after performing a compression test, and the noise should stop after the vehicle has been driven a short distance.

TECH TIP ✓ **The Hose Trick**

Installing spark plugs can be made easier by using a rubber hose on the end of the spark plug. The hose can be a vacuum hose, fuel line, or even an old spark plug wire end. See Figure 24–11.

The hose makes it easy to start the threads of the spark plug into the cylinder head. After starting the threads, continue to thread the spark plug for several turns. Using the hose eliminates the chance of cross-threading the plug. This is especially important when installing spark plugs in aluminum cylinder heads.

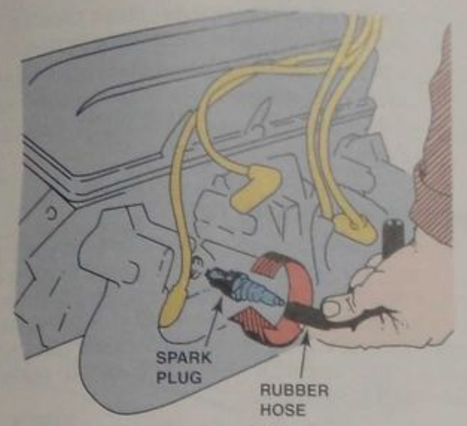


Figure 24–11 Use a vacuum or fuel line hose over the spark plug to install it without danger of cross-threading the cylinder head.

WET COMPRESSION TEST

If the compression test reading indicates low compression on one or more cylinders, add three squirts of oil to the cylinder and retest. This is called a **wet compression test,** when oil is used to help seal around the piston rings.

CAUTION: Do not use more oil than three squirts from a hand-operated oil squirt can. Too much oil can cause a hydrostatic lock, which can damage or break pistons or connecting rods or even crack a cylinder head.

Perform the compression test again and observe the results. If the first-puff readings greatly improve and the readings are much higher than without the oil, the cause of the low compression is worn or defective piston rings. If the compression readings increase only slightly (or not at all), then the cause of the low compression is usually defective valves. See Figure 24–12.

NOTE: During both the dry and wet compression tests, be sure that the battery and starting system are capable of cranking the engine at normal cranking speed.

RUNNING (DYNAMIC) COMPRESSION TEST

A compression test is commonly used to help determine engine condition and is usually performed with the engine cranking.

What is the RPM of a cranking engine? An engine idles at about 600 to 900 RPM, and the starter motor obviously cannot crank the engine as fast as the engine idles. Most manufacturers' specifications require the engine to crank at 80 to 250 cranking RPM. Therefore, a check of the engine's compression at cranking speed determines the condition of an engine that does not run at such low speeds.

But what should be the compression of a running engine? Some would think that the compression would be substantially higher, because the valve overlap of the cam is more effective at higher engine speeds, which would tend to increase the compression.

A **running compression test,** also called a **dynamic compression test,** is a compression test done with the engine running rather than during engine cranking as is done in a regular compression test.

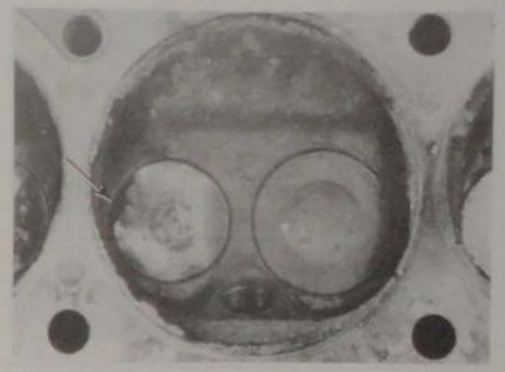


Figure 24–12 Badly burned exhaust valve. A compression test could have detected a problem, and a cylinder leakage test (leak-down test) could have been used to determine the exact problem.

Actually, the compression pressure of a running engine is much *lower* than cranking compression pressure. This results from the volumetric efficiency. The engine is revolving faster, and therefore, there is less *time* for air to enter the combustion chamber. With less air to compress, the compression pressure is lower. Typically, the higher the engine RPM, the lower the running compression. For most engines, the value ranges are as follows:

- Compression during cranking: 125 to 160 PSI
- Compression at idle: 60 to 90 PSI
- Compression at 2000 RPM: 30 to 60 PSI

As with cranking compression, the running compression of all cylinders should be equal. Therefore, a problem is not likely to be detected by single compression values, but by *variations* in running compression values among the cylinders. Broken valve springs, worn valve guides, bent pushrods, and worn cam lobes are some items that would be indicated by a low running compression test reading on one or more cylinders.

Performing a Running Compression Test To perform a running compression test, remove just one spark plug at a time. With one spark plug removed from the engine, use a jumper wire to *ground* the spark plug wire to a good engine ground. This prevents possible ignition coil damage. Start the engine, push the pressure release on the gauge, and read the compression. Increase the engine speed to about 2000 RPM and push the pressure release on the gauge again. Read the gauge. Stop the engine, reattach the spark plug wire, and repeat the test for each of the remaining cylinders. Just like the cranking compression test, the running compression test can inform a technician of the *relative* compression of all the cylinders.

CYLINDER LEAKAGE TEST

One of the best tests that can be used to determine engine condition is the **cylinder leakage test.** This test involves injecting air under pressure into the cylinders one at a time. The amount and location of any escaping air helps the technician determine the condition of the engine. The air is injected into the cylinder through a cylinder leakage gauge into the spark plug hole. See Figure 24–13. To perform the cylinder leakage test, take the following steps:

Step #1 For best results, the engine should be at normal operating temperature (upper radiator hose hot and pressurized).



Figure 24–13 A typical hand-held cylinder leakage tester.



Figure 24–14 A whistle stop used to find top dead center. Remove the spark plug and install the whistle stop, then rotate the engine by hand. When the whistle stops making a sound, the piston is at the top.

Step #2 The cylinder being tested must be at top dead center (TDC) of the compression stroke. See Figure 24–14.

> **NOTE:** The greatest amount of wear occurs at the top of the cylinder because of the heat generated near the top of the cylinders. The piston ring flex also adds to the wear at the top of the cylinder.

Step #3 Calibrate the cylinder leakage unit as per manufacturer's instructions.

Step #4 Inject air into the cylinders one at a time, rotating the engine as necessitated by firing order to test each cylinder at TDC on the compression stroke.

Step #5 Evaluate the results:

Less than 10% leakage: good

Less than 20% leakage: acceptable

Less than 30% leakage: poor

More than 30% leakage: definite problem

> **NOTE:** If leakage seems unacceptably high, repeat the test, being certain that it is being performed correctly and that the cylinder being tested is at TDC on the compression stroke.

Step #6 Check the source of air leakage.

a. If air is heard escaping from the oil filler cap, the *piston rings* are worn or broken.

b. If air is observed bubbling out of the radiator, there is a possible blown *head gasket* or cracked *cylinder head.*

c. If air is heard coming from the throttle body or air inlet on fuel injection-equipped engines, there is a defective *intake valve(s).*

d. If air is heard coming from the tailpipe, there is a defective *exhaust valve(s).*

CYLINDER POWER BALANCE TEST

Most large engine analyzers and scan tools have a cylinder power balance feature. The purpose of a cylinder **power balance test** is to determine if all cylinders are contributing power equally. It determines this by shorting out one cylinder at a time. If the engine speed (RPM) does not drop as much for one cylinder as for other cylinders of the same engine, then the shorted cylinder must be weaker than the other cylinders. For example:

Cylinder Number	RPM Drop When Ignition Is Shorted
1	75
2	70
3	15
4	65
5	75
6	70

Cylinder #3 is the weak cylinder.

> **NOTE:** Most automotive test equipment uses automatic means for testing cylinder balance. Be certain to correctly identify the offending cylinder. Cylinder #3 as identified by the equipment may be the third cylinder in the firing order instead of the actual cylinder #3.

POWER BALANCE TEST PROCEDURE

When point-type ignition was used on all vehicles, the common method for determining which, if any, cylinder was weak was to remove a spark plug wire from one spark plug at a time while watching a tachometer and a vacuum gauge. This method is not recommended on any vehicle with any type of electronic ignition. If any of the spark plug wires are removed from a spark plug with the engine running, the ignition coil tries to supply increasing levels of voltage attempting to jump the increasing gap as the plug wires are removed. This high voltage could easily track the ignition coil, damage the ignition module, or both.

The acceptable method of canceling cylinders, which will work on all types of ignition systems, including distributorless, is to *ground* the secondary current for each cylinder. See Figure 24–15. The cylinder with the least RPM drop is the cylinder not producing its share of power.

VACUUM TESTS

Vacuum is pressure below atmospheric pressure and is measured in **inches** (or millimeters) **of mercury (Hg).** An engine in good mechanical condition will run with high manifold vacuum. Manifold vacuum is developed by the pistons as they move down on the intake stroke to draw the charge from the throttle body and intake manifold. Air to refill the manifold comes past the throttle plate into the manifold. Vacuum will increase anytime the engine

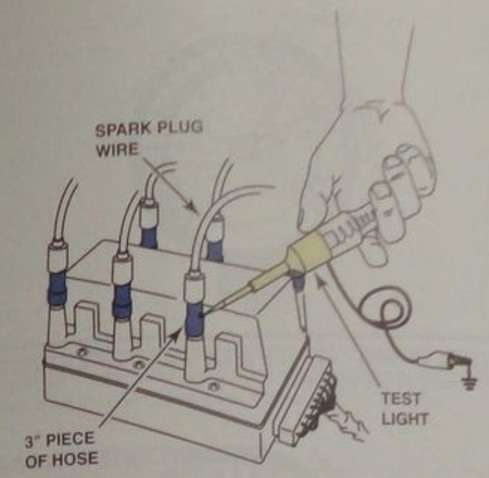


Figure 24–15 Using a vacuum hose and a test light to ground one cylinder at a time on a distributorless ignition system. This works on all types of ignition systems and provides a method for grounding out one cylinder at a time without fear of damaging any component.

turns faster or has better cylinder sealing while the throttle plate remains in a fixed position. Manifold vacuum will decrease when the engine turns more slowly or when the cylinders no longer do an efficient job of pumping. **Vacuum tests** include testing the engine for **cranking vacuum, idle vacuum,** and vacuum at 2500 RPM.

Cranking Vacuum Test Measuring the amount of manifold vacuum during cranking is a quick and easy test to determine if the piston rings and valves are properly sealing. (For accurate results, the engine should be warm and the throttle closed.) To perform the cranking vacuum test, take the following steps:

Step #1 Disable the ignition or fuel injection.

Step #2 Connect the vacuum gauge to a manifold vacuum source.

Step #3 Crank the engine while observing the vacuum gauge.

Cranking vacuum should be higher than 2.5 inches of mercury. (Normal cranking vacuum is 3 to 6 inches Hg.) If it is lower than 2.5 inches Hg, then the following could be the cause:

- Too slow a cranking speed
- Worn piston rings
- Leaking valves
- Excessive amounts of air bypassing the throttle plate (This could give a false low vacuum reading. Common sources include a throttle plate partially open or a high-performance camshaft with excessive overlap.)

Idle Vacuum Test An engine in proper condition should idle with a steady vacuum between 17 and 21 inches Hg. See Figure 24–16.

> **NOTE:** Engine vacuum readings vary with altitude. A reduction of 1 inch Hg per 1,000 feet (300 meters) of altitude should be subtracted from the expected values if testing a vehicle above 1,000 feet (300 meters).

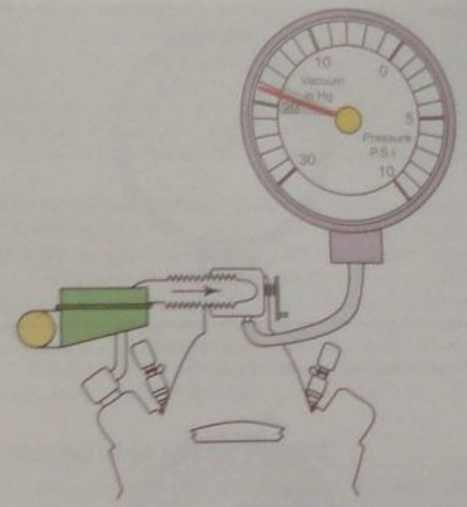


Figure 24–16 An engine in good mechanical condition should produce 17 to 21 in. Hg of vacuum at idle at sea level.



Figure 24–17 A steady but low reading could indicate retarded valve or ignition timing.

Low and Steady Vacuum If the vacuum is lower than normal, yet the gauge reading is steady, the most common causes include:

- Retarded ignition timing
- Retarded cam timing (check timing chain for excessive slack or timing belt for proper installation)

See Figure 24–17.

Fluctuating Vacuum If the needle drops, then returns to a normal reading, then drops again, and again returns, this indicates a sticking valve. A common cause of sticking valves is lack of lubrication of the valve stems. See Figures 24–18 through 24–26. If the vacuum gauge fluctuates above and below a center point, burned valves or weak valve springs may be indicated. If the fluctuation is slow and steady, unequal fuel mixture could be the cause.

> **NOTE:** A common trick that some technicians use is to squirt some automatic transmission fluid (ATF) down the throttle body or into the air inlet of a warm engine. Often the idle quality improves and normal vacuum gauge readings are restored. The use of ATF does create excessive exhaust smoke for a short time, but it should not harm oxygen sensors or catalytic converters.

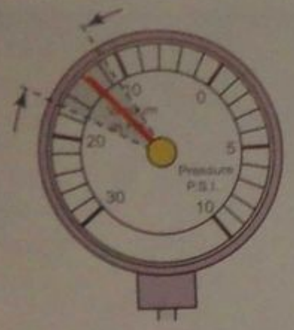


Figure 24–18 A gauge reading with the needle fluctuating 3 to 9 in. Hg below normal often indicates a vacuum leak in the intake system.

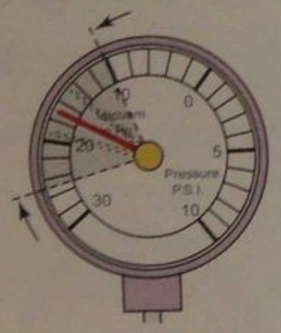


Figure 24–19 A leaking head gasket can cause the needle to vibrate as it moves through a range from below to above normal.

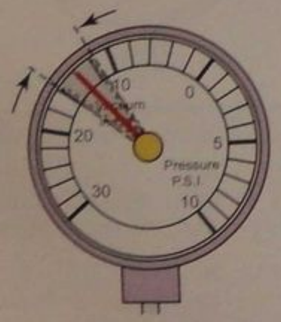


Figure 24–20 An oscillating needle 1 or 2 in. Hg below normal could indicate an incorrect air–fuel mixture (either too rich or too lean).

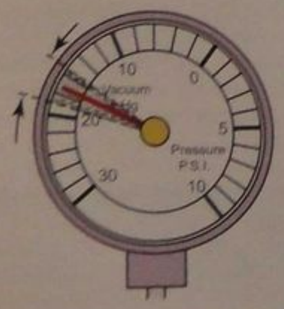


Figure 24–21 A rapidly vibrating needle at idle that becomes steady as engine speed is increased indicates worn valve guides.

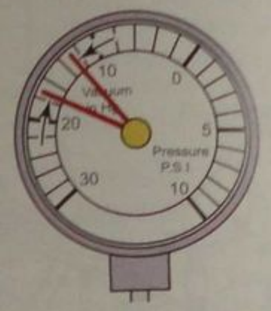


Figure 24–22 If the needle drops 1 or 2 in. Hg from the normal reading, one of the engine valves is burned or not seating properly.

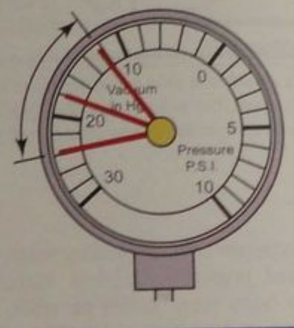


Figure 24–23 Weak valve springs will produce a normal reading at idle, but as engine speed increases, the needle will fluctuate rapidly between 12 and 24 in. Hg.

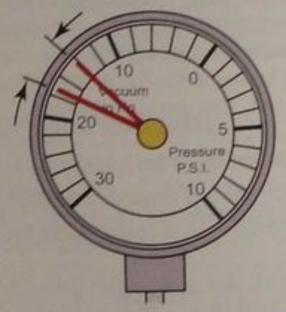


Figure 24–24 A steady needle reading that drops 2 or 3 in. Hg when the engine speed is increased slightly above idle indicates that the ignition timing is retarded.

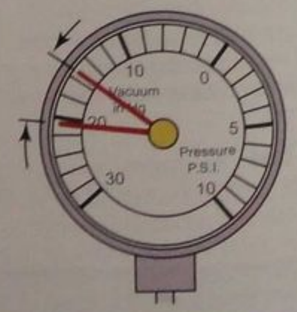


Figure 24–25 A steady needle reading that rises 2 or 3 in. Hg when the engine speed is increased slightly above idle indicates that the ignition timing is advanced.

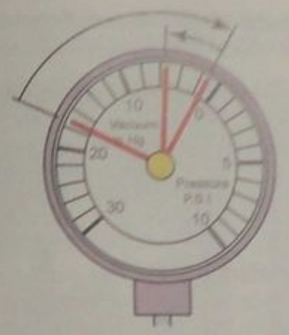


Figure 24–26 A needle that drops to near zero when the engine is accelerated rapidly and then rises slightly to a reading below normal indicates an exhaust restriction.

EXHAUST RESTRICTION TEST

If the exhaust system is restricted, the engine will be low on power, yet smooth. Common causes of **restricted exhaust** include the following:

- **Clogged catalytic converter.** Always check the ignition and fuel-injection systems for faults that could cause excessive amounts of unburned fuel to be exhausted. Excessive unburned fuel can overheat the catalytic converter and cause the beads or structure of the converter to fuse together, creating the restriction. A defective fuel delivery system could also cause excessive unburned fuel to be dumped into the converter.
- **Clogged or restricted muffler.** This can cause low power. Often a defective catalytic converter will shed particles that can clog a muffler. Broken internal baffles can also restrict exhaust flow.
- **Damaged or defective piping.** This can reduce the power of any engine. Some exhaust pipe is constructed with double walls, and the inside pipe can collapse and form a restriction that is not visible on the outside of the exhaust pipe.

TESTING BACK PRESSURE WITH A VACUUM GAUGE

A vacuum gauge can be used to measure manifold vacuum at a high idle (2000 to 2500 RPM). If the exhaust system is restricted, pressure increases in the exhaust system. This pressure is called **back pressure.** Manifold vacuum will drop gradually if the engine is kept at a constant speed if the exhaust is restricted.

The reason the vacuum will drop is that all exhaust leaving the engine at the higher engine speed cannot get through the restriction. After a short time (within 1 minute), the exhaust tends to "pile up" above the restriction and eventually remains in the cylinder of the engine at the end of the exhaust stroke. Therefore, at the beginning of the intake stroke, when the piston traveling downward should be lowering the pressure (raising the vacuum) in the intake manifold, the extra exhaust in the cylinder *lowers* the normal vacuum. If the exhaust restriction is severe enough, the vehicle can become undriveable because cylinder filling cannot occur except at idle.

TESTING BACK PRESSURE WITH A PRESSURE GAUGE

Exhaust system back pressure can be measured directly by installing a pressure gauge into an exhaust opening. This can be accomplished in one of the following ways:

- **With an oxygen sensor.** Use a back pressure gauge and adapter or remove the inside of an old, discarded oxygen sensor and thread in an adapter to convert to a vacuum or pressure gauge.

A pressure gauge adapter can be easily made by inserting a metal tube or pipe. A short section of brake line works great. The pipe can be brazed to the oxygen sensor housing or it can be glued in with epoxy. An 18-millimeter corrugated-steel gauge adapter can also be adapted to fit into the oxygen sensor opening. See Figure 24–27.

- **With the exhaust gas recirculation (EGR) valve.** Remove the EGR valve and fabricate a plate to connect to a pressure gauge.
- **With the air-injection reaction (AIR) check valve.** Remove the check valve from the exhaust tubes leading down to the exhaust manifold. Use a rubber cone with a tube inside to seal against the exhaust tube. Connect the tube to a pressure gauge.

At idle, the maximum back pressure should be less than 1.5 PSI (10 kPa), and it should be less than 2.5 PSI (15 kPa) at 2500 RPM.

DIAGNOSING HEAD GASKET FAILURE

Several items can be used to help diagnose a head gasket failure:

- **Exhaust gas analyzer.** With the radiator cap removed, place the probe from the exhaust analyzer above the radiator filler neck. If the HC reading increases, the exhaust (unburned hydrocarbons) is getting into the coolant from the combustion chamber.
- **Chemical test.** A chemical tester using blue liquid is also available. The liquid turns yellow if combustion gases are present in the coolant. See Figure 24–28.



Figure 24–27 A technician-made adapter used to test exhaust system backpressure.



Figure 24–28 A tester that uses a blue liquid to check for exhaust gases in the exhaust which would indicate a head gasket leak problem.

- **Bubbles in the coolant.** Remove the coolant pump belt to prevent pump operation. Remove the radiator cap and start the engine. If bubbles appear in the coolant before it begins to boil, a defective head gasket or cracked cylinder head is indicated.
- **Excessive exhaust steam.** If excessive water or steam is observed coming from the tailpipe, this means that coolant is getting into the combustion chamber from a defective head gasket or a cracked head. If there is leakage between cylinders, the engine usually misfires and a power balancer test and/or compression test can be used to confirm the problem.

If any of the preceding indicators of head gasket failure occur, remove the cylinder head(s) and check all of the following:

1. Head gasket
2. Sealing surfaces—for warpage
3. Castings—for cracks

NOTE: A leaking thermal vacuum valve can cause symptoms similar to those of a defective head gasket. Most thermal vacuum valves thread into a coolant passage, and they often leak only after they get hot.

DASH WARNING LIGHTS

Most vehicles are equipped with several dash warning lights often called "telltale" or "idiot" lights. These lights are often the only warning a driver receives that there may be engine problems. A summary of typical dash warning lights and their meanings follows.

Oil (Engine) Light The red oil light indicates that the engine oil pressure is too low (usually lights when oil pressure is 4 to 7 PSI [20 to 50 kPa]). Normal oil pressure should be 10 to 60 PSI (70 to 400 kPa) or 10 PSI per 1000 engine RPM.

When this light comes on, the driver should shut off the engine immediately and check the oil level and condition for possible dilution with gasoline caused by a fuel system fault. If the oil level is okay, then there is a possible serious engine problem or a possible defective oil pressure sending (sender) unit. The automotive technician should always check the oil pressure using a reliable mechanical oil pressure gauge if low oil pressure is suspected.

NOTE: Some automobile manufacturers combine the dash warning lights for oil pressure and coolant temperature into one light, usually labeled "engine." Therefore, when the engine light comes on, the technician should check for possible coolant temperature and/or oil pressure problems.

Coolant Temperature Light Most vehicles are equipped with a coolant temperature gauge or dash warning light. The warning light may be labeled "coolant," "hot," or "temperature." If the coolant temperature warning light comes on during driving, this usually indicates that the coolant temperature is above a safe level, or above about 250°F (120°C). Normal coolant temperature should be about 200° to 220°F (90° to 105°C).

If the coolant temperature light comes on during driving, the following steps should be followed to prevent possible engine damage:

1. Turn off the air conditioning and turn on the heater. The heater will help get rid of some of the heat in the cooling system.
2. Raise the engine speed in neutral or park to increase the circulation of coolant through the radiator.
3. If possible, turn the engine off and allow it to cool (this may take over an hour).
4. Do not continue driving with the coolant temperature light on (or the gauge reading in the red warning section or above 260°F) or serious engine damage may result.

NOTE: If the engine does not feel or smell hot, it is possible that the problem is a faulty coolant temperature sensor or gauge.

TECH TIP ✔ **Misfire Diagnosis**

If a misfire goes away with propane added to the air inlet, suspect a lean injector.

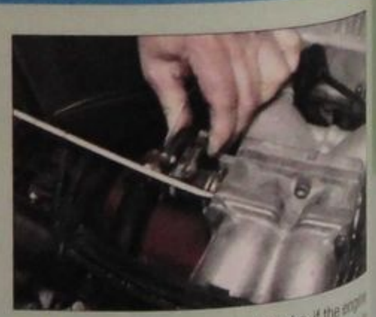
PHOTO SEQUENCE Compression Test



P24–1 The tools and equipment needed to perform a compression test include a compression gauge, an air nozzle, and the socket ratchets and extensions that may be necessary to remove the spark plugs from the engine.



P24–2 To prevent ignition and fuel-injection operation while the engine is being cranked, remove both the fuel-injection fuse and the ignition fuse. If the fuses cannot be removed, disconnect the wiring connectors for the injectors and the ignition system.



P24–3 Block open the throttle (and choke, if the engine is equipped with a carburetor). Here a screwdriver is being used to wedge the throttle linkage open. Keeping the throttle open ensures that enough air will be drawn into the engine so that the compression test results will be accurate.

PHOTO SEQUENCE Compression Test—continued



P24–4 Before removing the spark plugs, use an air nozzle to blow away any dirt that may be around the spark plug. This step helps prevent debris from getting into the engine when the spark plugs are removed.



P24–5 Remove all of the spark plugs. Be sure to mark the spark plug wires so that they can be reinstalled onto the correct spark plugs after the compression test has been performed.



P24–6 Select the proper adapter for the compression gauge. The threads on the adapter should match those on the spark plug.



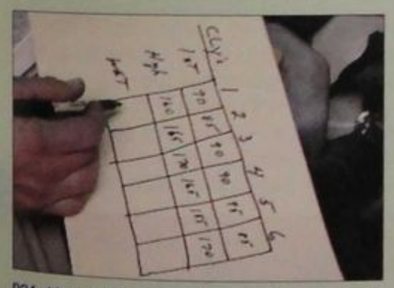
P24–7 If necessary, connect a battery charger to the battery before starting the compression test. It is important that consistent cranking speed be available for each cylinder being tested.



P24–8 Make a note of the reading on the gauge after the first "puff," which indicates the first compression stroke that occurred on that cylinder as the engine was being rotated. If the first puff reading is low and the reading gradually increases with each puff, weak or worn piston rings may be indicated.



P24–9 After the engine has been cranked for four "puffs," stop cranking the engine and observe the compression gauge.



P24–10 Record the first puff and this final reading for each cylinder. The final readings should all be within 20% of each other.



P24–11 If a cylinder(s) is lower than most of the others, use an oil can and squirt two squirts of engine oil into the cylinder and repeat the compression test. This is called performing a wet compression test.



P24–12 If the gauge reading is now much higher than the first test results, then the cause of the low compression is due to worn or defective piston rings. The oil in the cylinder temporarily seals the rings which causes the higher reading.

SUMMARY

1. The first step in diagnosing engine condition is to perform a thorough visual inspection, including a check of oil and coolant levels and condition.
2. Oil leaks can be found by using a white powder or a fluorescent dye and a black light.
3. Many engine-related problems make a characteristic noise.
4. Oil analysis by an engineering laboratory can reveal engine problems by measuring the amount of dissolved metals in the oil.
5. A compression test can be used to test the condition of valves and piston rings.
6. A cylinder leakage test fills the cylinder with compressed air, and the gauge indicates the percentage of leakage.
7. A cylinder balance test indicates whether all cylinders are working okay.
8. Testing engine vacuum is another procedure that can help the service technician determine engine condition.

REVIEW QUESTIONS

1. Describe the visual checks that should be performed on an engine if a mechanical malfunction is suspected.
2. List three simple items that could cause excessive oil consumption.
3. List three simple items that could cause engine noises.
4. Describe how to perform a compression test and how to determine what is wrong with an engine based on a compression test result.
5. Describe the cylinder leakage test.
6. Describe how a vacuum gauge would indicate if the valves were sticking in their guides.
7. Describe the test procedure for determining if the exhaust system is restricted (clogged) using a vacuum gauge.

CHAPTER QUIZ

1. Technician A says that the paper test could detect a burned valve. Technician B says that a grayish white stain on the engine could be a coolant leak. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Two technicians are discussing oil leaks. Technician A says that an oil leak can be found using a fluorescent dye in the oil with a black light to check for leaks. Technician B says that a white spray powder can be used to locate oil leaks. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Which of the following is the *least likely* to cause an engine noise?
   a. Carbon on the pistons
   b. Cracked exhaust manifold
   c. Loose accessory drive belt
   d. Vacuum leak
4. Antifreeze in the engine oil can cause _____.
   a. The oil to become thinner (decrease viscosity)
   b. The oil to become thicker (increase viscosity)
   c. The oil to congeal
   d. Both b and c
5. A smoothly operating engine depends on _____.
   a. High compression on most cylinders
   b. Equal compression between cylinders
   c. Cylinder compression levels above 100 PSI (700 kPa) and within 70 PSI (500 kPa) of each other
   d. Compression levels below 100 PSI (700 kPa) on most cylinders
6. A good reading for a cylinder leakage test would be _____.
   a. Within 20% between cylinders
   b. All cylinders below 20% leakage
   c. All cylinders above 20% leakage
   d. All cylinders above 70% leakage and within 7% of each other
7. Technician A says that during a power balance test, the cylinder that causes the biggest RPM drop is the weak cylinder. Technician B says that if one spark plug wire is grounded out and the engine speed does not drop, a weak or dead cylinder is indicated. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. *Cranking* vacuum should be _____.
   a. 2.5 inches Hg or higher
   b. Over 25 inches Hg
   c. 17 to 21 inches Hg
   d. 6 to 16 inches Hg
9. Technician A says that a worn (stretched) timing chain and worn gears will cause the valve and ignition timing to be retarded. Technician B says that if the timing chain slack is over 8 degrees, the timing chain and gears should be replaced. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. The low oil pressure warning light usually comes on _____.
    a. Whenever an oil change is required
    b. Whenever oil pressure drops dangerously low (4 to 7 PSI)
    c. Whenever the oil filter bypass valve opens
    d. Whenever the oil filter antidrainback valve opens

CHAPTER 25

Engine Disassembly, Cleaning, and Crack Detection

OBJECTIVES: After studying Chapter 25, the reader will be able to: Prepare for ASE Engine Repair (A1) certification test content area "A" (General Engine Diagnosis). • Describe how to remove an engine from a vehicle. • Discuss how to remove cylinder heads without causing warpage. • List the steps necessary to remove a piston from a cylinder. • Explain how to remove a valve from a cylinder head. • List the types of engine cleaning methods. • List the various methods that can be used to check engine parts for cracks. • Describe crack-repair procedures.

KEY TERMS: acid materials • agitation • aqueous-based solutions • caustic materials • fogging oil • fusible link • harmonic balancer • hydroseal • keepers • pH • putty knife • pyrolytic • soluble • stop drilling • ultrasonic cleaning • valve locks • vibration damper • Zyglo®

The decision to repair an engine should be based on all the information about the engine that is available to the service technician. In some cases, the engine might not be worth repairing. It is the responsibility of the technician to discuss the advantages and disadvantages of the different repair options with the customer.

ENGINE REMOVAL

The engine exterior and the engine compartment should be cleaned before work is begun. A clean engine is easier to work on and the cleaning not only helps to keep dirt out of the engine but also minimizes accidental damage from slipping tools. The battery ground cable is disconnected to avoid the chance of electrical shorts. An even better procedure is to remove the battery from the vehicle.

NOTE: Most technicians lightly scribe around the hood hinges prior to removal to make aligning the hood easier during reinstallation.

Working on the top of the engine is made easier if the hood is removed. With fender covers in place, the hood is loosened from the hinges. With a person on each side of the hood to support it, the hood is lifted off as the bolts that hold the hood are removed. The hood is usually stored on fender covers placed on the top of the vehicle, where it is least likely to be damaged.

The coolant is drained from the radiator and the engine block to minimize the chance of coolant getting into the cylinders when the head is removed. The exhaust manifold is disconnected.

HINT: On some engines, it is easier to remove the exhaust pipe from the manifold. On others, it is easier to separate the exhaust manifold from the head and leave the manifold attached to the exhaust pipe.

On *V*-type engines, the intake manifold must be removed before the heads can be taken off. In most cases, a number of wires, accessories, hoses, and tubing must be removed before the manifold head can be removed. If the technician is not familiar with the engine, it is a good practice to put tape on each of the items removed, marked with the proper location of each item so that all items can be easily replaced during engine assembly.

TECH TIP ✔ **A Picture Is Worth a Thousand Words**

Take pictures of the engine being serviced with a cell phone, digital camera, or video camera. These pictures will be worth their weight in gold when it comes time to reassemble or reinstall the engine. It is very difficult for anyone to remember the *exact* location of every bracket, wire, and hose. Referring back to the photos of the engine before work was started will help you restore the vehicle to like-new condition.

All coolant hoses are removed, and the transmission oil cooler lines are disconnected from the radiator. The radiator mounting bolts are removed, and the radiator is lifted from the engine compartment. This gets the radiator out of the way so that it will not be damaged while you are working on the engine. This is a good time to have the radiator cleaned, while it is out of the chassis.

The air-conditioning compressor can usually be separated from the engine, leaving all air-conditioning hoses securely connected to the compressor and lines. The compressor can be fastened to the side of the engine compartment, where it will not interfere with engine removal. If it is necessary to disconnect the air-conditioning lines, use a refrigerant recovery system to prevent loss of refrigerant to the atmosphere. All open air-conditioning lines should be securely plugged immediately after they are disconnected to keep dirt and moisture out of the system. They should remain plugged until immediately prior to reassembly.

There are two ways to remove the engine:

- The engine can be lifted out of the chassis with the transmission/transaxle attached.
- The transmission/transaxle can be disconnected from the engine and left in the chassis.

Under the vehicle, the drive shaft (propeller shaft) or half shafts are removed and the exhaust pipes disconnected. In some installations, it may be necessary to loosen the steering linkage idler arm to give clearance. The transmission controls, speedometer cable wiring, and clutch linkages are disconnected and tagged.

A sling, either a chain or lift cable, is attached to the engine.

HINT: For the best results, use the factory-installed lifting hooks that are attached to the engine. These hooks were used in the assembly plant to install the engine and are usually in the best location to remove the engine.

A hoist is attached to the sling and snugged to take most of the weight. This leaves the engine resting on the mounts. (Most engines use three mounts, one on each side and one at the back of the transmission or at the front of the engine.) The rear cross-member is removed, and on rear-wheel-drive vehicles, the transmission is lowered. The hoist is tightened to lift the engine. The engine will have to nose up as it is removed, and the front of the engine must come almost straight up as the transmission slides from under the floor pan, as illustrated in Figure 25–1. The engine and transmission are hoisted free of the automobile, swung clear, and lowered onto an open floor area.

NOTE: The engine is lowered and removed from underneath on many front-drive vehicles. See Figures 25–2 and 25–3.

ENGINE DISASSEMBLY

The following disassembly procedure applies primarily to pushrod engines. The procedure will have to be modified somewhat when

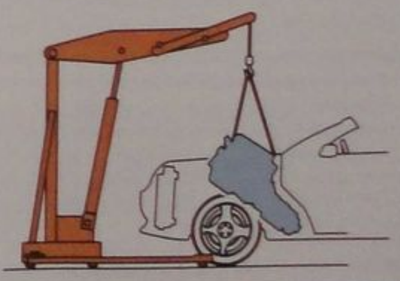


Figure 25–1 An engine must be tipped as it is pulled from the chassis.



Figure 25–2 When removing just the engine from a front-wheel-drive vehicle, the transaxle must be supported. Shown here is a typical fixture that can be used to hold the engine if the transaxle is removed or to hold the transaxle if the engine is removed.



Figure 25–3 The entire cradle, which included the engine, transaxle, and steering gear, was removed and placed onto a stand. The rear cylinder head has been removed to check for the root cause of a coolant leak.

working on overhead cam engines. Engines should be cold before disassembly to minimize the chance of warpage.

Remove the manifold hold-down cap screws and nuts, and lift off the manifold.

TECH TIP ✓ **Use the Proper Disassembly Procedure**

When an engine is operated, it builds up internal stresses. Even cast-iron parts such as cylinder heads can warp if the proper disassembly procedure is not followed. To disassemble any engine without causing harm, just remember these two important points:

- Disassemble parts from an engine only after it has been allowed to sit for several hours. All engines should be disassembled when the engine is at room temperature.
- Always loosen retaining bolts/nuts in the reverse order of assembly. Most vehicle manufacturers recommend tightening bolts from the center of the component such as a cylinder head toward the outside (ends). Therefore, to disassemble the engine, the outside (outer) bolts should be loosened first, followed by bolts closer to the center.

Taking these steps will help reduce the possibility of warpage occurring when the parts are removed.

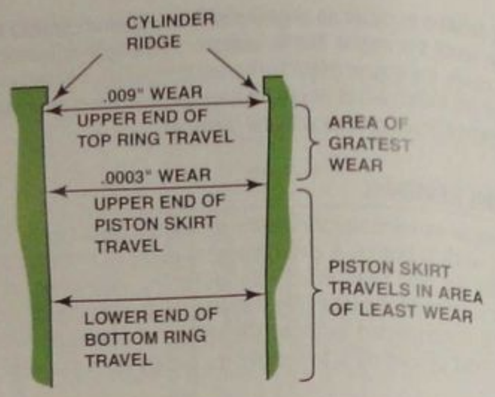


Figure 25–4 Most of the cylinder wear is on the top inch just below the cylinder ridge. This wear is due to the heat and combustion pressures that occur when the piston is near the top of the cylinder.

With the manifold off of the V-type engine, loosen the rocker arms, and remove the pushrods. The usual practice is to leave the lifters in place when doing only a valve job. Remove the head cap screws and lift the head from the block deck.

CHECKING CYLINDER BORE

At this point, the cylinder taper and out-of-round of the cylinder bore should be checked just below the ridge and just above the piston when it is at the bottom of the stroke, as shown on the cut away cylinder in Figure 25–4. These measurements will indicate how much cylinder-wall work is required. If the cylinders are worn beyond the specified limits, they will have to be rebored to return them to a satisfactory condition.

REMOVING THE OIL PAN

To remove the oil pan, turn the engine upside down. This will be the first opportunity to see the working parts in the bottom end of the engine. Deposits are again a good indication of the condition of the engine and the care it has had. Heavy sludge indicates infrequent oil changes; hard carbon indicates overheating. The oil pump pickup screen should be checked to see how much plugging exists. The connecting rods and caps and main bearing caps should be checked to make sure that they are *numbered*; if not, they should be numbered with number stamps or a punch so that they can be reassembled in exactly the same position. See Figures 25–5 and 25–6.

REMOVING THE CYLINDER RIDGE

The ridge above the top ring must be removed before the piston and connecting rod assembly is removed. Cylinder wear leaves an upper ridge and removing it is necessary to avoid catching a ring on the ridge and breaking the piston. Failure to remove the ridge is likely to cause the second piston land to break when the engine is run after reassembly with new rings, as pictured in Figure 25–7. The ridge is removed with a cutting tool that is fed into the metal ridge. One type of ridge reamer is shown in Figure 25–8. A guide on the tool prevents accidental cutting below the ridge. The reaming job should be done carefully with frequent checks of the work so that no more material than necessary is removed.



Figure 25–5 These connecting rods were numbered from the factory.

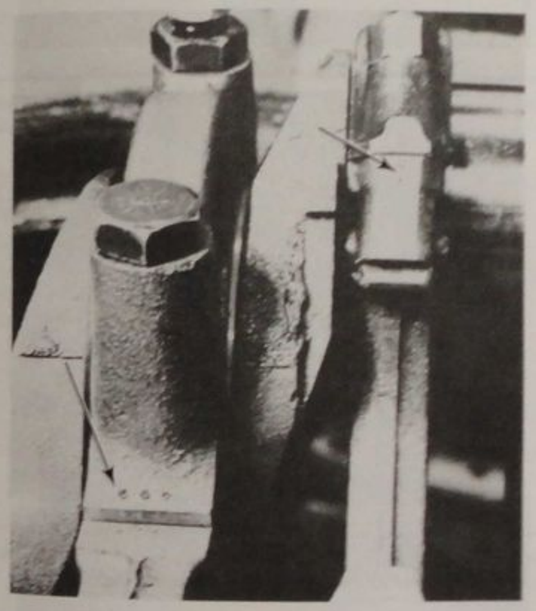


Figure 25–6 If the rods and mains are not marked, it is wise to use a punch to make identifying marks *before* disassembly of the engine.

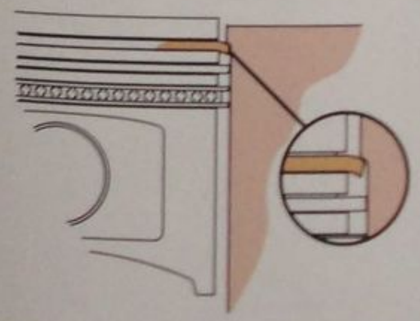


Figure 25–7 If the ridge at the top of a cylinder is not removed, the top piston ring could break the second piston ring land when the piston is pushed out of the cylinder during disassembly, or the second piston ring land could break when the engine is first run after reassembly with new rings. *(Courtesy of Sealed Power Corporation)*



Figure 25–8 Ridge being removed with one type of ridge reamer before the piston assemblies are removed from the engine.

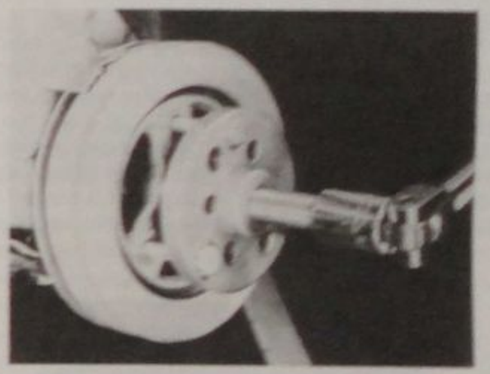


Figure 25–9 Puller being used to pull the vibration damper from the crankshaft.

REMOVING THE PISTONS

Rotate the engine until the piston that is to be removed is at top dead center (TDC). Remove connecting rod nuts from the rod so that the rod cap with its bearing half can be taken out. Fit the rod bolts with protectors to keep the bolt threads from damaging the crankshaft journals, and remove the piston and rod assemblies.

REMOVING THE HARMONIC BALANCER

The next step in disassembly is to remove the coolant pump and the crankshaft **vibration damper** (also called a **harmonic balancer**). First, the bolt and washer that hold the damper are removed. The damper itself should be removed only with a threaded puller similar to the one in Figure 25–9. If a *hook-type* puller is used around the edge of the damper, it may pull the damper ring from the hub. If this happens, the damper assembly will have to be replaced with a new assembly.

REMOVING THE TIMING CHAIN AND CAMSHAFT

With the damper assembly off, the timing cover can be removed, exposing the timing gear or timing chain. Examine these parts for excessive wear and looseness. A worn timing chain on a high-mileage engine is shown in Figure 25–10. Bolted cam sprockets can be removed to free the timing chain. If camshaft thrust plate retaining screws are used, it will be necessary to remove them.

The camshaft can be removed at this time, or it can be removed after the crankshaft is out. It must be carefully eased from the engine to avoid damaging the cam bearings or cam lobes. This is done most easily with the front of the engine pointing up. Bearing surfaces are soft and scratch easily, and the cam lobes are hard and chip easily.

REMOVING THE MAIN BEARING AND CRANKSHAFT

The main bearing caps should be checked for position markings before they are removed. They have been machined in place and will not fit perfectly in any other location. See Figure 25–11. After marking, they can be removed to free the crankshaft. When the crankshaft is removed, the main bearing caps and bearings are reinstalled on the block to reduce the chance of damage to the caps.

REMOVE AND DISASSEMBLE THE CYLINDER HEAD

Remove the cylinder head retaining bolts by loosening them from the outside toward the center to help prevent the possibility of warpage of the head. Remove the cylinder head(s) and check the head gasket for signs of failure. See Figure 25–12.

After the heads are removed and placed on the bench, the valves are removed. A C-type valve spring compressor, similar to the one in Figure 25–13, is used to free the **valve locks** or **keepers.** The valve spring compressor is air powered in production shops where valve jobs are done on a regular basis. Mechanical valve spring compressors are used where valve work is done only occasionally. After the valve lock is removed, the compressor is released to free the valve retainer and spring. The spring assemblies are lifted from the head together with any spacers used under them. The parts



Figure 25–10 Worn timing chain on a high-mileage engine. Notice that the timing chain could "jump a tooth" at the bottom of the smaller crankshaft gear where the chain is in contact with fewer teeth. Notice also that the technician placed all of the bolts back in the block after removal of the part. This procedure helps protect against lost or damaged bolts and nuts.



Figure 25–11 Most engines such as this Chevrolet V-8 with 4-bolt main bearing caps have arrows marked on the bearing caps which should point to the front of the engine.



Figure 25–12 This defective cylinder head gasket was discovered as soon as the head was removed. This cylinder head will require machining or replacement.



Figure 25–13 A valve spring compressor being used to remove the valve keepers (locks)

should be removed in order to aid in diagnosing the exact cause of any malfunction that shows up. The valve tip edge and lock area should be lightly filed to remove any burrs *before* sliding the valve from the head. Burrs will scratch the valve guide.

When all valves have been removed following this procedure for each one, the valve springs, retainers, locks, guides, and seats should be given another visual examination. See Figure 25–14.



Figure 25–14 After removing this intake valve, it became obvious why this engine had been running so poorly.

TECH TIP ✔ **The Wax Trick**

Before the engine block can be thoroughly cleaned, all oil gallery plugs must be removed. A popular trick of the trade for plug removal involves heating the plug (not the surrounding metal) with an oxyacetylene torch. The heat tends to expand the plug and make it tighter in the block. Do not overheat.

As the plug is cooling, touch the plug with paraffin wax (beeswax or candle wax may be used). See Figure 25–15. The wax will be drawn down around the threads of the plug by capillary attraction as the plug cools and contracts. After being allowed to cool, the plug is easily removed.

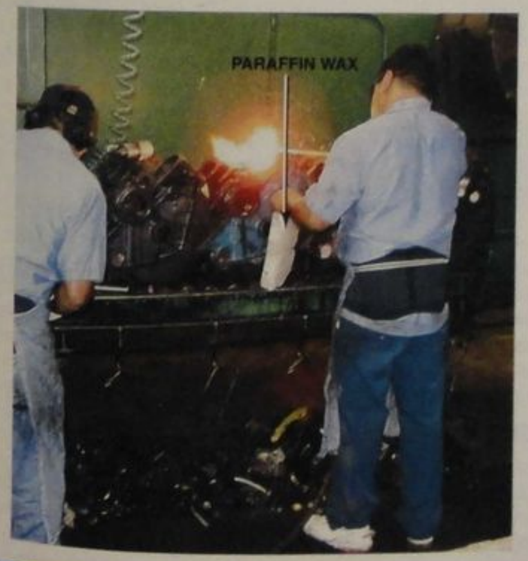


Figure 25–15 A torch is used to heat gallery plugs. Paraffin wax is then applied and allowed to flow around the threads. This procedure results in easier removal of the plugs and other threaded fasteners that cannot otherwise be loosened.



Figure 25–16 An air-powered grinder attached to a bristle pad being used to clean the gasket surface of a cylinder head. The color of the bristles indicates the grit number. The white is the finest and should be used on aluminum. Yellow is coarse and can be used on aluminum. Green is designed for cast-iron parts only. This type of cleaning pad should not be used on the engine block where the grit could get into the engine oil and cause harm when the engine is started and run after the repair.

MECHANICAL CLEANING

Heavy deposits that remain after chemical cleaning will have to be removed by mechanical cleaning. Mechanical cleaning involves scraping, brushing, and abrasive blasting. It should, therefore, be done very carefully on soft metals.

The scraper most frequently used is a **putty knife** or a plastic card. The broad blade of the putty knife helps avoid scratching the surface as it is used to clean the parts. A rotary disc can be used on disassembled parts that will be thoroughly cleaned to remove the fine abrasive that is part of the plastic bristles. See Figure 25–16.

CAUTION: Do not use a steel wire brush on aluminum parts! Steel is harder than aluminum and will remove some of the aluminum from the surface during cleaning.

CHEMICAL CLEANERS

Cleaning chemicals applied to engine parts will mix with and dissolve deposits. The chemicals loosen the deposits so that they can be brushed or rinsed from the surface. A deposit is said to be **soluble** when it can be dissolved with a chemical or solvent.

Most chemical cleaners used for cleaning carbon-type deposits are strong soaps called **caustic materials.** A **pH** value, measured on a scale from 1 to 14, indicates the amount of chemical activity in the soap. The term *pH* is from the French *pouvoir hydrogine*, meaning "hydrogen power." Pure water is neutral; on the pH scale, water is pH 7. Caustic materials have pH numbers from 8 through 14. The higher the number, the stronger the caustic action will be. **Acid materials** have pH numbers from 1 through 6. The lower the number, the stronger the acid action will be. Caustic materials and acid materials neutralize each other. This is what happens when baking soda (a caustic) is used to clean the outside of the battery (an acid surface). The caustic baking soda neutralizes any sulfuric acid that has been spilled or splashed on the outside of the battery.

CAUTION: Whenever working with chemicals, you must use eye protection.

SOLVENT-BASED CLEANING

Chemical cleaning can involve a spray washer or a soak in a cold or hot tank. The cleaning solution is usually solvent based, with a medium pH rating of between 10 and 12. Most chemical solutions also contain silicates to protect the metal (aluminum) against corrosion.

Strong caustics do an excellent job on cast-iron items but are often too corrosive for aluminum parts. Aluminum cleaners include mineral spirit solvents as well as alkaline detergents.

CAUTION: When cleaning aluminum cylinder heads, blocks, or other engine components, make sure that the chemicals used are "aluminum safe." Many chemicals that are not aluminum safe may turn the aluminum metal black. Try to explain that to a customer!

WATER-BASED CHEMICAL CLEANING

Because of environmental concerns, most chemical cleaning is now performed using water-based solutions (called **aqueous-based**). Most aqueous-based chemicals are silicate based and are mixed with water. Aqueous-based solutions can be sprayed on or used in a tank for soaking parts. Aluminum heads and blocks usually require overnight soaking in a solution kept at about 190°F (90°C). For best results, the cleaning solution should be agitated.

SPRAY WASHING

A spray washer directs streams of liquid through numerous high-pressure nozzles to dislodge dirt and grime on an engine surface. The force of the liquid hitting the surface, combined with the chemical action of the cleaning solution, produces a clean surface. Spray washing is typically performed in an enclosed washer (like a dishwasher), where parts are rotated on a washer turntable. See Figure 25–17.

Spray washing is faster than soaking. A typical washer cycle is less than 30 minutes per load, compared to eight or more hours for soaking. Most spray washers use an aqueous-based cleaning solution heated to 160° to 180°F (70° to 80°C) with foam suppressants. High-volume remanufacturers use industrial dishwashing machines to clean the disassembled engines' component parts.



Figure 25–17 A pressure jet washer is similar to a large industrial-sized dishwasher. The part(s) is then rinsed with water to remove chemicals or debris that may remain on the part while it is still in the tank.

STEAM CLEANING

Steam cleaners are a special class of sprayers. Steam vapor is mixed with high-pressure water and sprayed on the parts. The heat of the steam and the propellant force of the high-pressure water combine to do the cleaning. Steam cleaning must be used with extreme care. Usually, a caustic cleaner is added to the steam and water to aid in the cleaning. This mixture is so active that it will damage and even remove paint, so painted surfaces must be protected from the spray. Engines are often steam cleaned before they are removed from the chassis.

THERMAL CLEANING

Thermal cleaning uses heat to vaporize and char dirt into a dry, powdery ash. Thermal cleaning is best suited for cleaning cast iron, where temperatures as high as 800°F (425°C) are used, whereas aluminum should not be heated to over 600°F (315°C).

The major advantages of thermal cleaning include the following:

1. This process cleans the inside as well as the outside of the casting or part.
2. The waste generated is nonhazardous and is easy to dispose of.

However, the heat in the oven usually discolors the metal, leaving it looking dull.

A **pyrolytic** (high-temperature) oven cleans engine parts by decomposing dirt, grease, and gaskets with heat in a manner similar to that of a self-cleaning oven. This method of engine part cleaning is becoming the most popular because there is no hazardous waste associated with it. Labor costs are also reduced because the operator does not need to be present during the actual cleaning operation. See Figure 25–18.

COLD TANK CLEANING

The cold soak tank is used to remove grease and carbon. The disassembled parts are placed in the tank so that they are *completely* covered with the chemical cleaning solution. After a soaking period, the parts are removed and rinsed until the milky appearance of the emulsion is gone. The parts are then dried with compressed air. The clean, dry parts are then usually given a very light coating of clean oil to prevent rusting. Carburetor cleaner, purchased with a basket in a bucket, is one of the most common types of cold soak agents in the automotive shop. Usually, there will be a layer of water over the chemical to prevent evaporation of the chemical. This water layer is called a **hydroseal.**

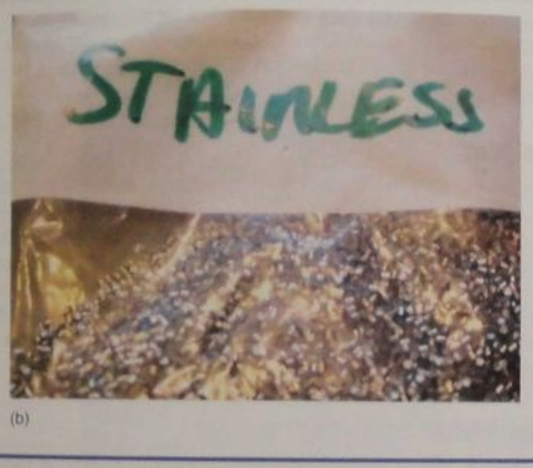
Parts washers are often used in place of soaking tanks. This equipment can move parts back and forth through the cleaning solution or pumps the cleaning solution over the parts. This movement, called **agitation,** keeps fresh cleaning solution moving past the soil to help it loosen. The parts washer is usually equipped with a safety cover held open by a low-temperature **fusible link.** If a fire occurs, the fusible link will melt and the cover will drop closed to snuff the fire out.

HOT TANK CLEANING

The hot soak tank is used for cleaning heavy organic deposits and rust from iron and steel parts. The caustic cleaning solution used in the hot soak tank is heated to near 200°F (93°C) for rapid cleaning action. The solution must be inhibited when aluminum is to be cleaned. After the deposits have been loosened, the parts are removed from the tank and rinsed with hot water or steam cleaned, which dries them rapidly. They must then be given a light coating of oil to prevent rusting.



(a)



(b)

Figure 25–18 (a) A pyrolytic (high temperature) oven cleans by baking the engine parts. After the parts have been cleaned, they are then placed into an airless blaster. This unit uses a paddle to scoop stainless steel shot from a reservoir and forces it against the engine part. The parts must be free of grease and oil to function correctly. (b) Stainless steel shot used in an airless blaster.

HINT: **Fogging oil** from a spray can does an excellent job of coating metal parts to keep them from rusting.

VAPOR CLEANING

Vapor cleaning is popular in some automotive service shops. The parts to be cleaned are suspended in hot vapors above a perchloroethylene solution. The vapors of the solution loosen the soil from the metal so that it can be blown, wiped, or rinsed from the surface.

ULTRASONIC CLEANING

Ultrasonic cleaning is used to clean small parts that must be absolutely clean; for example, hydraulic lifters and diesel injectors. The disassembled parts are placed in a tank of cleaning solution which is then vibrated at ultrasonic speeds to loosen all the soil from the parts. The soil goes into the solution or falls to the bottom of the tank.



Figure 25–19 Small engine parts can be blasted clean in a sealed cabinet.

VIBRATORY CLEANING

The vibratory method of cleaning is best suited for small parts. Parts are loaded into a vibrating bin with small, odd-shaped ceramic or steel pieces, called media, with a cleaning solution of mineral spirits or water-based detergents that usually contain a lubricant additive to help the media pieces slide around more freely. The movement of the vibrating solution and the scrubbing action of the media do an excellent job of cleaning metal.

BLASTERS

Cleaning cast-iron or aluminum engine parts with solvents or heat usually requires another operation to achieve a uniform surface finish. Blasting the parts with steel, cast-iron, aluminum, or stainless-steel shot or glass beads is a simple way to achieve a matte or satin surface finish on the engine parts. To keep the shot or beads from sticking to the parts, they must be dry, without a trace of oil or grease, prior to blasting. This means that blasting is the second cleaning method, after the part has been precleaned in a tank, spray washer, or oven. Some blasting is done automatically in an airless shot-blasting machine. Another method is to hard-blast parts in a sealed cabinet. See Figure 25–19.

CAUTION: Glass beads often remain in internal passages of engine parts, where they can come loose and travel through the cylinders when the engine is started. Among other places, these small, but destructive, beads can easily be trapped under the oil baffles of rocker covers and in oil pans and piston-ring grooves. To help prevent the glass beads from sticking, make sure that the parts being cleaned are free of grease and dirt and completely dry.

VISUAL INSPECTION

After the parts have been thoroughly cleaned, they should be re-examined for defects. A magnifying glass is helpful in finding defects. Critical parts of a performance engine should be checked for cracks using specialized magnetic or penetration inspection equipment. Internal parts such as pistons, connecting rods, and crankshafts that have cracks should be replaced. Cracks in the block and heads, however, can often be repaired, and these repair procedures are described in a later section.

MAGNETIC CRACK INSPECTION

Checking for cracks using a magnetic field is commonly called Magnaflux®, a brand name. Cracks in engine blocks, cylinder heads, crankshafts, and other engine components are sometimes difficult to find during a normal visual inspection, which is why all remanufacturers and most engine builders use a crack detection procedure on all critical engine parts.

Magnetic flux testing is the method most often used on steel and iron components. A metal engine part (such as a cast-iron cylinder head) is connected to a large electromagnet. Magnetic lines of force are easily conducted through the iron part and concentrate on the edges of a crack. A fine iron powder is then applied to the part being tested, and the powder will be attracted to the strong magnetic concentration around the crack. See Figures 25–20 through 25–22.

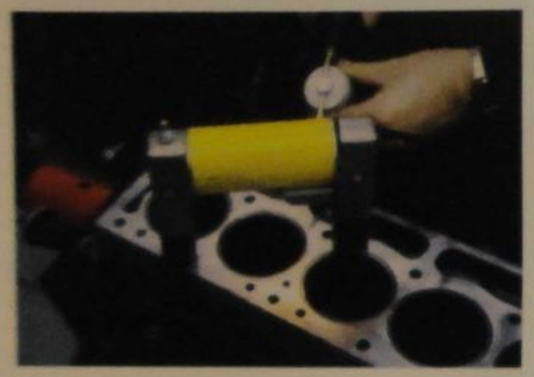


Figure 25–20 The top deck surface of a block being tested using magnetic crack inspection equipment.

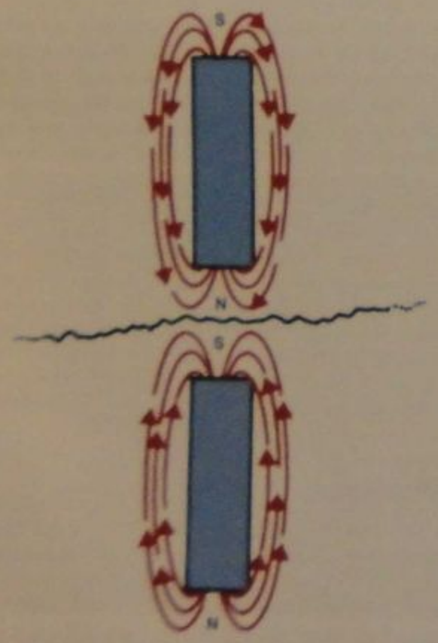


Figure 25–21 If the lines of force are interrupted by a break (crack) in the casting, two magnetic fields are created and the powder will lodge in the crack.

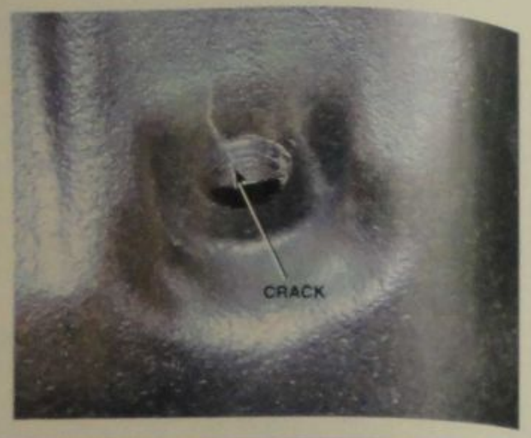


Figure 25–22 This crack in a vintage Ford 289, V-8 block was likely caused by the technician using excessive force trying to remove the plug from the block. The technician should have used heat and wax, not only to make the job easier, but also to prevent damaging the block.

DYE-PENETRANT TESTING

Dye-penetrant testing is usually used on pistons and other parts constructed of aluminum or other nonmagnetic material. A dark-red penetrating chemical is first sprayed on the component being tested. After cleaning, a white powder is sprayed over the test area. If a crack is present, the red dye will stain the white powder. Even though this method will also work on iron and steel (magnetic) parts, it is usually used only on nonmagnetic parts because magnetic methods do not work on these parts.

FLUORESCENT-PENETRANT TESTING

To be seen, fluorescent penetrant requires a black light. It can be used on iron, steel, or aluminum parts. Cracks show up as bright lines when viewed with a black light. The method is commonly called **Zyglo,** a trademark of the Magnaflux Corporation.

PRESSURE TESTING

Cylinder heads and blocks are often pressure tested with air and checked for leaks. All coolant passages are blocked with rubber plugs or gaskets, and compressed air is applied to the water jacket(s). The head or block is then lowered into water, where air bubbles indicate a leak. For more accurate results, the water should be heated because the hot water expands the casting by about the same amount as an operating engine would. An alternative method involves running heated water with a dye through the cylinder or block. Any leaks revealed by the dyed water indicate a crack. See Figures 25–23 and 25–24.

CRACK REPAIR

Cracks in the engine block can cause coolant to flow into the oil or oil into the coolant. A cracked block can also cause coolant to leak externally from a crack that goes through to a coolant passage. Cracks in the head will allow coolant to leak into the engine, or they will allow combustion gases to leak into the coolant. Cracks across the valve seat cause hot spots on the valve, which will burn the valve face. A head with a crack will either have to be replaced or the crack will have to be repaired. Two common methods of crack repair are welding and plugging.



Figure 25–23 To make sure that the mark observed in the cylinder wall was a crack, compressed air was forced into the water jacket while soapy water was sprayed on the cylinder wall. Bubbles confirmed that the mark was indeed a crack.



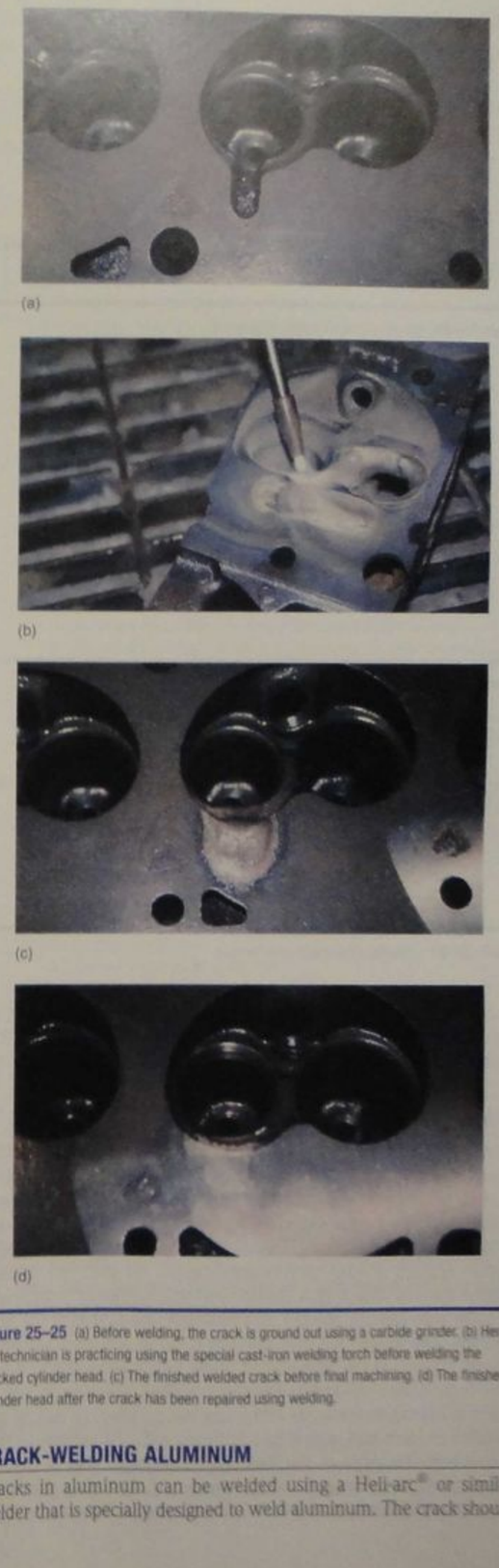
Figure 25–24 A cylinder head is under water and being pressure tested using compressed air. Note that the air bubbles indicate a crack.

NOTE: A hole can be drilled at each end of the crack to keep it from extending further, a step sometimes called **stop drilling.** Cracks that do not cross oil passages, bolt holes, or seal surfaces can sometimes be left alone if stopped.

CRACK-WELDING CAST IRON

It takes a great deal of skill to weld cast iron. The cast iron does not puddle or flow as steel does when it is heated. Heavy cast parts, such as the head and block, conduct heat away from the weld so fast that it is difficult to get the part hot enough to melt the iron for welding. When it does melt, a crack will often develop next to the edge of the weld bead. Welding can be done satisfactorily when the entire cast part is heated red hot.

A new technique involves flame welding using a special torch. See Figure 25–25.



(a)

(b)

(c)

(d)

Figure 25–25 (a) Before welding, the crack is ground out using a carbide grinder. (b) Here the technician is practicing using the special cast-iron welding torch before welding the cracked cylinder head. (c) The finished welded crack before final machining. (d) The finished cylinder head after the crack has been repaired using welding.

CRACK-WELDING ALUMINUM

Cracks in aluminum can be welded using a Heli-arc® or similar welder that is specially designed to weld aluminum. The crack should

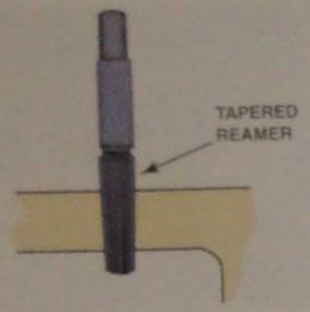


Figure 25–26 Reaming a hole for a tapered plug.

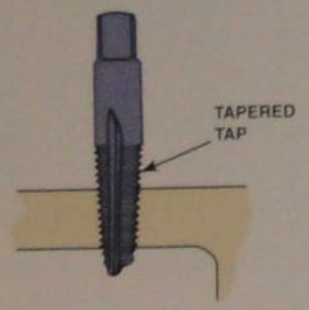


Figure 25–27 Tapping a tapered hole for a plug.

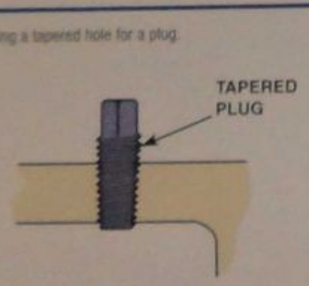


Figure 25–28 Screwing a tapered plug in the hole.

be cut or burned out before welding begins. The old valve-seat insert should be removed if the crack is in or near the combustion chamber.

CRACK PLUGGING

In the process of crack plugging, a crack is closed using interlocking tapered plugs. This procedure can be performed to repair cracks in both aluminum and cast-iron engine components. The ends of the crack are center punched and drilled with the proper size of tap drill for the plugs. The hole is reamed with a tapered reamer (Figure 25–26) and is then tapped to give full threads (Figure 25–27). The plug is coated with sealer; then it is tightened into the hole (Figure 25–28), sawed about one-fourth of the way through, and broken off. The saw slot controls the breaking point (Figure 25–29). If the plug should break below the surface, it will have to be drilled out and a new plug installed. The plug should go to the full depth or thickness of the cast metal. After the first plug is installed on each end, a new hole is drilled with the tap drill so that it cuts into the edge of the first plug. This new hole is reamed and tapped, and a plug is inserted as before. The plug should fit about one-fourth of the way into the first plug to lock it into place

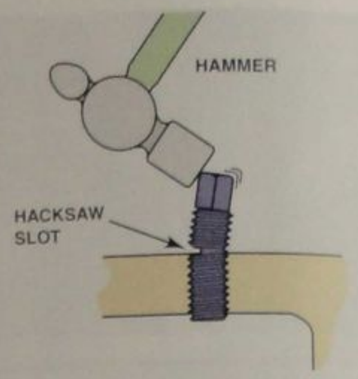


Figure 25–29 Cutting the plug with a hacksaw.

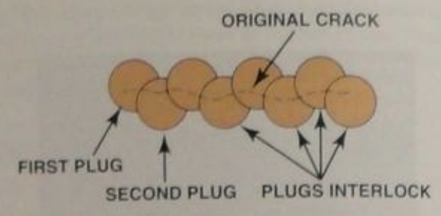
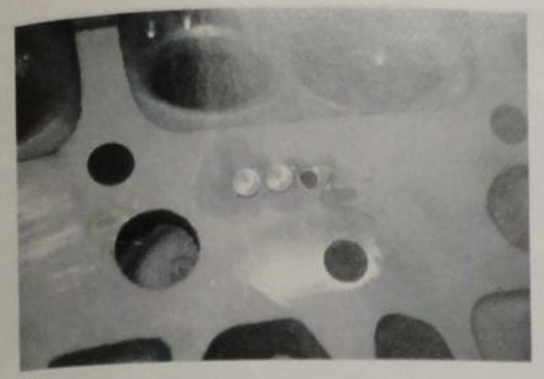


Figure 25–30 Interlocking plugs.

(Figure 25–30). Interlocking plugs are placed along the entire crack, alternating slightly from side to side. The exposed ends of the plugs are peened over with a hammer to help secure them in place. The surface of the plugs is then ground or filed down nearly to the gasket surface. In the combustion chamber and at the ports, the plugs are ground down to the original surface using a hand grinder. The gasket surface of the head must be resurfaced after the crack has been repaired. See Figure 25–31 for an example of a cylinder head repair using plugs.

SUMMARY

1. The factory-installed lifting hooks should be used when hoisting an engine.
2. Engine component parts should only be removed when the engine is cold. Also, the torque table should always be followed backward, starting with the highest-number head bolt and working toward the lowest-number. This procedure helps prevent warpage.
3. The ridge at the top of the cylinder should be removed before removing the piston(s) from the cylinder.
4. The connecting rod and main bearing caps should be marked before removing to ensure that they can be reinstalled in the exact same location when the engine is reassembled.
5. The tip of the valve stem should be filed before removing valves from the cylinder head to help prevent damage to the valve guide.
6. Mechanical cleaning with scrapers or wire brushes is used to remove deposits.
7. Steel wire brushes should never be used to clean aluminum parts.
8. Most chemical cleaners are strong soaps called caustic materials.
9. Always use aluminum-safe chemicals when cleaning aluminum parts or components.
10. Thermal cleaning is done in a pyrolytic oven in temperatures as high as 800°F (425°C) to turn grease and dirt into harmless ash deposits.



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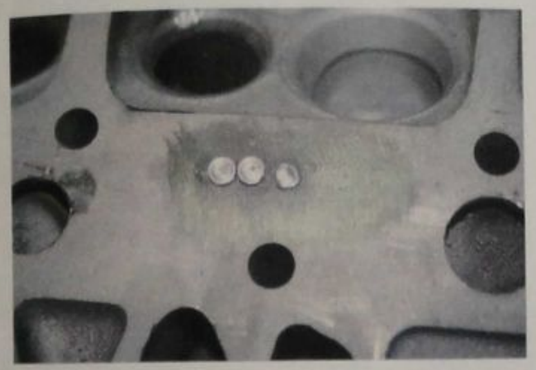

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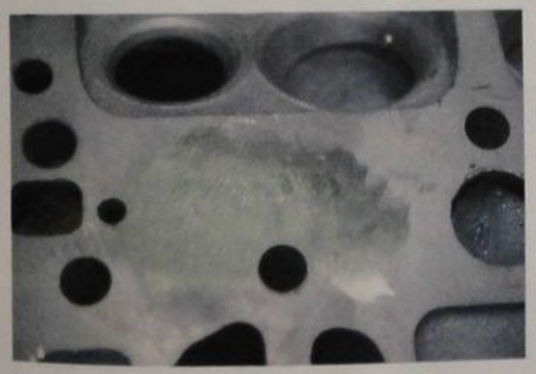


(c)

Figure 25–31 (a) A hole is drilled and tapped for the plugs. (b) The plugs are installed. (c) After final machining, the cylinder head can be returned to useful service.

11. Blasters use metal shot or glass beads to clean parts. All of the metal shot or glass beads must be cleaned from the part so as not to cause engine problems.
12. All parts should be checked for cracks using magnetic, dye-penetrant, fluorescent-penetrant, or pressure testing methods.
13. Cracks can be repaired by welding or by plugging.

REVIEW QUESTIONS

1. When should the factory-installed lifting hooks be used?
2. Explain why the cylinder bore should be measured for taper and out-of-round before continuing with an engine disassembly.
3. State two reasons for the removal of the ridge at the top of the cylinder.
4. Explain why the burrs must be removed from valves before removing the valves from the cylinder head.
5. Describe five methods that could be used to clean engines or engine parts.
6. Explain magnetic crack inspection, dye-penetrant testing, and fluorescent-penetrant testing methods and where each can be used.

CHAPTER QUIZ

1. Technician A says that the intake and exhaust manifolds have to be removed before removing the engine from the vehicle. Technician B says that it is often easier to remove the engine from underneath rather than remove the engine from the top of the vehicle. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Lifting hooks are often installed at the factory because _____.
   a. They make removing the engine easier for the technician
   b. They are used to install the engine at the factory
   c. They are part of the engine and should not be removed
   d. They make servicing the top of the engine easier for the technician
3. The ridge at the top of the cylinder _____.
   a. Is caused by wear at the top of the cylinder by the rings
   b. Represents a failure of the top piston ring to correctly seal against the cylinder wall
   c. Should not be removed before removing pistons except when reboring the cylinders
   d. Means that a crankshaft with an incorrect stroke was installed in the engine
4. Before the timing chain can be inspected and removed, the following component(s) must be removed:
   a. Rocker cover (valve cover)
   b. Vibration damper
   c. Cylinder head(s)
   d. Intake manifold (V-type engines only)
5. Before the valves are removed from the cylinder head, what operations need to be completed?
   a. Remove valve locks (keepers)
   b. Remove cylinder head(s) from the engine
   c. Remove burrs from the stem of the valve(s)
   d. All of the above
6. Cleaning chemicals are usually either a caustic material or an acid material. Which of the following statements is true?
   a. Both caustics and acids have a pH of 7 if rated according to distilled water.
   b. An acid is lower than 7 and a caustic is higher than 7 on the pH scale.
   c. An acid is higher than 7 and a caustic is lower than 7 on the pH scale.
   d. Pure water is a 1 and a strong acid is a 14 on the pH scale.
7. Many cleaning methods involve chemicals that are hazardous to use and expensive to dispose of after use. The least hazardous method is generally considered to be the _____.
   a. Pyrolytic oven
   b. Hot vapor tank
   c. Hot soak tank
   d. Cold soak tank
8. Magnetic crack inspection _____.
   a. Uses a red dye to detect cracks in aluminum
   b. Uses a black light to detect cracks in iron parts
   c. Uses a fine iron powder to detect cracks in iron parts
   d. Uses a magnet to remove cracks from iron parts

9. Technician A says that engine parts should be cleaned before a thorough test can be done to detect cracks. Technician B says that pressure testing can be used to find cracks in blocks or cylinder heads. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Plugging can be used to repair cracks _____
   a. In cast-iron cylinder heads
   b. In aluminum cylinder heads
   c. In both cast-iron and aluminum cylinder heads
   d. Only in cast-iron blocks

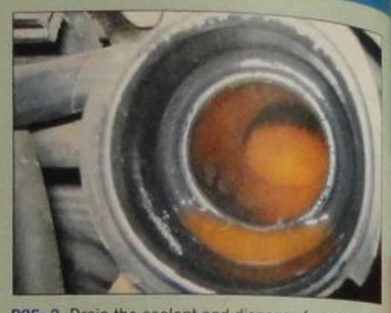
PHOTO SEQUENCE Engine Removal



P25–1 Before beginning work on removing the engine, mark and remove the hood and place it in a safe location.



P25–2 For safety, remove the negative battery cable to avoid any possible electrical problems from occurring.



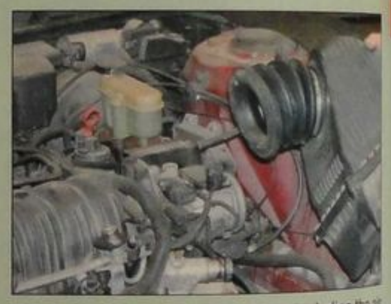
P25–3 Drain the coolant and dispose of properly.



P25–4 Disconnect all cooling system and heater hoses and remove the radiator.



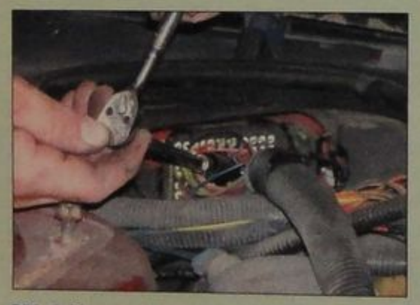
P25–5 Remove the accessory drive belt(s) and set the generator (alternator), power steering pump, and air-conditioning compressor aside.



P25–6 Remove the air intake system including the air filter housing as needed.



P25–7 Remove the electrical connector from all sensors and label.



P25–8 Disconnect the engine wiring harness connector at the bulkhead.



P25–9 Safely hoist the vehicle and disconnect the exhaust system from the exhaust manifolds.

PHOTO SEQUENCE Engine Removal—continued



P25–10 Mark and then remove the fasteners connecting the flex plate to the torque converter.



P25–11 Lower the vehicle and remove the engine mount bolts and transaxle bell housing fasteners.



P25–12 Secure the lifting chain to the engine hooks and carefully remove the engine from the vehicle.

CHAPTER 26

Cylinder Heads and Valves

OBJECTIVES: After studying Chapter 26, the reader will be able to: Prepare for ASE Engine Repair (A1) certification test content area "B" (Cylinder Head and Valve Train Diagnosis and Repair). • Identify combustion chamber types. • List the steps necessary to recondition a cylinder head. • Describe how to inspect and measure valve guides. • Discuss valve-guide repair options. • Discuss various engine-valve types and materials. • Describe how to test valve springs. • Explain the purpose, function, and operation of valve rotators. • List the steps necessary to reface a valve. • Describe how to grind valve seats. • Discuss how to measure and correct installed height and valve-stem height.

KEY TERMS: aluminum • arithmetic average roughness height (RA) • beehive spring • bend • bronze • bronze guide liners • cast iron • collet • concentric • cross-flow • deflector valve stem seal • displaces • distortion • fire deck • free rotators • hemiwedge • integral • interference angle • kidney-shaped • microinch (μ in.) • nickel cobalt • O-ring valve stem seal • oversize (OS) • pentroof • polyspherical • poppet valve • port • porting • positive rotators • positive valve stem seal • powdered metal (PM) • quench area • relieving • stainless steel • stellite • squish • truing the valve tip • twist • umbrella valve stem seal • valve face • valve guide inserts • valve rotators • valve seat • valve spring inserts (VSI) • valve spring lock (keeper) • valve spring retainer • warpage

Cylinder heads are the most frequently serviced engine components. The highest temperatures and pressures in the entire engine are located in the combustion chamber. The valves in the cylinder head(s) must open and close thousands of times each time the engine is operated.

Combustion chambers of modern automotive overhead-valve engines are of two basic types: the nonturbulent hemispherical chamber and the turbulent wedge chamber.

THE HEMISPHERICAL COMBUSTION CHAMBER

In nonturbulent hemispherical combustion chambers, the charge is inducted through widely slanted valves. The charge is compressed and then ignited from a centrally located spark plug (Figure 26–1). The spark plug is as close as possible to all edges of the combustion chamber. Combustion radiates out from it, completely burning the fuel in the shortest possible time.

Hemispherical combustion chambers are usually fully machined to form the hemispherical shape. This is an expensive operation that increases the cost of the engine.



Figure 26–1 Hemispherical combustion chamber with a two-valve head.



Figure 26–2 Cutaway of a Chevrolet V-8 cylinder head showing a wedge-shaped combustion chamber.

THE WEDGE COMBUSTION CHAMBER

The wedge-shaped combustion chamber is designed to produce smooth, uniform burning by controlling the rate of combustion. A sectional view of a wedge-shaped combustion chamber is shown in Figure 26–2. In wedge-shaped combustion chambers, the charge is inducted through valves that are side by side. As the piston nears the top of the compression stroke, it moves to a position that is close to a low or flat portion of the head. The gases are squeezed between the piston and this head surface area, called a **squish** or **quench area.** The gases squeezed from the squish area produce turbulence within the charge. *The turbulence thoroughly mixes the air and fuel in the charge.* The spark plug is positioned so as to be in the highly turbulent part of the charge. Ignition is followed by smooth and rapid burning of the turbulent charge. The combustion flame front radiates out from the spark plug.

New designs use cast combustion chambers rather than expensive machined chambers. These chambers are called by such names as **polyspherical, hemiwedge, kidney-shaped,** and **pentroof.** All cylinder head designs try to place the spark plug in an ideal location for best combustion as shown in Figure 26–3.

MULTIPLE-VALVE COMBUSTION CHAMBER

The power that any engine produces is directly related to the amount of air–fuel mixture that is ignited in the cylinder. Increasing cylinder displacement is a common method of increasing engine power. Turbocharging and supercharging also increase engine power, but these increase engine cost as well.

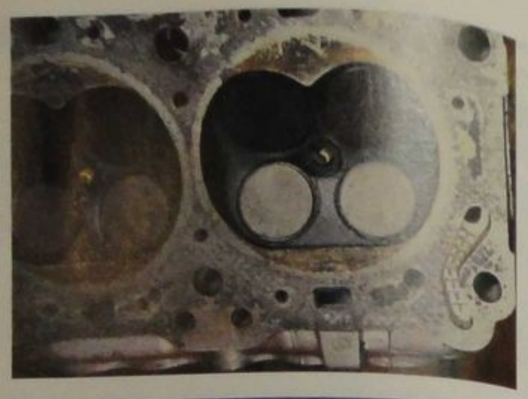


Figure 26–3 A General Motors Quad-4 engine with a combustion chamber shape called a modified pentroof. Note the central location of the spark plug.

Adding more than two valves per cylinder permits more gas to flow into and out of the engine with greater velocity without excessive valve duration. The maximum amount of gas moving through the opening area of a valve depends on the distance around the valve and the degree to which it lifts open.

More total area under the valve is possible when two smaller valves are used rather than one larger valve at the same valve lift. The smaller valves allow smooth low-speed operation (because of the increased velocity of the mixture as it enters the cylinder as a result of smaller intake ports). Good high-speed performance with smaller valves is also possible because of the increased valve area and lighter-weight valves. See Figures 26–4 and 26–5.

INTAKE AND EXHAUST PORTS

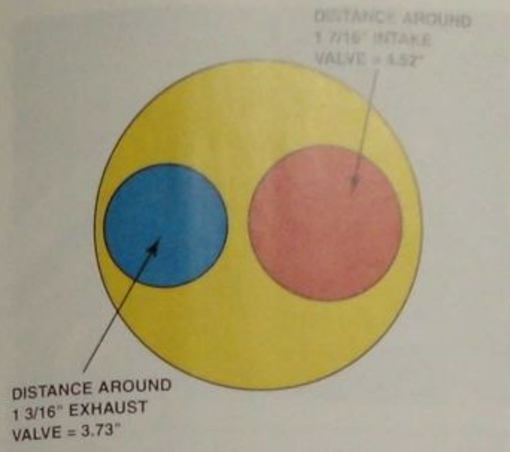
The part of the intake or exhaust system passage that is cast in the cylinder head is called a **port.** Ports lead from the manifolds to the valves. Engines that have the intake port on one side of the head and the exhaust port on the opposite side are said to have a **cross-flow** head design. The cross-flow head shown in Figure 26–6 allows the valve to be located and angled so as to permit the most efficient engine breathing. It also allows the spark plug to be placed near the center of the combustion chamber. All V-type engines have the cross-flow head design.

The flow of gases is often different than one might expect. At times, a restricting hump within a port may actually increase the airflow capacity of the port. It does this by redirecting the flow to an area of the port that is large enough to handle the flow. Modifications in the field, such as **porting** or **relieving,** would result in restricting the flow of such a carefully designed port. See Figures 26–7 and 26–8.

The intake port in the head is relatively long, whereas the exhaust port is short. The long intake port wall is heated by coolant flowing through the head. The heat aids in vaporizing the fuel in the intake charge. The exhaust port is short so that the least amount of exhaust heat is transferred to the engine coolant.

REMOVING THE OVERHEAD CAMSHAFT

The overhead camshaft will have either one-piece bearings in a solid bearing support or split bearings and a bearing cap. When one-piece bearings are used, the valve springs will have to be compressed with a fixture or the finger follower will have to be removed before the camshaft can be pulled out endwise. When bearing caps are used, they should be loosened alternately so that bending loads are not placed on either the cam or bearing caps (Figure 26–9).



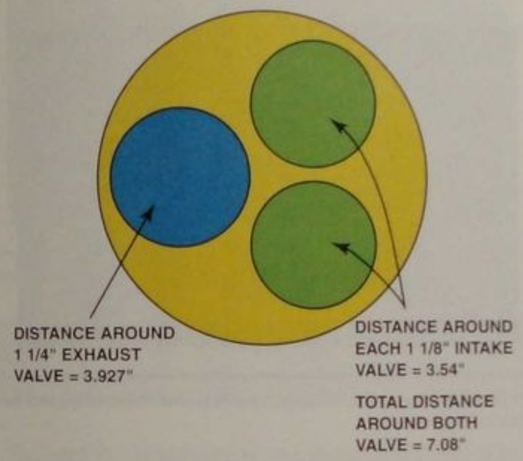


Figure 26–4 Comparing the valve opening areas between two- and three-valve combustion chambers when the valves are open.

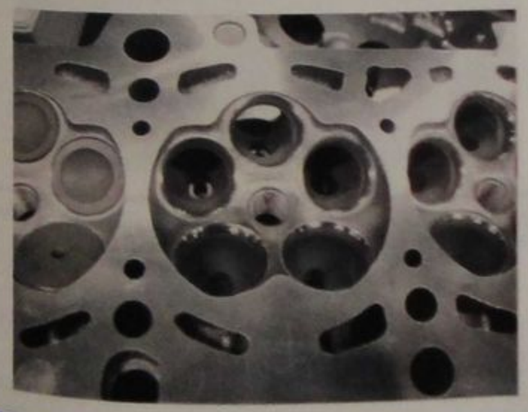


Figure 26–5 Audi five-valve cylinder head. This design uses three intake valves (top) and two exhaust valves (bottom).



Figure 26–6 A typical two-valve cross-flow cylinder head. The intake is on the top and the exhaust is on the bottom.



Figure 26–7 The top cylinder head is stock and the bottom cylinder head has been ported.

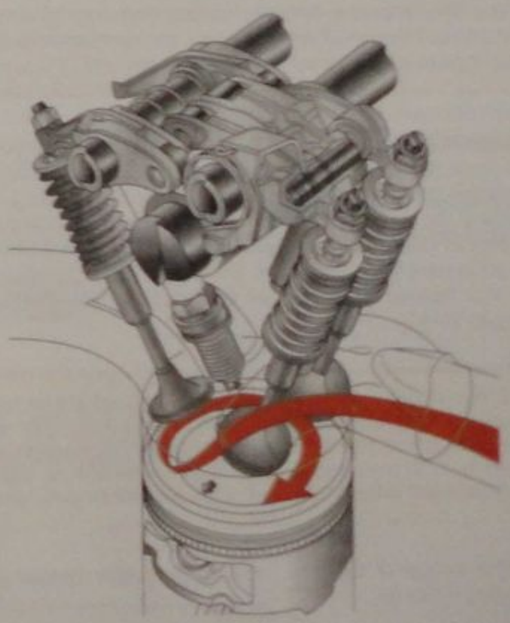


Figure 26–8 The intake manifold design and combustion chamber design both work together to cause the air–fuel mixture to swirl as it enters the combustion chamber.



Figure 26–9 A high-performance racing engine that uses a rocker arm shaft. When disassembling this style of engine, it is important to loosen the rocker arm shaft bearing caps a little at a time along the entire length of the shaft to prevent binding.

CYLINDER HEAD RECONDITIONING SEQUENCE

Although not all cylinder heads require all service operations, cylinder heads should be reconditioned using the following sequence:

1. Disassemble and thoroughly clean the heads. See Chapter 25.
2. Check for cracks and repair as necessary. See Chapter 25.
3. Check the surface that contacts the engine block and machine if necessary.
4. Check valve guides and replace or service as necessary.
5. Grind valves and reinstall the valves in the cylinder head with new valve-stem seals.
6. Check valve spring force and installed height.

SAFETY TIP **Boing!**

When disassembling or reassembling a cylinder head, always wear safety glasses. Valve springs, when compressed, represent stored energy. Valve keepers can be sent flying through the air by the force of an expanding valve spring, which could put out an eye or cause other physical harm.

Disassembling the Cylinder Head The engine should be cool (room temperature) before the cylinder heads are removed. As mentioned in Chapter 6, the head bolts should be loosened in the reverse of the order used for tightening to avoid the possibility of warping. In other words, the head bolts should be loosened from the outside and you should work your way toward the center of the head. Remove the valves from the cylinder head as illustrated in Figure 26–10.

CAUTION: All valve train components that are to be reused must be kept together. As wear occurs, parts become worn together. Pushrods can be labeled and kept in order if stuck through a cardboard box as shown in Figure 26–11. Be sure to keep the top part of the pushrod at the top. Intake and exhaust valve springs are different and must be kept with the correct valve.

The surface of the head must be thoroughly cleaned and inspected as follows:

- The surface is first scraped and then draw filed to remove any small burrs.



Figure 26–10 A valve spring compressor is used to compress the valve spring before removing the keepers (locks).



Figure 26–11 Sticking pushrods through a cardboard box is a method used to keep the valve train parts in proper order.

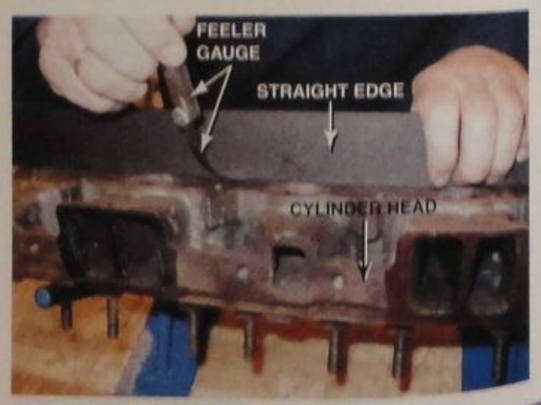


Figure 26–12 A precision ground straightedge and a feeler gauge are used to check the cylinder head for flatness.

- The head should be checked in five planes as shown in Figures 26–12 and 26–13 for **warpage, distortion, bend,** and **twist.**

Trying to slide a 0.004-inch (0.10-millimeter) feeler gauge under a straightedge held against the head surface will reveal these defects.

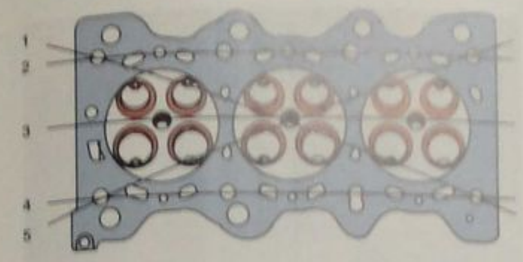


Figure 26–13 Cylinder heads should be checked in five planes for warpage, distortion, bend, or twist.



Figure 26–14 A cylinder head being resurfaced.

NOTE: The cylinder head surface that mates with the top deck of the block is often called the **fire deck.**

The head should not vary by over 0.002 inches (0.05 millimeters) in any 6-inch (15-centimeter) length, or by more than 0.004 inches overall. Always check the manufacturer's recommended specifications.

Cylinder Head Resurfacing The head should be resurfaced if there is any roughness caused by corrosion of the head gasket. This roughness can be felt on the head surface when you rub your fingernail across it. In precision engine rebuilding, *both* the head and the block deck are resurfaced as a standard practice. See Figure 26–14.

NOTE: Always check the cylinder head thickness and specifications to be sure that material can be safely removed from the surface. Some manufacturers do not recommend any machining, but rather require cylinder head replacement if cylinder head surface flatness is not within specifications.

The head will usually have some warpage when the engine is disassembled.

NOTE: Aluminum cylinder heads are usually straightened before being resurfaced.

Surface Finish The surface finish of a reconditioned part is as important as the size of the part. Surface finish is measured in units called ***microinches*** (abbreviated **µ in.**). The symbol in front of the inch abbreviation is the Greek letter *mu*. One microinch equals 0.000001 inches (0.025 micrometers [µm]). The finish classification in microinches gives the distance between the highest peak and the deepest valley. The usual method of expressing surface finish is by the **arithmetic average roughness height,** abbreviated **RA,** which is the average of the distances of all peaks and valleys from the mean (average) line. See Figure 26–15.

Typical surface finish roughness recommendations for cast-iron and aluminum cylinder heads and blocks include the following:

- **Cast Iron.** Recommended range: 60 to 100 RA
- **Aluminum.** Recommended range: 50 to 60 RA

The rougher the surface is, the higher the microinch finish measurement will be.

VALVE GUIDES

The valve guide supports the valve stem so that the valve face will remain perfectly centered or **concentric** with the valve seat. The valve guide is generally **integral** with the head casting for better heat transfer and for lower manufacturing costs. See Figure 26–16. **Valve guide inserts** are always used where the valve stem and head materials are not compatible. See Figure 26–17.

A valve guide must be reconditioned to match the valve that is to be used with it. Engine manufacturers usually recommend the following valve stem-to-valve guide clearances.

Intake valve: 0.001 to 0.003 inches (0.025 to 0.075 millimeters)

Exhaust valve: 0.002 to 00.004 inches (0.05 to 0.10 millimeters)

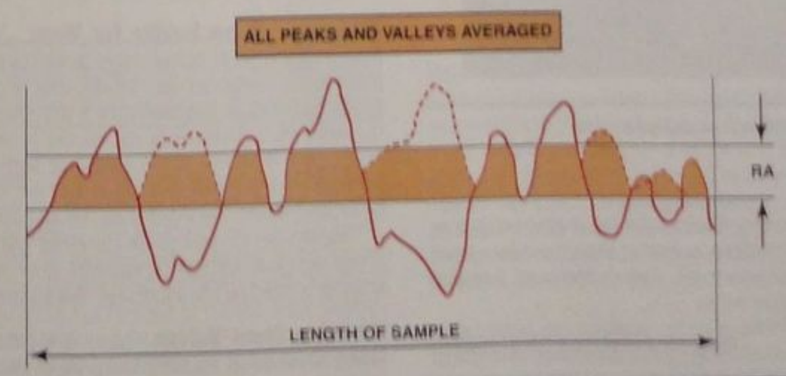


Figure 26–15 A graph showing a typical rough surface as would be viewed through a magnifying glass. RA is an abbreviation indicating the average height of all peaks and valleys.



Figure 26–16 An integral valve guide is simply a guide that has been drilled into the cast-iron cylinder head.

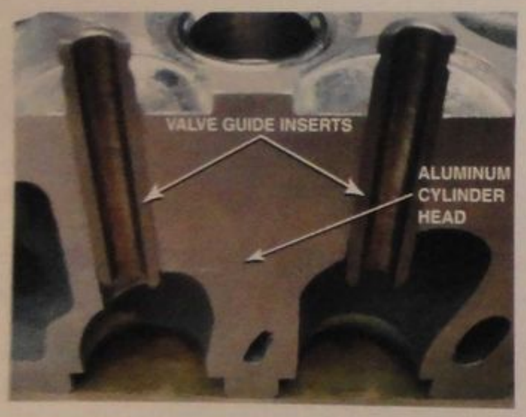


Figure 26–17 All aluminum cylinder heads use valve guide inserts.

Be sure to check the exact specifications for the engine being serviced. The exhaust valve clearance is greater than the intake valve clearance because the exhaust valve runs hotter and therefore expands more than the intake valve.

Excessive valve stem-to-valve guide clearance can cause excessive oil consumption. The intake valve guide is exposed to manifold vacuum that can draw oil from the top of the cylinder head down into the combustion chamber.

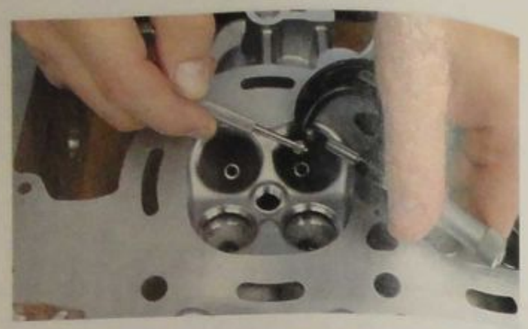


Figure 26–18 A small hole gauge and a micrometer are being used to measure the valve guide. The guide should be measured in three places: at the top, middle, and bottom.

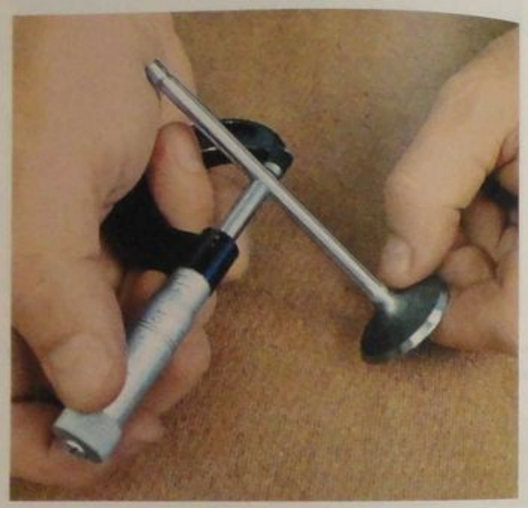


Figure 26–19 The diameter of the valve stem is being measured using a micrometer. The difference between the inside diameter of the valve guide and the diameter of the valve stem is the valve guide-to-valve stem clearance.

HINT: A human hair is about 0.002 inches (0.05 millimeters) in diameter. Therefore, the typical clearance between a valve stem and the valve guide is only the thickness of a human hair.

Measuring Valve Guides for Wear Valves should be measured for stem wear before valve guides are measured. The valve guide is measured in the middle with a small hole gauge. The gauge size is then checked with a micrometer. The dimension of the valve stem diameter is subtracted from the dimension of the valve guide diameter. If the clearance between the stem and the guide exceeds the specified clearance, the valve guide will have to be reconditioned. See Figures 26–18 and 26–19.

Valve stem-to-valve guide clearance can also be checked using a dial indicator (gauge) to measure how much the valve moves when it is lifted off the valve seat. See Figure 26–20.

Oversize Stem Valves Most domestic automobile manufacturers recommend reaming worn valve guides and installing new valves with **oversize** stems in engines that have integral valve guides. When a valve guide is worn, the valve stem is also likely to



Figure 26–20 Measuring valve guide-to-stem clearance with a dial indicator while rocking the stem in the direction of normal thrust. The reading on the dial indicator should be compared to specifications because it does not give the guide-to-stem clearance directly. The valve is usually limited to its maximum operating lift.

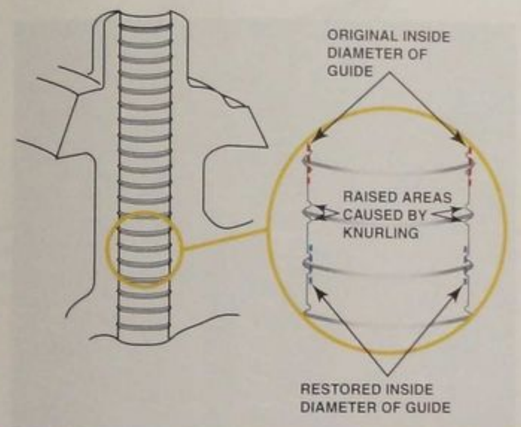


Figure 26–21 Sectional view of a knurled valve guide.

be worn. In this case, new valves are required. New valves can just as well have oversize stems as standard stems. Typically, available sizes include 0.003, 0.005, 0.008, 0.015, and 0.030 inches oversize (often abbreviated **OS**). The valve guide is reamed or honed to the correct size to fit the oversize stem of the new valve.

NOTE: Many remanufacturers of cylinder heads use oversize valve stems to simplify production.

Valve Guide Knurling In the process known as valve guide knurling, a tool is rotated as it is driven into the guide. The tool **displaces** the metal to reduce the hole diameter of the guide. Knurling is ideally suited to engines with integral valve guides (guides that are part of the cylinder head and are nonremovable). It is recommended that knurling not be used to correct wear exceeding 0.006 inches (0.15 millimeters). In the displacing process, the knurling tool pushes a small tapered wheel or dull threading tool into the wall of the guide hole. This makes a groove in the wall of the guide without removing any metal, as pictured in Figure 26–21.

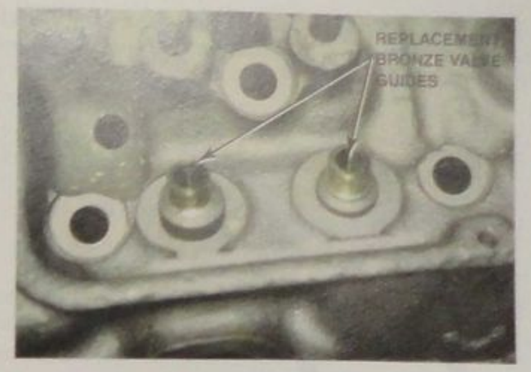


Figure 26–22 This cylinder head has been restored to service by replacing the original valve guides with bronze valve guides.



Figure 26–23 A typical assortment of valve guide reamers as found in an engine rebuilding shop.

VALVE GUIDE REPLACEMENT

When an engine is designed with replaceable valve guides, their replacement is always recommended when the valve assembly is being reconditioned. The original valve guide height should be measured before the guide is removed so that the new guide can be properly positioned.

Replacement valve guides can also be installed to repair worn integral guides. Both cast-iron and **bronze** guides are available. See Figure 26–22. Three common valve guide sizes are:

1. 5/16 or 0.313 inches
2. 11/32 or 0.343 inches
3. 3/8 or 0.375 inches

Valve Guide Inserts A badly worn integral valve guide can be reconditioned using an insert. This repair method is usually preferred in heavy-duty and high-speed engines. Two types of guide inserts are commonly used for guide repair: a thin-walled bronze alloy sleeve bushing and a spiral bronze alloy bushing. The thin-walled bronze sleeve bushings are also called **bronze guide liners.** The valve guide rebuilding kit used to install each of these bushings includes all of the reamers, installing sleeves, broaches, burnishing tools, and cutoff tools that are needed to install and properly size the bushings. See Figure 26–23.

INTAKE AND EXHAUST VALVES

Valves need to be reconditioned more often than any other engine part. Automotive engine valves are of a **poppet valve** design. The

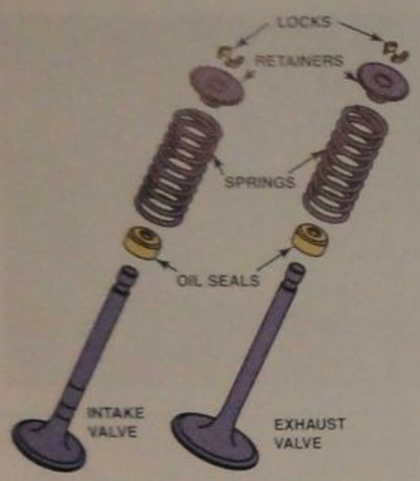


Figure 26–24 Identification and relationship of valve components. Note the different valve locks (keepers) used on the exhaust valve as compared to the intake valve. The oil seals shown are also called umbrella-type valve stem seals.

valve is opened by means of a valve train that is operated by a cam. The cam is timed to the piston position and crankshaft cycle. The valve is closed by one or more springs.

The valve guide is centered over the **valve seat** so that the **valve face** and seat make a gas-tight fit. The face and seat will have an angle of 30° or 45°. Actual service angles might be a degree or two different from these. Most engines use a nominal 45° valve and seat angle. A typical valve assembly is shown in Figure 26–24.

TECH TIP ✔ **Hot Engine + Cold Weather = Trouble**

Serious valve damage can occur if cold air reaches hot exhaust valves soon after the engine is turned off. An engine equipped with exhaust headers and/or straight-through mufflers can allow cold air a direct path to the hot exhaust valve. The exhaust valve can warp and/or crack as a result of rapid cooling. This can easily occur during cold, windy weather when the wind can blow cold outside air directly up the exhaust system. Using reverse-flow mufflers with tailpipes and a catalytic converter reduces the possibility of this occurring.

Valve Materials Alloys used in exhaust valve materials are largely of chromium for oxidation resistance, with small amounts of nickel, manganese, and nitrogen added. Many vehicle manufacturers use valves that have chrome-plated stems. Because chrome provides a hard, smooth surface, this design feature helps prevent valve scuffing and galling, especially when the engine is first started. In severe applications, facing alloys such as stellite are welded to the valve face and valve tip. **Stellite** is an alloy of nickel, chromium, and tungsten and is nonmagnetic. Some heavy-duty applications use hollow stem exhaust valves that are partially filled with metallic sodium. An unfilled hollow valve stem is shown in Figure 26–25. The sodium in the valve becomes a liquid at operating temperatures. As it splashes back and forth in the valve stem, the sodium transfers heat from the valve head to the valve stem. The heat goes through the valve guide into the coolant.

Valve Springs A valve spring holds the valve tightly against the seat when the valve is closed. One end of the valve spring is seated against the head. The other end of the spring is attached under



Figure 26–25 Hollow valve stem.

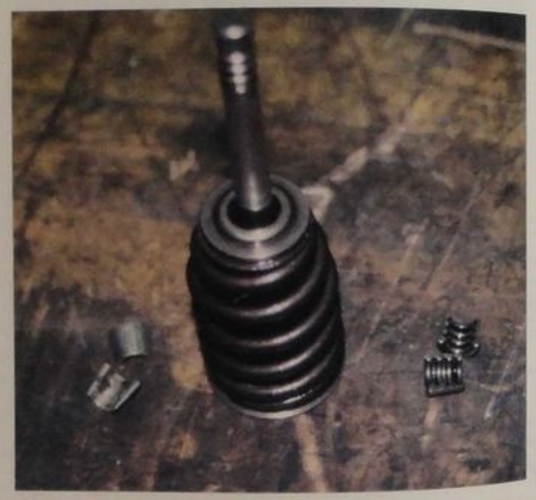


Figure 26–26 A valve assembly after being removed from the cylinder head. Note how the technician tried to keep the valve spring, retainer, and locks (keepers) together as a set. The style (shape) of valve spring is commonly called a **beehive spring**.

compression to the valve stem through a **valve spring retainer** and a **valve spring lock (keeper),** as shown in Figure 26–26.

Variable-rate springs add spring force when the valve is in the open position by using closely spaced coils on the cylinder head end of the spring. The closely spaced coils also tend to dampen vibrations that may be created by an equally wound coil spring. The damper helps to reduce valve seat wear. Some valve springs use a flat coiled damper inside the spring. This eliminates spring surge and adds some valve spring tension.

Multiple valve springs are used where large lifts are required and a single spring does not have enough strength to control the valve. Multiple valve springs generally have their coils wound in opposite directions.

Valve Spring Inspection Valve springs close the valves after they have been opened by the cam. Valve springs must close the valve squarely to form a tight seal and to prevent valve stem and guide

wear. The valve springs are checked for squareness by rotating them on a flat surface with a square held against the side. They should be within 1/16 inch or 1.6 millimeter of being square. This is shown in Figure 26–27. A valve spring scale is used to measure the valve spring force. One popular type of scale, shown in Figure 26–28, measures the spring force directly. Valve springs are checked for the following:

1. Free height (without being compressed) should be within 1/16 (0.060) inch
2. Force with valve closed and height as per specifications (with damper spring removed)
3. Force with valve open and height as per specifications (with damper spring removed)

Most specifications allow for variations of plus or minus 10% from the published figures.

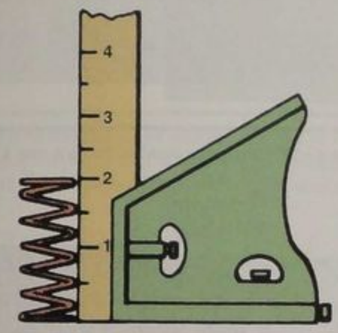


Figure 26–27 All valve springs should be checked for squareness by using a square on a flat surface. The spring should be replaced if more than 1/16 inch (1.6 mm) is measured between the top of the spring and the square.



Figure 26–28 One popular type of valve spring tester used to measure the compressed force of valve springs. Specifications usually include (1) free height (height without being compressed), (2) pressure at installed height with the valve closed, and (3) pressure with the valve open to the height specified.

Valve Rotators Some retainers have built-in devices called **valve rotators.** They cause the valve to rotate in a controlled manner as it is opened. The purposes and functions of valve rotators include the following:

- Preventing carbon buildup from forming
- Reducing hot spots on the valves by constantly turning them
- Evening out the wear on the valve face and seat
- Improving valve guide lubrication

There are two types of valve rotators: free and positive.

Free rotators. The free rotators simply take the pressure off the valve to allow engine vibration to rotate the valve.

Positive rotators. The opening of the valve forces the valve to rotate.

See Figure 26–29.

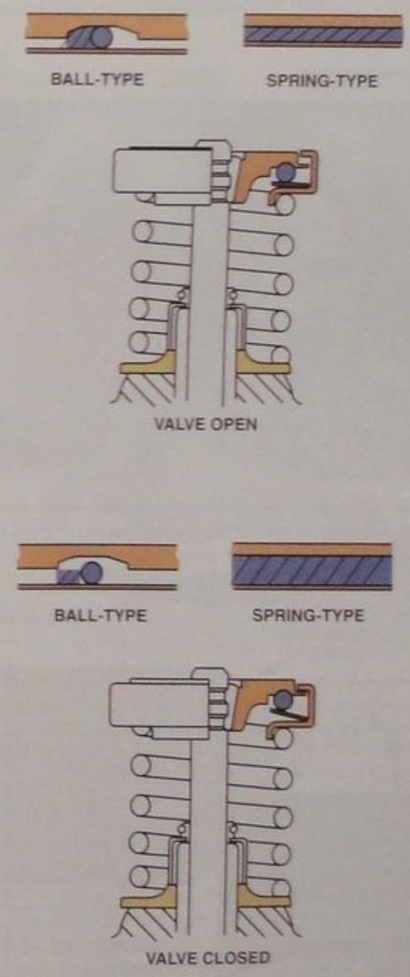


Figure 26–29 Type of valve rotator operation. Ball-type operation is on the left and spring-type operation is on the right.

VALVE RECONDITIONING PROCEDURE

Valve reconditioning is usually performed using the following sequence:

- The tip of the valve stem is lightly ground and chamfered. This step helps to ensure that the valve will rest in the **collet** (holder of the valve stem during valve grinding) of the valve grinder correctly. This process is often called **truing the valve tip.**
- The face of the valve is ground using a valve grinder. See Figure 26–30.
- The valve seat is ground in the head (the seat must be matched to the valve that will be used in that position). See Figures 26–31 through 26–34.
- Many manufacturers recommend that the angle ground on the valve seat and valve face be 1° different to provide a wedging force that results in a better initial seal. This 1° difference is called the **interference angle.**
- Installed height and valve stem height are checked and corrected as necessary.
- After a thorough cleaning, the cylinder head is assembled with new valve stem seals installed. See the photo sequence at chapter's end for details on valve reconditioning.



Figure 26–30 Resurfacing the face of a valve. Both the valve and the grinder stone or disc are turned to ensure a smooth surface finish on the face of the valve.

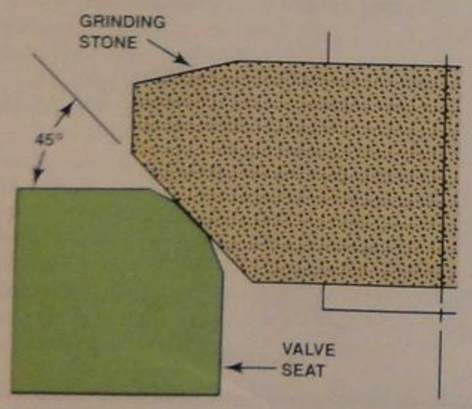


Figure 26–31 Grinding a 45° angle establishes the valve seat in the combustion chamber.

NOTE: Some experts recommend using lapping compound on the valve seat and valve face and rotating the valve to improve the valve seating. See Figure 26–35.

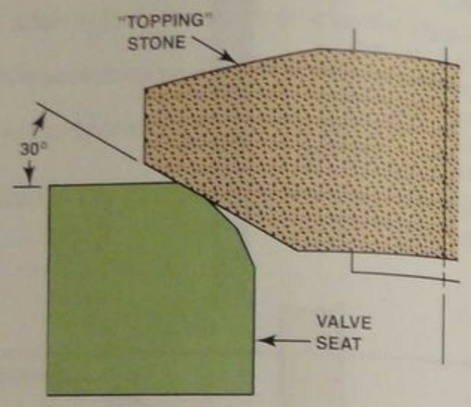


Figure 26–32 Grinding a 30° angle removes metal from the top to lower and narrow the seat.

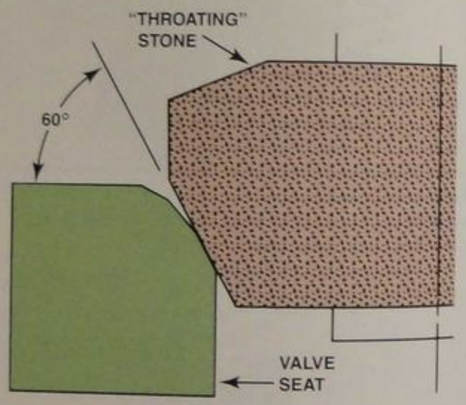


Figure 26–33 Grinding a 60° angle removes metal from the bottom to raise and narrow the seat.

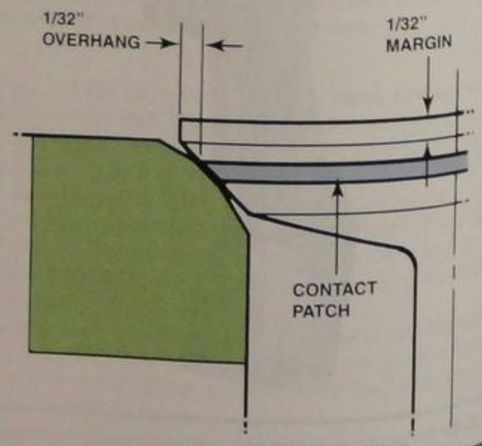


Figure 26–34 The seat must contact evenly around the valve face. For good service life both margin and overhang should be at least 1/32 inch (0.8 mm).

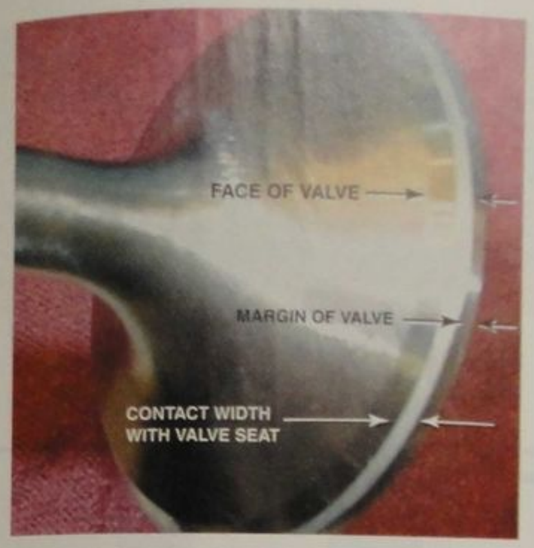


Figure 26–35 After the valve face and the valve seat are ground (reconditioned), lapping compound is used to smooth the contact area between the two mating surfaces. Notice that the contact is toward the top of the face. For maximum life, the contact should be in the middle of the face.

HIGH-PERFORMANCE TIP

Grinding the Valves for More Power

A normal "valve job" includes grinding the face of the valve to clean up any pits and grinding the valve stems to restore the proper stem height. However, a little more airflow in and out of the cylinder head can be accomplished by performing two more simple grinding operations.

- Use the valve grinder and adjust to 30° (for a 45° valve) and grind a transition between the valve face and the valve stem area of the valve. While this step may reduce some desirable swirling of the air–fuel mixture at lower engine speeds, it also helps increase cylinder filling, especially at times when the valve is not fully open.
- Chamfer or round the head of the valve between the top of the valve and the margin on the side. By rounding this surface, additional airflow into the cylinder is achieved. See Figure 26–36.

VALVE SEAT REPLACEMENT

Valve seats need to be replaced if they are cracked or if they are burned or eroded too much to be resurfaced. Damaged integral valve seats must be counterbored to make a place for the new insert seat.

Manufacturers of replacement valve seats supply tables that specify the proper seat insert to be used. Insert exhaust valve seats operate at temperatures that are 100° to 150°F (56° to 83°C) hotter than those of integral seats. Removable valve seats are available in cast iron, **stainless steel, nickel cobalt,** or **powdered metal (PM).** See Figure 26–37.

VALVE STEM HEIGHT

Valve stem height is different from installed height. See Figure 26–38. Valve stem height is important to maintain for all engines, but especially for overhead camshaft engines. When the valve seat and the valve face are ground, the valve stem extends deeper into the combustion chamber and extends higher or further into the cylinder head.

The valve is put in the head, and the length of the valve tip is measured. The tip is ground to shorten the valve stem length to compensate for the valve face and seat grinding. The valve will not close if the valve tip extends too far from the valve guide in engines that have hydraulic lifters and nonadjustable rocker arms. The tip may be ground by as much as 0.020 inch (0.50 millimeter) to reduce its length.

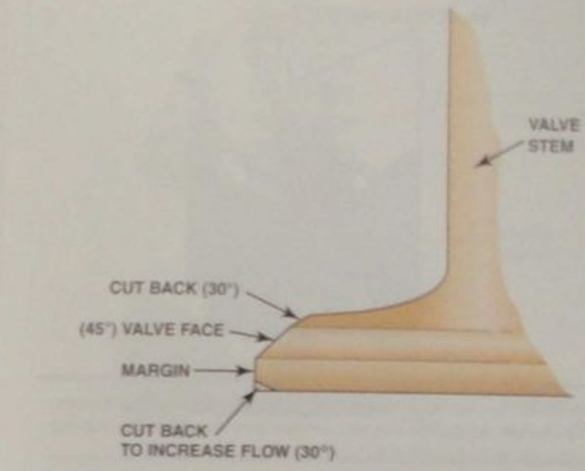


Figure 26–36 After grinding the 45° face angle, additional airflow into the engine can be accomplished by grinding a transition between the face angle and the stem, and by angling or rounding the transition between the margin and the top of the valve.



Figure 26–37 All aluminum cylinder heads use valve seat inserts. If an integral valve seat (cast-iron head) is worn, it can be replaced with a replacement valve seat by machining a pocket (counterbore) to make a place for the new insert seat.

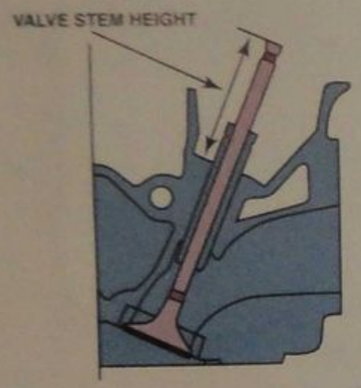


Figure 26–38 Valve stem height is measured from the spring seat to the tip of the valve after the valve seat and valve face have been refinished. If the valve stem height is too high, up to 0.020 inch can be ground from the tips of most valves.

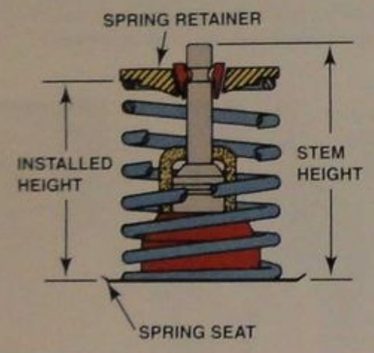


Figure 26–39 Installed height is determined by measuring the distance from the spring seat to the bottom of the valve spring retainer.

Checking Installed Height When the valves and/or valve seats have been machined, the valve projects farther than before on the rocker arm side of the head. (The valve face is slightly recessed into the combustion chamber side of the head.) The valve spring tension is, therefore, reduced because the spring is not as compressed as it was originally. To restore original valve spring tension, special valve spring spacers or inserts are installed under the valve springs. These shims are usually called **valve spring inserts (VSI).** Valve spring inserts are generally available in three different thicknesses:

1. 0.015 inch (0.38 millimeter) for balancing valve spring pressure.
2. 0.030 inch (0.75 millimeter) generally, for new springs on cylinder heads that have had the valve seats ground and valves refaced
3. 0.060 inch (1.5 millimeter) necessary to bring assembled height to specifications, especially if the seats have been resurfaced more than one time
   - To determine the exact thickness of the insert to install, measure the valve spring height (as installed in the head). See Figure 26–39.
   - If the installed height is greater than specifications, select the insert (shim) that brings the installed height to within specifications. See Figure 26–40.



Figure 26–40 Valve spring inserts are used to restore proper installed height.

VALVE STEM SEALS

Leakage past the valve guides is a major oil consumption problem in any overhead valve (or overhead cam) engine. A high vacuum exists in the intake port. Most engine manufacturers use valve stem seals on both the intake and the exhaust valve.

Two basic types of valve stem seals are used. The **umbrella valve stem seal** holds tightly to the valve stem and moves up and down with the valve. Any oil that spills off the rocker arms is deflected out over the valve guide, much as water is deflected over an umbrella. As a result, umbrella valve stem seals are often called **deflector valve stem seals.**

Positive valve stem seals hold tightly around the valve guide, and the valve stem moves through the seal. The seal wipes the excess oil from the valve stem (Figures 26–41 through 26–43).

The Chevrolet **O-ring type of valve stem seal** keeps oil from leaking between the valve stem and valve spring retainer. The oil is deflected over the retainer and shield. The assembly controls oil like an umbrella-type oil seal.

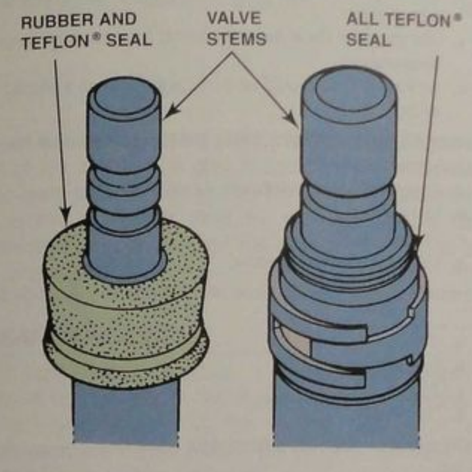
INSTALLING THE VALVES

The cylinder head can be assembled after the head is thoroughly cleaned with soap and water to wash away any remaining grit and metal shavings from the valve grinding operation. Valves are assembled in the head one at a time. Give the valve guide and stem a light coating of engine oil, and install the valve in its guide. Install umbrella or positive valve stem seals. Push umbrella seals down until they touch the valve guide. Use a plastic sleeve over the tip of the valve when installing positive seals. Make sure that the positive seal is fully seated on the valve guide and that it is square. Hold the valve against the seat as the valve spring seat or insert, valve spring, valve seals, and retainer are placed over the valve stem. Install the valve spring seat if assembling an aluminum head. See Figure 26–44. One end of the valve spring compressor pushes on the retainer to compress the spring. The O-ring type of valve stem seal is installed in the lower groove. The valve locks are installed while the valve spring is compressed. See Figure 26–45. To test the seal, attach the hose from a vacuum pump to the top of the assembled valve. *A vacuum will hold if the O-ring type of valve stem seal is correctly installed.*

TECH TIP ✔ **Do Not Simply Bolt on New Cylinder Heads**

New, assembled cylinder heads, whether aluminum or cast iron, are a popular engine build-up option. However, experience has shown that metal shavings and casting sand are often found inside the passages.

Before bolting on these "ready-to-install" heads, disassemble them and clean all passages. Often machine shavings are found under the valves. If this debris were to get into the engine, the result would be extreme wear or damage to the pistons, rings, block, and bearings. This cleaning may take several hours, but how much is your engine worth?



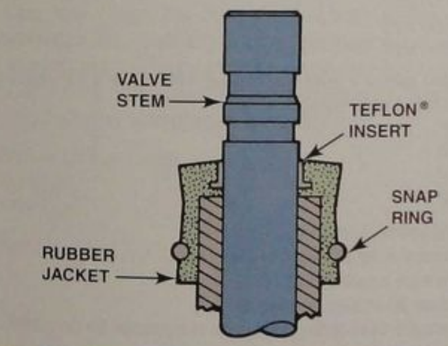


Figure 26–41 Positive valve stem seals are the most effective type because they remain stationary on the valve guide and wipe the oil from the stem as the valve moves up and down.



Figure 26–42 An assortment of shapes, colors, and materials of positive valve stem seals.

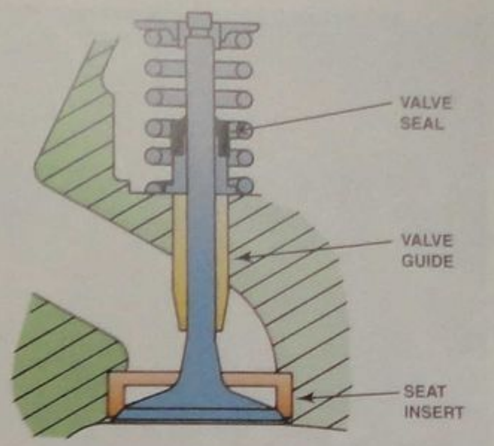


Figure 26–43 The positive valve stem seal is installed on the valve.



Figure 26–44 A metal valve spring seat must be used between the valve spring and the aluminum cylinder head. Many Chrysler aluminum cylinder heads use a combination valve spring seat and valve stem seal.

SUMMARY

1. The most commonly used combustion chamber types include hemispherical, wedge, and pentroof.
2. Cylinder head reconditioning should start with cleaning and repairing, if needed, followed by resurfacing of valves and, finally, grinding of valves and seats.
3. Valve guides should be checked for wear using a ball gauge or a dial indicator. Typical valve stem-to-guide clearance is 0.001 to 0.003 inches for intake valves and 0.002 to 0.004 inches for exhaust valves.
4. Valve guide repair options include using oversize stem valves, replacement valve guides, valve guide inserts, and knurling of the original valve guide.
5. Valve springs should be kept with the valve at the time of disassembly and tested for squareness and proper spring force.
6. Free and positive are two types of valve rotators.



Figure 26–45 Assembling a race engine using a heavy-duty valve spring compressor.

7. Valve grinding should start with truing the valve tip; then the face should be refinished. A pilot is placed into the valve guide to position the stone or cutter correctly for resurfacing the valve seat.
8. The installed height should be checked and corrected with valve spring inserts if needed.
9. Valve stem height should be checked and the tip of the valve ground if necessary.
10. After a thorough cleaning, the cylinder head should be assembled using new valve stem seals.

REVIEW QUESTIONS

1. What is meant by the term *cross flow head?*
2. What are the advantages of using four valves per cylinder?
3. Why is valve guide reconditioning the first cylinder head servicing operation?
4. When is the valve tip ground? How do you know how much to remove from the tip?
5. What is an interference angle between the valve and the seat?
6. How is a valve seat insert installed?
7. How is the correct valve spring insert (shim) selected and why are they used?

CHAPTER QUIZ

1. The gasket surface of a cylinder head, as measured with a straightedge, should have a maximum variation of _____.
   a. 0.002 inches in any 6-inch length or 0.004 inches overall
   b. 0.001 inches in any 6-inch length or 0.004 inches overall
   c. 0.020 inches in any 10-inch length or 0.020 inches overall
   d. 0.004 inches in any 10-inch length or 0.008 inches overall
2. Most vehicle manufacturers recommend repairing integral guides using _____.
   a. OS stem valves
   b. Knurling
   c. Replacement valve guides
   d. Valve guide inserts
3. The typical valve stem-to-valve guide clearance is _____.
   a. 0.030 to 0.045 inches (0.8 to 0.10 millimeters)
   b. 0.015 to 0.020 inches (0.4 to 0.5 millimeters)
   c. 0.005 to 0.010 inches (0.13 to 0.25 millimeters)
   d. 0.001 to 0.004 inches (0.03 to 0.01 millimeters)
4. Which statement is true about surface finish?
   a. Cast-iron surfaces should be smoother than aluminum surfaces.
   b. The rougher the surface, the higher the microinch finish measurement.
   c. The smoother the surface, the higher the microinch finish measurement.
   d. A cylinder head should be a lot smoother than a crankshaft journal.
5. In a normally operating engine, intake and exhaust valves are opened by a cam and closed by the _____.
   a. Rocker arms or cam follower
   b. Valve spring
   c. Lifters (tappets)
   d. Valve guide and/or pushrod
6. If an interference angle is machined on a valve or seat, this angle is usually _____.
   a. 1°
   b. 0.005°
   c. 1° to 3°
   d. 0.5° to 0.75°
7. A valve should be discarded if the margin is less than _____ after refacing.
   a. 0.001 inch
   b. 0.006 inch
   c. 0.030 inch
   d. 0.060 inch
8. To lower and narrow a valve seat that has been cut at a 45° angle, use a cutter or stone of what angle?
   a. 60°
   b. 45°
   c. 30°
   d. 15°
9. Valve spring inserts (shims) are designed to:
   a. Increase installed height of the valve
   b. Decrease installed height of the valve
   c. Adjust the correct installed height
   d. Decrease valve spring pressure to compensate for decreased installed height
10. Umbrella-type valve stem seals _____.
    a. Fit tightly onto the valve guide
    b. Fit on the valve face to prevent combustion leaks
    c. Fit tightly onto the valve stem
    d. Lock under the valve retainer

CHAPTER 27

Camshafts and Valve Trains

OBJECTIVES: **After studying Chapter 27, the reader will be able to:** Prepare for ASE Engine Repair (A1) certification test content area "C" (Engine Block Diagnosis and Repair). • Describe how the camshaft and valve train function. • Discuss valve train noise and its causes. • Explain how to degree a camshaft. • Explain how a hydraulic lifter works.

KEY TERMS: bucket • cam follower • camshaft bearings • contour • duration of the camshaft • finger follower • flat-link type • freewheeling • hydraulic valve lifter • intake centerline • intake lobe centerline method • minutes • Morse • roller chain type • silent chain type • solid valve lifter • straight up • tappets • valve lash

The cam is driven by timing gears, chains, or belts located at the front of the engine. The gear or sprocket on the camshaft has twice as many teeth, or notches, as the one on the crankshaft. This results in two crankshaft turns for each turn of the camshaft. *The camshaft turns at one-half the crankshaft speed in all four-stroke-cycle engines.*

CAMSHAFT FUNCTION

The camshaft's major function is to operate the valve train. Cam shape or **contour** is the major factor in determining the operating characteristics of the engine. The lobes on the camshaft open the valves against the force of the valve springs. The camshaft lobe changes rotary motion (camshaft) to linear motion (valves).

Cam lobe shape has more control over engine performance characteristics than does any other single engine part. Engines identical in every way except cam lobe shape may have completely different operating characteristics and performance. See Figure 27–1. The camshaft may also operate the following:

- Mechanical fuel pump
- Oil pump
- Distributor

See Figures 27–2 and 27–3.

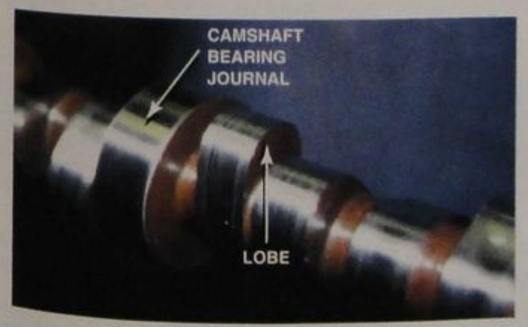


Figure 27–1 This high-performance camshaft has a lobe that opens the valve quickly and keeps it open for a long time.

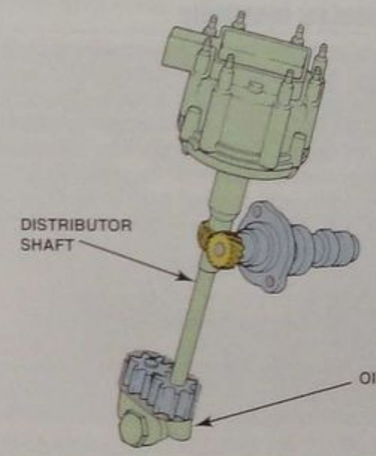


Figure 27–2 In many engines, the camshaft drives the distributor and the oil pump through a shaft from the end of the distributor.

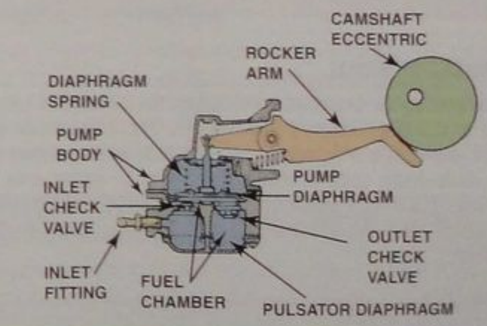


Figure 27–3 The fuel pump plunger rides on the camshaft eccentric.

CAMSHAFT LOCATION

Pushrod engines have the cam located in the block. They are smaller and lighter than overhead cam engines. The camshaft is supported in the block by **camshaft bearings** and driven by the crankshaft with a gear or sprocket and chain drive. See Figure 27–4.



Figure 27–4 Cutaway of a Chevrolet V-8 showing the valve train components.

CAMSHAFT PROBLEM DIAGNOSIS

A partially worn lobe on the camshaft is often difficult to diagnose. Sometimes a valve "tick tick tick" noise is heard if the cam lobe is worn. The ticking noise can be intermittent, which makes it harder to determine the cause. If the engine has an overhead camshaft (OHC), it is usually relatively easy to remove the cam cover and make a visual inspection of all cam lobes and the rest of the valve train. In an overhead valve (OHV) engine, the camshaft is in the block, where easy visual inspection is not possible. See Figure 27–5 and Tech Tip "The Rotating Pushrod Test."

TECH TIP ✔ **The Rotating Pushrod Test**

To quickly and easily test whether or not the camshaft is okay, observe if the pushrods are rotating when the engine is running. This test will work on any overhead valve pushrod engine that uses a flat-bottom lifter. Due to the slight angle on the cam lobe and lifter offset, the lifter (and pushrod) should rotate whenever the engine is running. To check, simply remove the rocker arm cover and observe the pushrods when the engine is running. If one or more pushrods is *not* rotating, this camshaft and/or the lifter for that particular valve is worn and needs to be replaced.

CAMSHAFT REMOVAL

If the engine has an overhead valve design, the camshaft is usually located in the block above the crankshaft. The timing chain and gears (if the vehicle is so equipped) should be removed after the timing chain (gear) cover is removed. Loosen the rocker arms (or rocker arm shaft) and remove the pushrods. Remove or lift up the lifters before carefully removing the camshaft. See Tech Tip "The Tube Trick."

NOTE: Be sure to keep the pushrods and rocker arms together if they are to be reused.

CAMSHAFT DRIVES

The crankshaft gear or sprocket that drives the camshaft is usually made of sintered iron. When gears are used, the camshaft gear teeth must be made from a soft material to reduce noise. Usually, the whole gear is made of aluminum or fiber. See Figure 27–6. When a chain and sprocket are used, the camshaft



(a)



(b)

Figure 27–5 (a) Here is what can happen if a roller lifter breaks loose from its retainer. The customer complained of "a little noise from the engine." (b) All engines equipped with roller lifters have some type of retainer for keeping the lifters from rotating.

TECH TIP ✔ **The Tube Trick**

Valve lifters are often difficult to remove because the ends of the lifters become mushroomed (enlarged) where they have contacted the camshaft. Varnish buildup can also prevent the lifters from being removed. Try this method:

Step #1 Raise the lifters upward as far away from the camshaft as possible.

Step #2 Slide in a thin plastic or cardboard tube with slots in place of the camshaft.

Step #3 Push the lifters downward into the tube. Use a long magnet to retrieve the lifters from the end of the tube.

This trick will work on almost every engine that has the camshaft in the block. If the tube is made from plastic, it has to be thin plastic to allow it to flex slightly. The length of the lifters is greater than the diameter of the cam bearings. Therefore, the lifter has to be pushed downward into the tube slightly to allow the lifter room to fall over into the tube.

sprocket may be made of iron or it may have an aluminum hub with nylon teeth for noise reduction. Two types of timing chain are used.

1. **Silent chain type** (also known as a **flat-link type,** or **Morse** type for its original manufacturer). This type operates quietly but tends to stretch with use. See Figures 27–7 and 27–8.

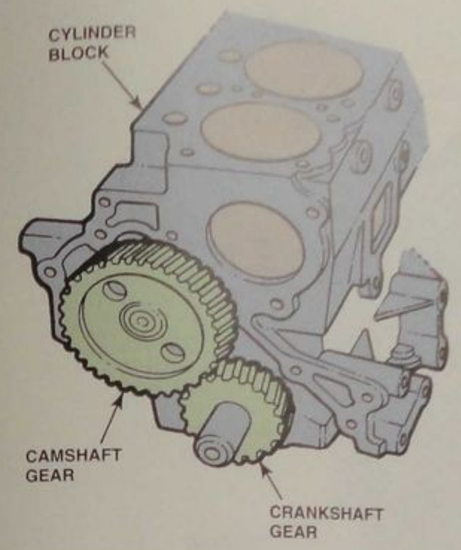


Figure 27–6 The larger camshaft gear is usually made from fiber and given a helical cut to help reduce noise. By making the camshaft gear twice as large as the crankshaft gear, the camshaft rotates one revolution for every two of the crankshaft.



Figure 27–7 A replacement silent chain and sprockets. The original camshaft sprocket was aluminum with nylon teeth to help control noise. This replacement set will not be noticeably louder than the original and should give the owner many thousands of miles of useful service.

NOTE: When the timing chain stretches, the valve timing will be retarded and the engine will lack low-speed power. In some instances, the chain can wear through the timing-chain cover and create an oil leak.

2. **Roller chain type.** This type is noisier but operates with less friction and stretches less than the silent type of chain. See Figure 27–9.

Some four-cam engines use a two-stage camshaft drive system:

Primary: from crankshaft to camshaft
Secondary: from one camshaft to another

See Figure 27–10.

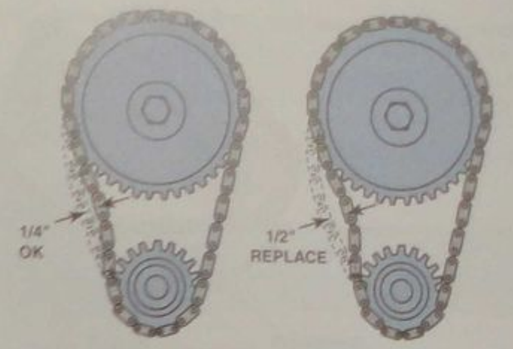


Figure 27–8 The industry standard for when to replace a timing chain and gears is when 1/2 inch (13 millimeters) or more of slack is measured in the chain. However, it is best to replace the timing chain and gear anytime the camshaft is replaced or the engine is disassembled for repair or overhaul.



Figure 27–9 A replacement high-performance double roller chain. Even though a bit noisier than a flat-link chain, a roller chain does not stretch as much and will therefore be able to maintain accurate valve timing for a long time.

CAMSHAFT BELT DRIVES

Many overhead camshaft engines use a timing belt rather than a chain. The belt is generally considered to be quieter, but it requires periodic replacement, usually every 60,000 miles (100,000 kilometers). Unless the engine is **freewheeling,** the piston can hit the valves if the belt breaks. See Figures 27–11 through 27–13.

REAL WORLD FIX **Best to Warn the Customer**

A technician replaced a timing chain and gears on a Chevrolet V-8. The repair was accomplished correctly, yet, after starting, the engine burned an excessive amount of oil. Before the timing chain replacement, oil consumption was minimal. The replacement timing chain restored proper operation of the engine and increased engine vacuum. Increased vacuum can draw oil from the crankcase past worn piston rings and through worn valve guides during the intake stroke. Similar increased oil consumption problems occur if a valve regrind is performed on a high-mileage engine with worn piston rings and/or cylinders.

To satisfy the owner of the vehicle, the technician had to disassemble and refinish the cylinders and replace the piston rings. Therefore, all technicians should warn customers that increased oil usage may result from almost any repair to a high-mileage engine.

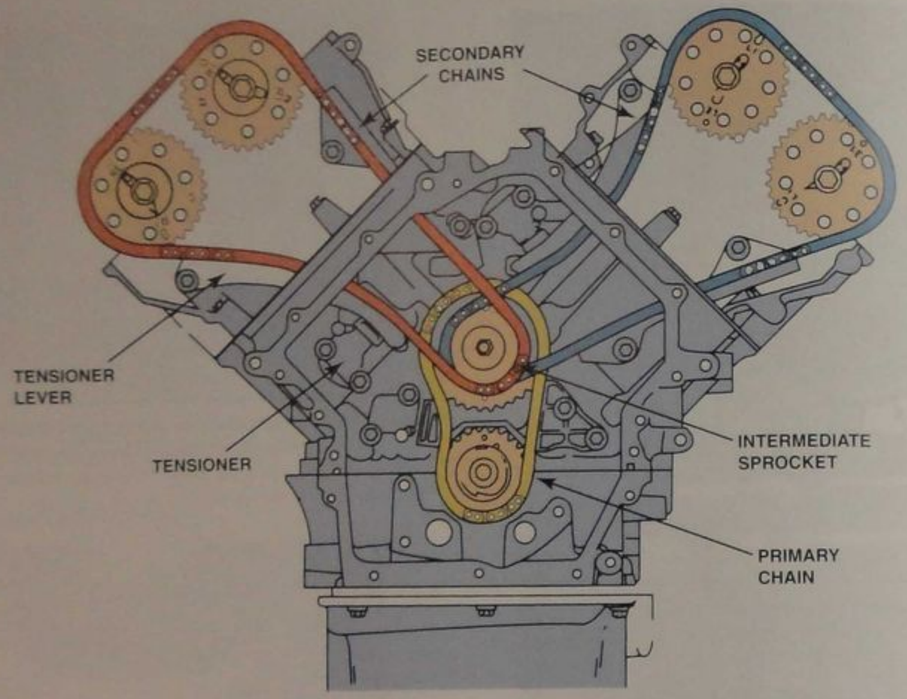


Figure 27–10 Typical dual overhead camshaft V-type engine that uses one primary timing chain and two secondary chains.

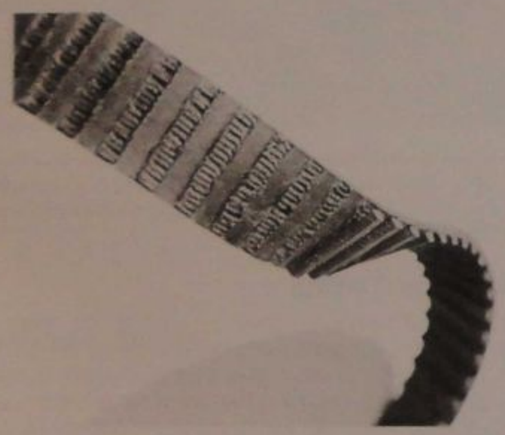


Figure 27–11 Broken timing belt. Also notice the missing teeth. This belt broke at 88,000 miles because the owner failed to replace it at the recommended interval of 60,000 miles.



Figure 27–12 This timing belt broke because an oil leak from one of the camshaft seals caused oil to get into and weaken the belt. Most experts recommend replacing all engine seals in the front of the engine anytime a timing belt is replaced. If the timing belt travels over the water pump, the water pump should also be replaced as a precaution.

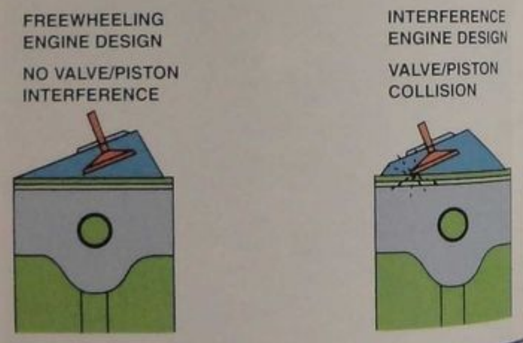


Figure 27–13 Many engines are of the interference design. If the timing belt (or chain) breaks, the piston still moves up and down in the cylinder while the valves remain stationary. With a freewheeling design, nothing is damaged, but in an interference engine, the valves are often bent

REAL WORLD FIX **The Noisy Camshaft**

The owner of an overhead cam four-cylinder engine complained of a noisy engine. After taking the vehicle to several technicians and getting high estimates to replace the camshaft and followers, the owner tried to find a less expensive solution. Finally, another technician replaced the serpentine drive belt on the front of the engine and "cured" the "camshaft" noise for a fraction of the previous estimates.

Remember, accessory drive belts can often make noises similar to valve or bad-bearing types of noises. Many engines have been disassembled and/or overhauled because of a noise that was later determined to be from one of the following:

- Loose or defective drive belt(s)
- Loose torque converter-to-flex plate (drive plate) bolts (nuts)
- Defective mechanical fuel pump

ROCKER ARMS

Rocker arms reverse the upward movement of the pushrod to produce a downward movement on the tip of the valve. They are designed to reduce the travel of the cam follower or lifter and pushrod while maintaining the required valve lift. This is doneby using a rocker arm ratio of approximately 1.5:1, as shown in Figure 27–14. For a given amount of lift on the pushrod, the valve will open up to 1.5 times the pushrod lift distance. This ratio allows the camshaft to be small, so the engine can be smaller. It also results in lower lobe-to-lifter rubbing speeds.

CAUTION: Using rocker arms with a higher ratio than stock can also cause the valve spring to compress too much and actually bind. Valve spring bind occurs when the valve spring is compressed to the point where there is no clearance at all in the spring. (It is completely compressed.) When coil bind occurs in a running engine, bent pushrods, broken rocker arms, or other valve train damage can result.

Rocker arms may be cast, forged, or stamped. See Figure 27–15.

1. One type of rocker arm opens the valves directly with a **cam follower** or **bucket.** See Figure 27–16.
2. The second type uses a **finger follower** that provides an opening ratio similar to that of a rocker arm. Finger followers open the valves by approximately 1 1/2 times the cam lift. The pivot point of the finger follower may have a mechanical or automatic hydraulic adjustment.
3. A third type moves the rocker arm directly through a hydraulic lifter (Figure 27–17).

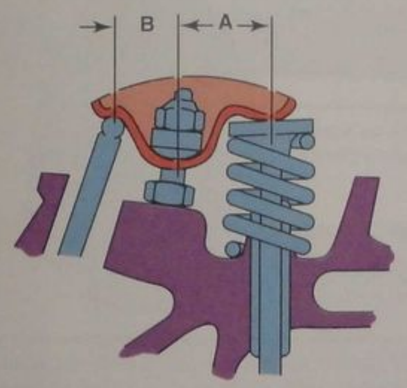


Figure 27–14 A 1.5:1 ratio rocker arm means that the dimension A is 1.5 times the length of B. Therefore, if the pushrod is moved up 0.400 inch by the camshaft lobe, the valve will be pushed down (opened) 0.400 inch × 1.5, or 0.600 inch.



Figure 27–15 A high-performance aluminum roller arm. Both the pivot and the tip that contacts the stem of the valve are equipped with rollers to help reduce friction for more power and better fuel economy.

NOTE: Some newer engines have the hydraulic adjustment in the rocker arm and are called hydraulic lash adjusters (HLA). See Figure 27–17.

TECH TIP **Rocker Arm Shafts Can Cause Sticking Valves**

As oil oxidizes, it forms a varnish. Varnish buildup is particularly common on hot upper portions of the engine, such as rocker arm shafts. The varnish restricts clean oil from getting into and lubricating the rocker arms. The cam lobe can easily *force* the valves open, but the valve springs often do not exert enough force to fully close the valves. The result is an engine miss, which may be intermittent. Worn valve guides and/or weak valve springs can also cause occasional rough idle, uneven running, or missing. See Figure 27–18.

PUSHRODS

Pushrods are designed to be as light as possible and still maintain their strength. They may be either solid or hollow. If they are to be

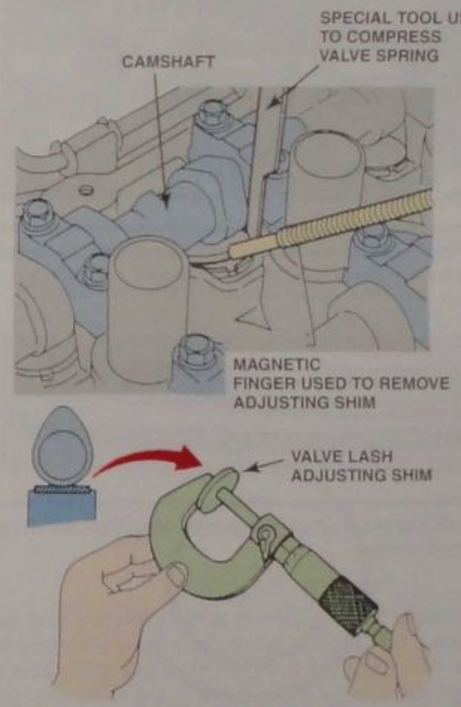


Figure 27–16 Some overhead camshaft engines use a bucket-type cam follower which uses valve lash adjusting shims to adjust the valve lash. A special tool is usually required to compress the valve spring so that a magnet can remove the shim.



Figure 27–17 This single overhead camshaft engine has four valves per cylinder because each pivot arm opens two valves and each contain a small hydraulic lash adjuster (hydraulic lifter).

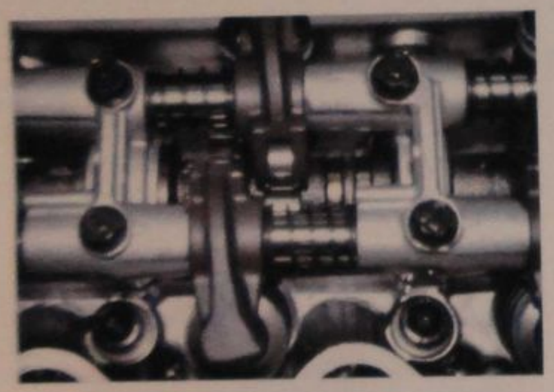


Figure 27–18 Some engines today use rocker shafts to support rocker arms such as the V-6 engine with a single overhead camshaft located in the center of the cylinder head.



Figure 27–19 When the timing chain broke, the engine stopped quickly, which caused most of the pushrods to bend.

used as passages for oil to lubricate rocker arms, they *must* be hollow. Pushrods have a convex ball on the lower end that seats in the lifter. The rocker arm end is also a convex ball unless there is an adjustment screw in the pushrod end of the rocker arm. In this case, the rocker arm end of the pushrod has a concave socket. It mates with the convex ball on the adjustment screw in the rocker arm. All pushrods should be rolled on a flat surface to check if they are bent. See Figure 27–19.

TECH TIP ✔ **Hollow Pushrod Dirt**

Many engine rebuilders and remanufacturers do not reuse old hollow pushrods. Dirt, carbon, and other debris are difficult to thoroughly clean from inside a hollow pushrod. When an engine is run with used pushrods, the trapped particles can be dislodged and ruin new bearings and other new engine parts.

CAMSHAFT DURATION

The **duration of the camshaft** is the number of degrees of crankshaft rotation for which the valve is lifted off the seat. See Figures 27–20 and 27–21. The specifications for duration can be different for the intake valves and the exhaust valves. The specification for duration can be expressed by several different methods and must be considered when comparing one cam to another. The two most commonly used methods are the following:

1. **Duration of valve opening at zero lash** (clearance). If a hydraulic lifter is used, the lash is zero. If a solid lifter is used, this expression refers to the duration of the opening of the valve after the specified clearance (lash) has been closed.

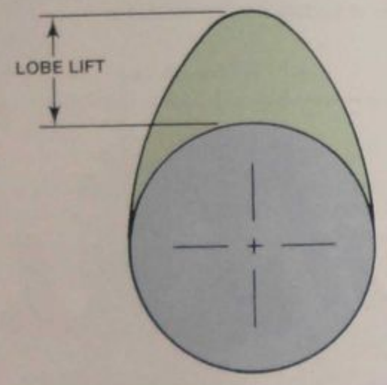


Figure 27–20 The lobe lift is the amount the cam lobe lifts the lifter. Because the rocker arm adds to this amount, the entire valve train has to be considered when selecting a camshaft that has the desired lift and duration.

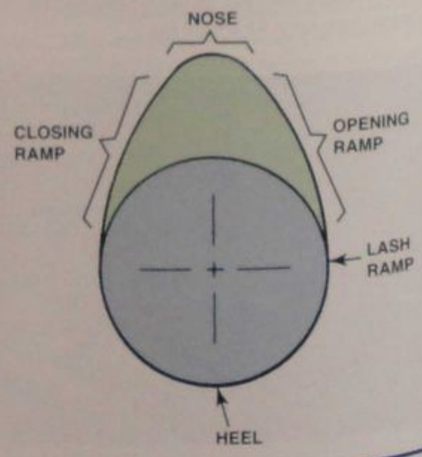


Figure 27–21 The ramps on the cam lobe allow the valves to be opened and closed quickly yet under control to avoid damaging valve train components, especially at high engine speeds.

2. **Duration at 0.050-inch lifter (tappet) lift.** Because this specification method eliminates all valve lash clearances and compensates for lifter (tappet) styles, it is the preferred method to use when comparing one camshaft to another. The camshaft can be tested using a dial indicator as shown in Figures 27–22 and 27–23.

NOTE: Fractions of a degree are commonly expressed in units called **minutes** (′). **Sixty minutes equal one degree.** For example, 45′ = 3/4°, 30′ = 1/2°, and 15′ = 1/4°.

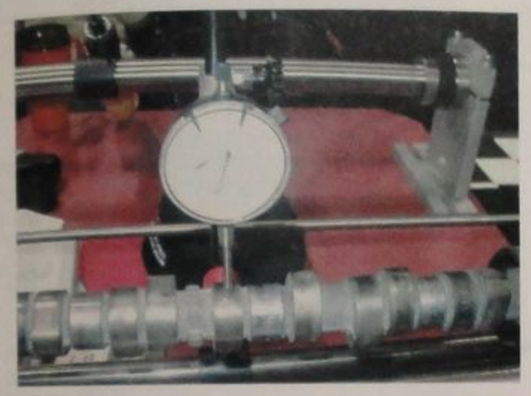


Figure 27–22 A camshaft can be checked for straightness and as well as for lift and duration using a dial indicator on a fixture that allows the camshaft to be rotated. This same equipment can be used to check crankshafts.



Figure 27–23 The lift of a camshaft lobe can be quickly determined by using this dial indicator that attaches directly to the camshaft.

CAM TIMING CHART

During the four strokes of a four-stroke-cycle gasoline engine, the crankshaft revolves 720° (it makes two complete revolutions [2 × 360° = 720°]). Camshaft specifications are given in crankshaft degrees. The usual method of drawing a camshaft timing diagram is in a circle illustrating two revolutions (720°) of the crankshaft. In the example in Figure 27–24, the intake valve starts to open at 15° BTDC, remains open through the entire 180° of the intake stroke, and does not close until 59° ATDC. Therefore, the duration of the intake valve is 15° plus 180° plus 59°, or 254°.

The exhaust valve camshaft in the example opens at 59° BBDC and closes at 15° ATDC. When the exhaust valve specifications are added to the intake valve specifications in the diagram, the overlap period is easily observed. The overlap in the example is 15° plus 15° or 30°.

INSTALLING THE CAMSHAFT

When the camshaft is installed, the lobes must be coated with a special lubricant containing molydisulfide. This special lube helps to ensure proper initial lubrication to the critical cam lobe sections of the camshaft. Many manufacturers recommend multiviscosity engine oil such as SAE 5W-30 or SAE 10W-30. Some camshaft manufacturers recommend using straight SAE 30 or SAE 40 engine oil and not a multiviscosity oil for the first oil fill. Some manufacturers also recommend the use of an antiwear additive such as zinc dithiophosphate (ZDP). See Figures 27–25 and 27–26.

The camshaft must be broken in by maintaining engine speed above 1500 RPM for the first 10 minutes of engine operation. If the engine speed is decreased to idle (about 600 RPM), the lifter (tappet) will be in contact with and exerting force on the lobe of the cam for a longer period of time than occurs at higher engine speeds. The pressure and volume of oil supplied to the camshaft area are also increased at the higher engine speeds. Therefore, to ensure long camshaft and lifter life, make certain that the engine will start quickly after a new camshaft and lifters have been installed to prevent long cranking periods and subsequent low engine speeds. When repairing an engine, follow these rules regarding the camshaft and lifters:

1. When installing a new camshaft, always install new valve lifters (tappets).

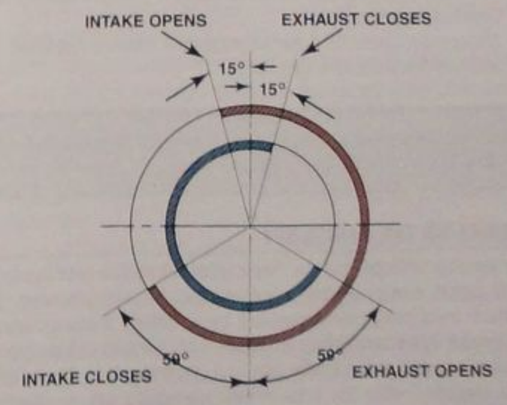


Figure 27–24 Typical cam timing diagram.



Figure 27–25 Special lubricant such as this one from General Motors is required to be used on the lobes of the camshaft and the bottom of the flat-bottomed lifters. The use of an additive at every oil change is recommended also because the new oils do not contain enough zinc for flat bottom lifters and cams.



Figure 27–26 Care should be taken when installing a camshaft not to nick or scrape the cam bearings.

2. When installing new lifters, if the original cam is not excessively worn and if the pushrods all rotate with the original camshaft, the camshaft may be reused.
3. *Never* use a hydraulic camshaft with solid lifters or hydraulic lifters with a solid lifter camshaft.

NOTE: Some manufacturers recommend that a new camshaft always be installed when replacing valve lifters.

DEGREEING THE CAMSHAFT

The purpose of degreeing the camshaft in the engine is to locate the valve action exactly as the camshaft manufacturer intended. The method most often recommended by camshaft manufacturers is the **intake lobe centerline method.** This method determines the exact centerline of the intake lobe and compares it to the specifications supplied with the replacement camshaft. On an overhead valve engine, the camshaft is usually degreed after the crankshaft, pistons with rods, and camshaft are installed and before the cylinder heads are installed. To determine the centerline of the intake lobe, follow these steps, using a degree wheel mounted on the crankshaft:

Step #1 Locate the exact top dead center. Install a degree wheel and bring the cylinder #1 piston close to TDC. Install a piston stop (a piston stop is any object attached to the block that can act as a solid mechanical stop to prevent the piston from reaching the top of the cylinder). Turn the engine clockwise until the piston gently hits the stop.

CAUTION: Do not use the starter motor to rotate the engine. Use a special wrench on the flywheel or the front of the crankshaft.

Record the reading on the degree wheel, and then turn the engine in the opposite direction until it stops again and record that number. See Figure 27–27 indicating a reading of 30° ATDC and 26° BTDC. Add the two readings together and divide by two (30° + 26° = 56° ÷ 2 = 28°). Move the degree wheel until it is 28° and the engine has stopped rotating in either direction. Now TDC on the degree wheel is exactly at top dead center.

Step #2 Remove the piston stop and place a dial indicator on an intake valve lifter. To accurately locate the point of maximum lift (intake lobe centerline), rotate the engine until the lifter drops 0.050 inch on each side of the maximum lift point. Mark the degree wheel at these points on either side of the maximum lift point. Now count the degrees between these two points and mark the halfway point. This halfway point represents the **intake centerline.** This point is often located between 100° and 110°. See Figure 27–28.

Step #3 Now that both TDC and the intake centerline have been marked, compare the actual intake centerline with the specification. For example, if the actual intake centerline is 106° and the camshaft specification indicates 106°, then the camshaft is installed **straight up.** See Figure 27–29. If the actual reading is 104°, the camshaft is advanced by 2°. If the actual reading is 108°, the camshaft is retarded by 2°.

HIGH-PERFORMANCE TIP

Varying the Valve Timing to Vary Engine Performance

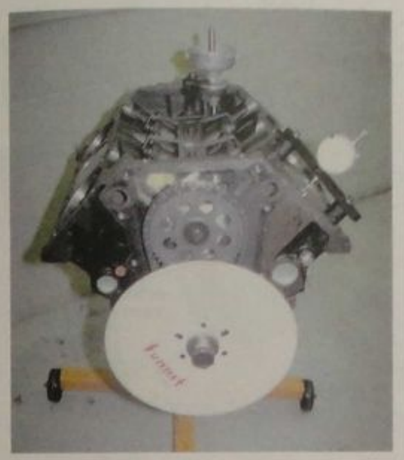
If the camshaft is slightly ahead of the crankshaft, the camshaft is called *advanced.* An advanced camshaft (maximum of 4°) results in more low-speed torque with a slight decrease in high-speed power. Some aftermarket camshaft manufacturers design about a 4° advance into their timing gears or camshaft. This permits the use of a camshaft with more lift and duration, yet still provides the smooth idle and low-speed responses of a milder camshaft.

If the camshaft is slightly behind the crankshaft, the camshaft is called *retarded.* A retarded camshaft (maximum of 4°) results in more high-speed power at the expense of low-speed torque.

If the measured values are different from specifications, special offset pins or keys are available to relocate the cam gear by the proper amount. Some manufacturers provide adjustable cam timing sprockets for overhead cam engines.



Figure 27–27 Degree wheel indicating where the piston stopped near top dead center. By splitting the difference between the two readings, the true TDC (28°) can be located on the degree wheel.



(a)



(b)

Figure 27–28 (a) The setup required to degree a camshaft. (b) Close-up of the pointer and the degree wheel.

LIFTERS

Valve lifters (also called **tappets**) follow the contour or shape of the camshaft lobe. This arrangement changes the cam motion to a reciprocating motion in the valve train. Most older-style lifters have a slightly convex surface that slides on the cam. See Figure 27–30. Some lifters, however, are designed with a roller to follow the cam contour. Roller lifters are used in production engines to reduce valve train friction (by up to 8%). This friction reduction can increase fuel economy and help to offset the greater manufacturing cost. All roller lifters must use a retainer to prevent lifter rotation.

Valve train clearance is also called **valve lash.** Valve train clearance must not be excessive, or it will cause noise or result in premature failure. Two methods are commonly used to make the necessary valve clearance adjustments. One involves a **solid valve lifter** with a mechanical adjustment, and the other involves a lifter with an automatic hydraulic adjustment built into the lifter body, called a **hydraulic valve lifter.**

A hydraulic lifter consists primarily of a hollow cylinder body enclosing a closely fitted hollow plunger, a check valve, and a pushrod cup. Lifters that feed oil up through the pushrod have a metering disk or restrictor valve located under the pushrod cup. Engine oil under pressure is fed through an engine passage to the exterior lifter body. An undercut portion allows the oil under pressure to surround the lifter body. Oil under pressure goes through holes in the undercut section into the center of the plunger. From there, it goes down through the check valve to a clearance space between the bottom of the plunger and the interior bottom of the lifter body. It fills this space with oil at engine pressure. Slight leakage allowance is designed into the lifter so that the air can bleed out and the lifter can leak down if it should become overfilled. See Figures 27–31 through 27–34.

CAUTION: Using too thick (high viscosity) an engine oil can cause the hydraulic lifters or hydraulic lash adjusters to not bleed down as fast as they should. This slow bleed down can cause a valve(s) to remain open, which results in an engine miss. Using an SAE 10W-30 instead of the specified SAE 5W-30 could cause the lifters to bleed down slower than normal and cause a driveability problem, especially if the oil is not changed at specified intervals.

SUMMARY

1. The camshaft rotates at one-half the crankshaft speed.
2. The pushrods should be rotating while the engine is running if the camshaft and lifters are okay.
3. On overhead valve engines, the camshaft is usually placed in the block above the crankshaft. The lobes of the camshaft are usually lubricated by splash lubrication.
4. Silent chains are quieter than roller chains but tend to stretch with use.
5. The lift of a cam is usually expressed in decimal inches and represents the distance that the valve is lifted off the valve seat.
6. In many engines, camshaft lift is transferred to the tip of the valve stem to open the valve by the use of a rocker arm or follower.
7. Pushrods transfer camshaft motion upward from the camshaft to the rocker arm.
8. Camshaft duration is the number of degrees of crankshaft rotation for which the valve is lifted off the seat.
9. Valve overlap is the number of crankshaft degrees for which both valves are open.
10. Camshafts should be installed according to the manufacturer's recommended procedures. Flat lifter camshafts should be thoroughly lubricated with extreme pressure lubricant.
11. If a new camshaft is installed, new lifters should also be installed.

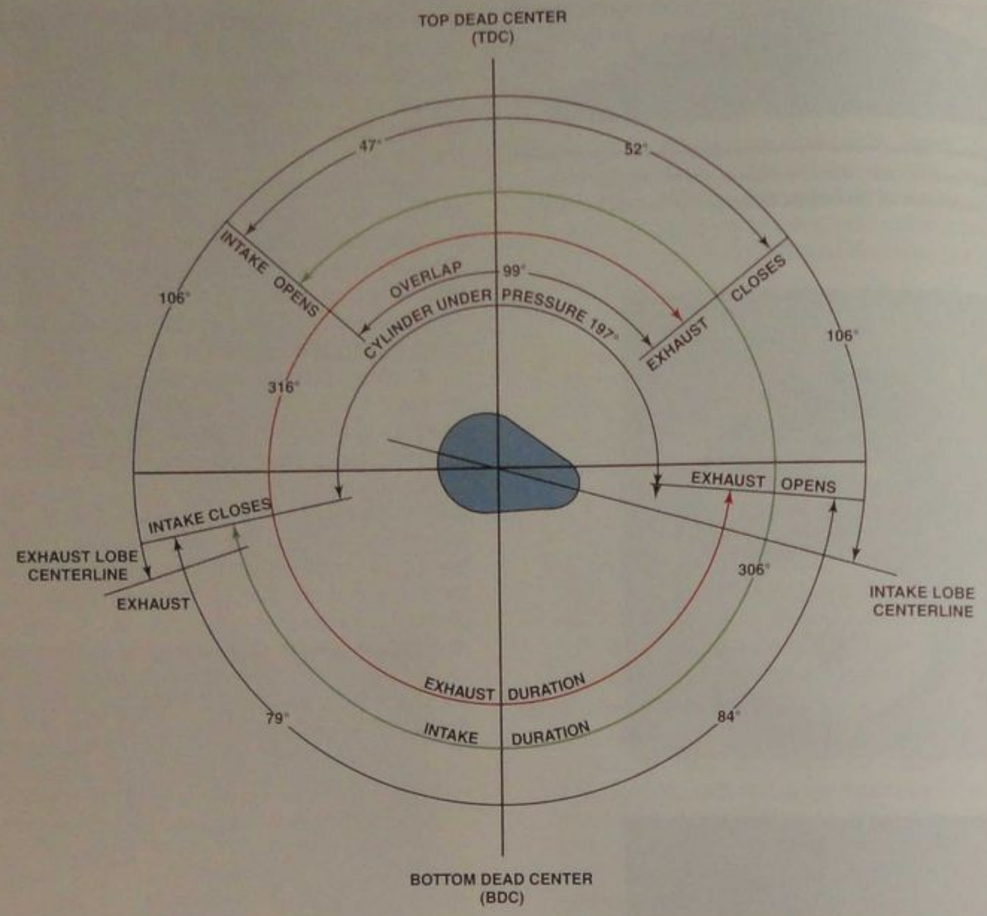


Figure 27–29 Typical valve timing diagram showing the intake lobe centerline at 106° ATDC.

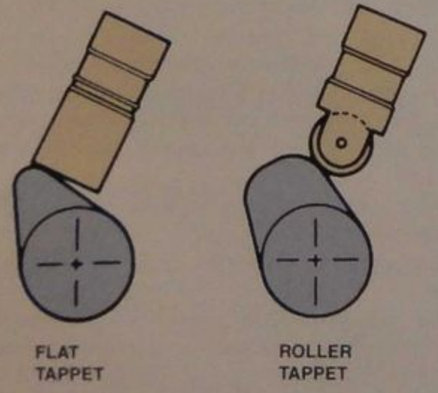


Figure 27–30 Lifters or tappets are made in two styles: flat bottom and roller.

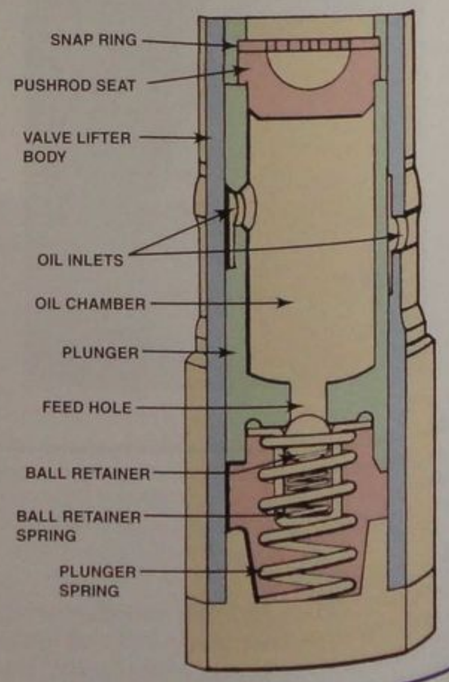


Figure 27–31 A cross-sectional view of a typical flat-bottomed hydraulic lifter.

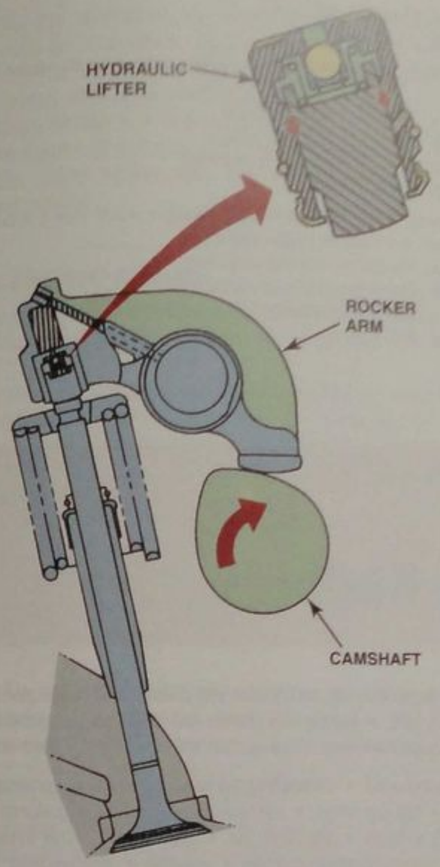


Figure 27–32 Hydraulic lash adjusters (HLA) are built into the rocker arm on some OHC engines.

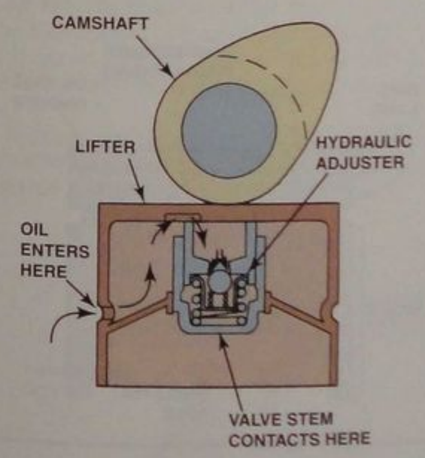


Figure 27–33 Hydraulic lifters are also built into bucket-type lifters on many OHC engines.

REVIEW QUESTIONS

1. Explain why the lift and duration and lobe-center dimension of the camshaft determine the power characteristics of the engine.
2. Explain lobe centerline.
3. Describe the operation of a hydraulic lifter.
4. Describe how to adjust hydraulic lifters.

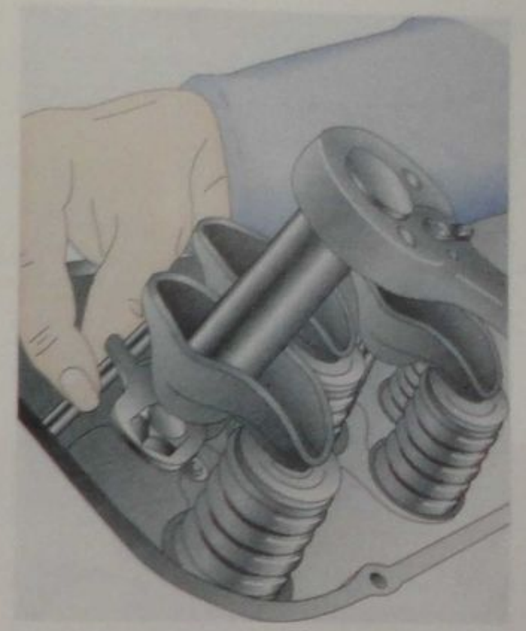


Figure 27–34 To correctly adjust the valve clearance (lash), position the camshaft on the base circle of the camshaft lobe for the valve being adjusted. Remove all clearance by spinning the pushrod and tightening the nut until all clearance is removed. The adjusting nut is then tightened one complete revolution. This is what is meant by the term "zero lash plus 1 turn."

CHAPTER QUIZ

1. The camshaft makes _____ for every revolution of the crankshaft.
   a. One-quarter revolution
   b. One-half revolution
   c. One revolution
   d. Two revolutions
2. Flat-bottom valve lifters rotate during operation because of the _____ of the camshaft.
   a. Taper of the lobe
   b. Thrust plate
   c. Chain tensioner
   d. Bearings
3. If lift and duration remain constant and the lobe center angle decreases _____.
   a. The valve overlap decreases
   b. The effective lift increases
   c. The effective duration increases
   d. The valve overlap increases
4. Which timing chain type is also called a "silent chain"?
   a. Roller
   b. Morse
   c. Flat link
   d. Both b and c
5. On an engine equipped with a timing belt, engine damage can occur if the engine is which design?
   a. Freewheeling
   b. Interference

6. Many technicians always use new pushrods because _____.
   a. It is less expensive to buy than clean
   b. All of the dirt cannot be cleaned out from the hollow center
   c. Pushrods wear at both ends
   d. Pushrods shrink in length if removed from an engine
7. A DOHC V-6 has how many camshafts?
   a. 4
   b. 3
   c. 2
   d. 1
8. The intake valve opens at 39° BTDC and closes at 71° ABDC. The exhaust valve opens at 78° BBDC and closes at 47° ATDC. Which answer is correct?
   a. Intake valve duration is 110°
   b. b. Exhaust valve duration is 125°
   c. Overlap is 86°
   d. Both a and b
9. Hydraulic valve lifters can make a ticking noise when the engine is running if _____.
   a. The valve lash is too close
   b. The valve lash is too loose
   c. The lobe centerline is over 110°
   d. Both a and c
10. Hydraulic lifters or hydraulic lash adjusters (HLA) may not bleed down properly and cause an engine miss if _____.
    a. The engine oil is one quart low
    b. The wrong API-rated engine oil is used
    c. The wrong SAE-rated engine oil is used
    d. Both a and b

CHAPTER 28 Pistons, Rings, and Connecting Rods

OBJECTIVES: After studying Chapter 28, the reader will be able to: Prepare for Engine Repair (A1) ASE certification test content area "C" (Engine Block Diagnosis and Repair). • Describe the purpose and function of pistons, rings, and connecting rods. • Explain how pistons and rods are constructed and what to look for during an inspection. • Discuss connecting rod reconditioning procedures. • Explain how piston rings operate and how to install them on a piston.

KEY TERMS: back clearance • balancing bosses (pads) • bleed hole • blowby • cam ground • connecting rod bearing journal • compression rings • crank throw • crankpin • dish • ductile iron • double-knock • eyebrows • flat-top piston • full floating • grooves • gudgeon pins • heat dams • hypereutectic • identification marks • inertia forces • interference fit • lands • left-hand rule • lock rings • major thrust surface • notch • oil control ring • piloting surfaces • piston • piston pin • piston ring • piston ring expanding tool • pop-ups • positive twist • recesses • reverse twist • ring gap • scraper ring • skirt • side clearance • slipper skirt • slots • spit hole • struts • taper face ring • valve pockets • valve reliefs • wrist pin

All engine power is developed by burning fuel in the presence of air in the combustion chamber. Heat from the combustion causes the burned gas to increase in pressure. The force of this pressure is converted into useful work through the piston, connecting rod, and crankshaft.

PURPOSE AND FUNCTION OF PISTONS, RINGS, AND CONNECTING RODS

The **piston** forms a movable bottom to the combustion chamber. It is attached to the connecting rod with a **piston pin** or **wrist pin.** See Figure 28–1. The piston pin is allowed to have a rocking movement because of a swivel joint at the piston end of the connecting rod. The connecting rod is connected to a part of the crankshaft called a **crank throw, crankpin,** or **connecting rod bearing journal.** This provides another swivel joint. The center of the crank throw is the amount by which the large end of the connecting rod is offset from the crankshaft main bearing centerline. This dimension of the crankshaft determines the stroke of the engine.

NOTE: The stroke is the distance from the center of the main bearing journal to the center of the connecting rod journal times two.

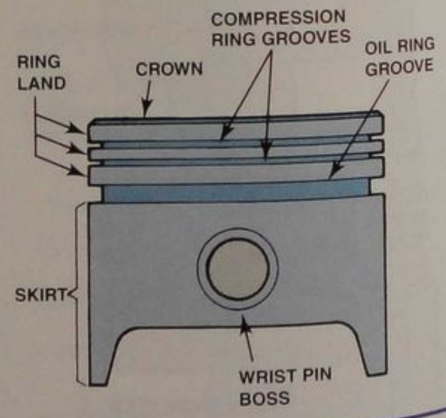


Figure 28–1 All pistons share these parts in common.

Piston rings seal the small space between the piston and cylinder wall, keeping the pressure above the piston. When the pressure builds up in the combustion chamber, it pushes on the piston. The piston, in turn, pushes on the piston pin and upper end of the connecting rod. The lower end of the

connecting rod pushes on the crank throw. This provides the force to turn the crankshaft. As the crankshaft turns, it develops inertia. *Inertia is the force that causes the crankshaft to continue rotating.* This action will bring the piston back to its original position, where it will be ready for the next power stroke. While the engine is running, the combustion cycle keeps repeating as the piston reciprocates (moves up and down) and the crankshaft rotates.

PISTON AND ROD REMOVAL

After the oil pan and cylinder head(s) have been removed, the piston and rod can be removed by the following steps:

Step #1 The rod and caps should be checked for markings that identify their location. *If the rod and caps are not marked, they should be marked before disassembly.* If number stamps are not available, punch marks, as shown in Figure 28–2, can be used.

CAUTION: Powdered metal connecting rods should only be marked with a permanent marker to avoid damage to the rod. See Figure 28–3.

Step #2 The crankshaft is turned until the piston is at the bottom of its stroke. This places the connecting rod nuts or cap screws where they are easily accessible. They are removed, and the rod cap is taken off. This may require light tapping on the connecting rod bolts with a soft-faced hammer.

Step #3 Protectors should be placed over the rod bolt threads to protect the threads and the surface of the crankshaft journal. The piston and rod assembly is pushed out, with care being taken to avoid hitting the bottom edge of the cylinder with the rod.

The rod caps should be reattached to the rod after the assembly has been removed from the cylinder. The rod caps are not interchangeable between rods. The assembly must be handled carefully. It should be placed on a parts stand so that the piston and rod do not strike each other. The aluminum piston can be easily scratched or nicked.

The rings are carefully removed from the piston to avoid damage to either the piston or the ring. The best way to remove them is to use a **piston ring expanding tool.**

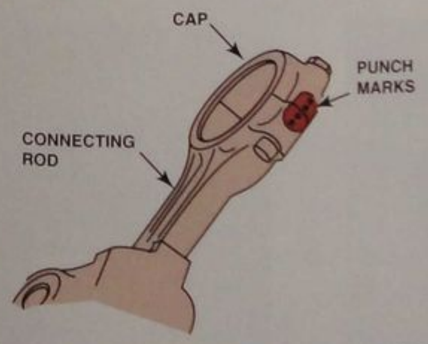


Figure 28–2 Punch marks on connecting rod and rod cap to identify their location in the engine.



Figure 28–3 Powdered metal connecting rods can be identified by their smooth appearance.

PISTON DESIGN

When the engine is running, the piston starts at the top of the cylinder. As it moves downward, it accelerates until it reaches a maximum velocity slightly before it is halfway down. The piston comes to a stop at the bottom of the cylinder at 180 degrees of crankshaft rotation. During the next 180 degrees of crankshaft rotation, the piston moves upward. It accelerates to reach a maximum velocity slightly above the halfway point and then comes to a stop at the top of the stroke. Thus, the piston starts, accelerates, and stops twice in each crankshaft revolution.

NOTE: A typical piston in an engine at 4000 RPM accelerates from 0 to 60 miles per hour (97 kilometers per hour) in about 0.004 second (4 milliseconds) as it descends about halfway down the cylinder.

This reciprocating action of the piston produces large **inertia forces.** Inertia is the force that causes a part that is stopped to stay stopped or a part that is in motion to stay in motion. The lighter the piston can be made, the less inertia force that is developed. Less inertia will allow higher engine operating speeds. For this reason, pistons are made to be as light as possible while still having the strength that is needed.

The piston operates with its head exposed to the hot combustion gases, whereas the skirt contacts the relatively cool cylinder wall. This results in a temperature difference of about 275°F (147°C) between the top and bottom of the piston.

TECH TIP ✓ **Piston Weight Is Important!**

All pistons in an engine should weigh the same to help ensure a balanced engine. Piston weight becomes a factor when changing pistons. Most aluminum pistons range in weight from 10 to 30 ounces (280 to 850 grams) (1 oz = 28.35 grams). A typical paper clip weighs 1 gram. If the cylinder has been bored, larger replacement pistons are obviously required. If the replacement pistons weigh more, this puts additional inertia loads on the rod bearings. Therefore, to help prevent rod bearing failure on an overhauled engine, the replacement pistons should not weigh more than the original pistons.

CAUTION: Some less-expensive replacement cast pistons or high-performance forged pistons are much heavier than the stock pistons, even in the stock bore size. This means that the crankshaft may need heavy metal added to the counterweights of the crankshaft for the engine to be balanced.

For the same reason, if one piston is being replaced, all pistons should be replaced or at least checked and corrected to ensure the same weight.

PISTON HEADS

Because the piston head forms a portion of the combustion chamber, its shape is very important to the combustion process. Generally, low-cost, low-performance engines have **flat-top** pistons. Some of these flat-top pistons come so close to the cylinder head that **recesses** are cut in the piston top for valve clearance. Pistons used in high-powered engines may have raised domes or **pop-ups** on the piston heads. These are used to increase the compression ratio. Pistons used in other engines may be provided with a depression or a **dish.** The varying depths of the dish provide different compression ratios required by different engine models. Several piston head shapes are shown in Figure 28–4.

NOTE: Newer engines do not use valve reliefs because this requires that the thickness of the top of the piston be increased to provide the necessary strength. The thicker the top of the piston, the lower down from the top of the top piston ring. To reduce unburned hydrocarbon (HC) exhaust emissions, engineers attempt to place the top piston ring as close to the top of the piston as possible to prevent the unburned fuel from being trapped (and not burned) between the top of the piston and the top of the top piston ring.

Recesses machined or cast into the tops of the pistons for valve clearance are commonly called **eyebrows, valve reliefs,** or **valve pockets.** The depth of the eyebrows has a major effect on the compression ratio and is necessary to provide clearance for the valves if the timing belt of an overhead camshaft engine should break. Without the eyebrows, the pistons could hit the valves near TDC if the valves are not operating (closing) because of nonrotation of the camshaft. If an engine is designed not to have the pistons hitting the valves, the engine is called freewheeling.

Figure 28–4 Piston head shapes: (a) flat (b) recessed, (c and d) pop-up, and (e and f) dished.

CAM GROUND PISTONS

Aluminum pistons expand when they get hot. A method of expansion control was devised using a **cam ground** piston skirt. With this design, the piston thrust surfaces closely fit the cylinder, and the piston pin boss diameter is fitted loosely. As the cam ground piston is heated, it expands along the piston pin so that it becomes nearly round at its normal operating temperatures. A cam ground piston skirt is illustrated in Figure 28–5. See Figure 28–6 for an example of how to measure the diameter of a piston.

PISTON FINISH

The finish on pistons varies with the manufacturer, but they all are designed to help reduce scuffing. Scuffing is a condition where the metal of the piston actually contacts the cylinder wall. When the piston stops at the top of the cylinder, welds or transfer of metal from one part to the other can take place. Scuffing can be reduced by coating the piston skirts with tin 0.0005 inch (0.0125 mm) thick or a moly graphite coating. See Figure 28–7.

PISTON HEAD SIZE

The top or head of the piston is smaller in diameter than the rest of the piston. The top of the piston is exposed to the most heat and therefore tends to expand more than the rest of the piston. See Figure 28–8. Most pistons have horizontal separation **slots** that act as **heat dams.** These slots reduce heat transfer from the hot piston head to the lower skirt. This, in turn, keeps the skirt temperature lower so that there will be less skirt expansion. Because the slot is placed in the oil ring groove, it can be used for oil drainback and expansion control.

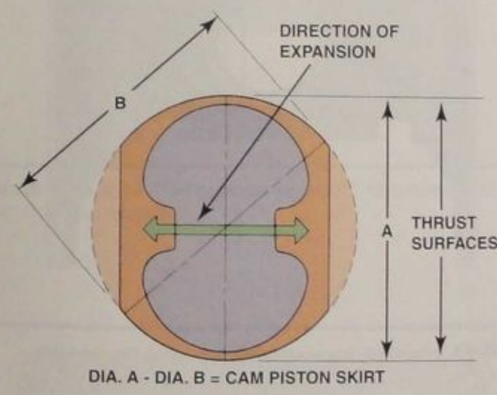


Figure 28–5 Piston cam shape. The largest diameter is across the thrust surfaces and perpendicular to the piston pin (lettered *A*).



Figure 28–6 A piston diameter is measured across the thrust surfaces.

PISTON STRUT INSERTS

A major development in expansion control occurred when the piston aluminum was cast around two stiff steel **struts.** The struts are not chemically bonded to the aluminum, nor do they add any strength to the piston. There is only a mechanical bond between the steel and aluminum. The bimetallic action of this strut in the aluminum forces the piston to bow outward



Figure 28–7 A moly graphite coating on the skirt of this piston from a General Motors 3800 V-6 engine helps prevent piston scuffing when the engine is cold.

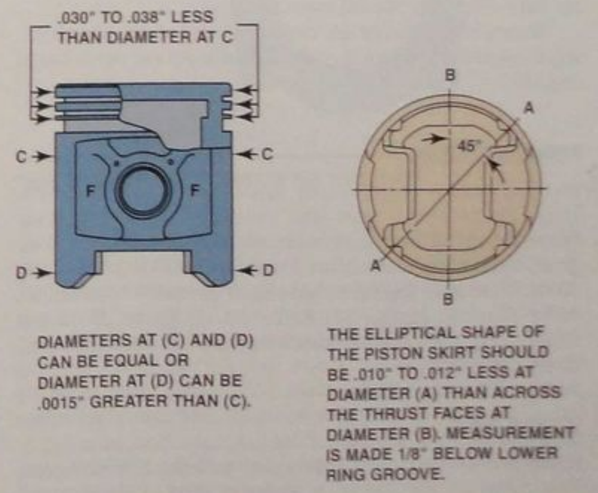


Figure 28–8 Piston skirt cam shape.



Figure 28–9 Steel struts cast inside pistons help control expansion.

along the piston pin. This keeps the piston skirt thrust surfaces from expanding more than the cast-iron cylinder in which the piston operates. Pistons with steel strut inserts allow good piston-to-cylinder wall clearance at normal temperatures. At the same time, they allow the cold operating clearance to be as small as 0.0005 inch (one-half thousandth of an inch) (0.0127 millimeter). This small clearance will prevent cold piston slap and noise. A typical piston expansion control strut is visible in Figure 28–9.

With newer engines, the number and thickness of the piston rings have decreased and the cast-aluminum piston skirt has been reduced to a minimum by using an open-type **slipper skirt.** Examples of the slipper skirt piston are shown in Figure 28–10.

HYPEREUTECTIC PISTONS

A standard cast-aluminum piston contains about 9% to 12% silicon and is called a eutectic piston. To add strength, the silicon content is increased to about 16%, and the resulting piston is called a **hypereutectic** piston. Other advantages of a hypereutectic piston are its 25% weight reduction and lower expansion rate. The disadvantage of hypereutectic pistons is their higher cost, because they are more difficult to cast and machine.

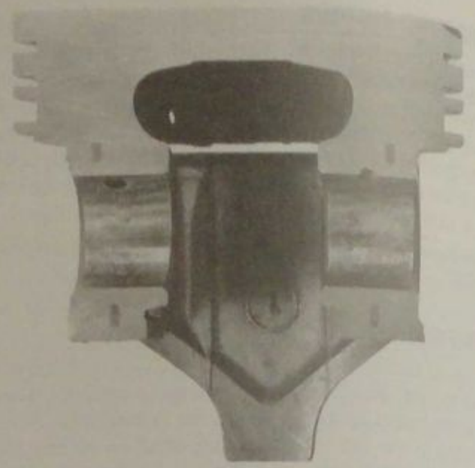
Hypereutectic pistons are commonly used in the aftermarket and as original equipment in many turbocharged and supercharged engines.

FORGED PISTONS

High-performance engines need pistons with added strength. Forged pistons have a dense grain structure and are very strong. Forged pistons are often used in turbocharged or supercharged engines. Because forged pistons are less porous than cast pistons, they conduct heat more quickly. Forged pistons generally run about 20% cooler than cast pistons. See Figure 28–11. Figure 28–12 is a forged heavy-duty truck aluminum piston, which shows the grain of the aluminum.

PISTON PINS

Piston pins are used to attach the piston to the connecting rod. Piston pins are also known as **gudgeon pins** (a British term). The piston pin transfers the force produced by combustion chamber pressures and piston inertia to the connecting rod. The


(a)

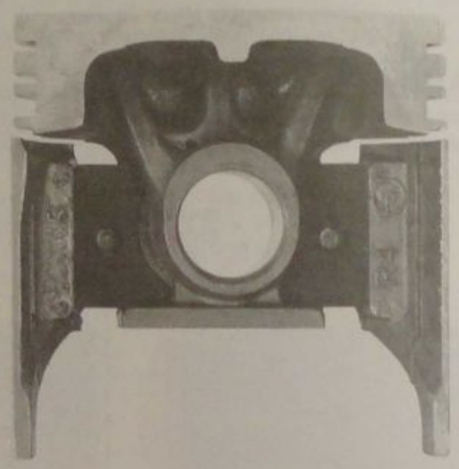

(b)

Figure 28–10 Two sectional views of a slipper-skirt-type piston that uses a steel expansion strut.

piston pin is made from high-quality steel in the shape of a tube to make it both strong and light. Sometimes, the interior hole of the piston pin is tapered, so it is large at the ends and small in the middle of the pin. This gives the pin strength that is proportional to the location of the load placed on it. A double-taper hole such as this is more expensive to manufacture, so it is used only where its weight advantage merits the extra cost. See Figure 28–13.

Piston Pin Offset The piston pin holes are not centered in the piston. They are located toward the **major thrust surface,** approximately 0.062 inch (1.57 millimeters) from the piston centerline, as shown in Figure 28–14.

Pin offset is designed to reduce piston slap and the noise that can result as the large end of the connecting rod crosses over top dead center.

The minor thrust side of the piston head has a greater area than does the major side. This is caused by the pin offset. As the piston moves up in the cylinder on the compression stroke, it rides against the minor thrust surface. When compression pressure becomes high enough, the greater head area on the minor side causes the

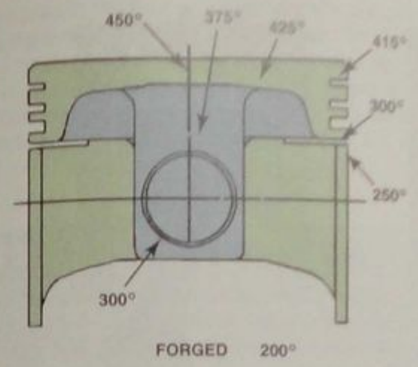


Figure 28–11 The critical crown temperature can be 100°F (38°C) cooler on a forged piston compared to a cast piston.

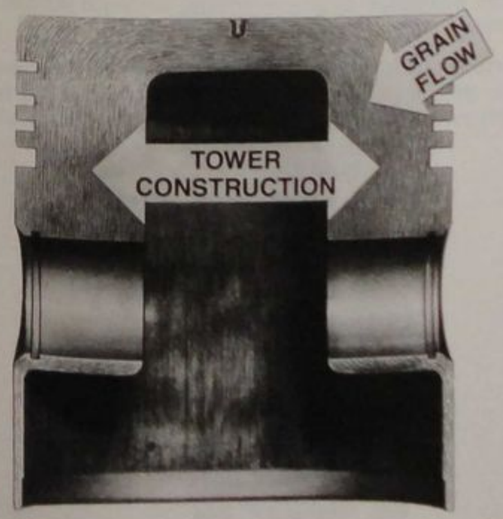


Figure 28–12 Grain flow lines can be seen in this forged aluminum piston with a trunk skirt.

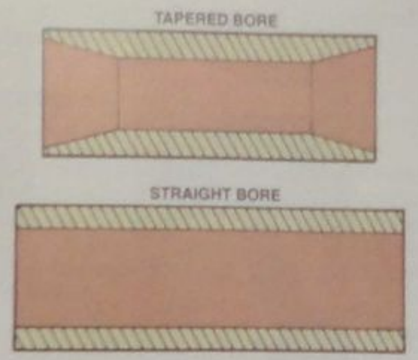


Figure 28–13 Most piston pins are hollow to reduce weight and have a straight bore. Some pins have a tapered bore to reinforce the pin.

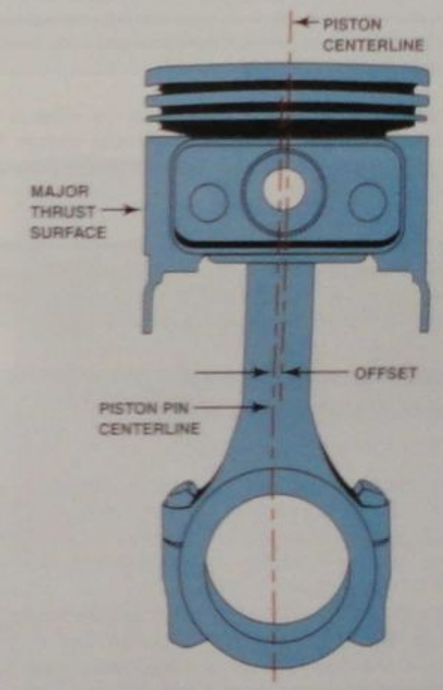


Figure 28–14 Piston pin offset toward the major thrust surface.

piston to cock slightly in the cylinder. This keeps the top of the minor thrust surface on the cylinder. It forces the bottom of the major thrust surface to contact the cylinder wall. As the piston approaches top center, both thrust surfaces are in contact with the cylinder wall. When the crankshaft crosses over top center, the force on the connecting rod moves the entire piston toward the major thrust surface. The lower portion of the major thrust surface has already been in contact with the cylinder wall. The rest of the piston skirt slips into full contact just after the crossover point, thereby controlling piston slap. This action is illustrated in Figure 28–15.

Offsetting the piston toward the minor thrust surface would provide a better mechanical advantage. It also would cause less

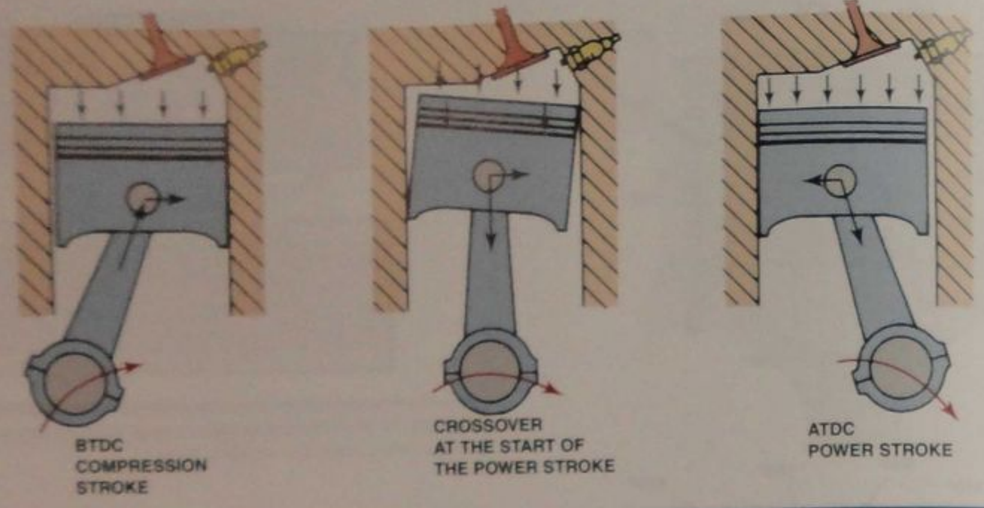


Figure 28–15 Engine rotation and rod angle during the power stroke causes the piston to press harder against one side of the cylinder, which is called the major thrust surface.

piston-to-cylinder friction. For these reasons, the offset is often placed toward the minor thrust surface in racing engines. Noise and durability are not as important in racing engines as is maximum performance.

NOTE: Not all piston pins are offset. In fact, many engines operate without the offset to help reduce friction and improve power and fuel economy.

FREQUENTLY ASKED QUESTION ???

Which Side Is the Major Thrust Side?

The thrust side is the side the rod points to when the piston is on the power stroke. Any V-block engine (V-6 or V-8) that rotates clockwise is viewed from the front of the engine—the left bank piston thrust side faces the inside (center) of the engine. The right bank piston thrust side faces the outside of the block. This rule is called the **left-hand rule** and states:

- Stand at the rear of the engine and point toward the front of the engine.
- Raise your thumb straight up, indicating the top of the engine.
- Point your middle finger toward the right. This represents the major thrust side of the piston.

Always assemble the connecting rods onto the rods so that the notch or "F" on the piston is pointing toward the front of the engine and the oil squirt hole on the connecting rod is pointing toward the major thrust side with your left hand.

Piston Pin Fit The finish and size of piston pins are closely controlled. Piston pins have a smooth mirrorlike finish. Their size is held to tens of thousandths of an inch so that exact fits can be maintained. If the piston pin is loose in the piston or in the connecting rod, it will make a sound while the engine is running. This is often described as a **double knock.** The noise is created when the piston stops at top dead center and occurs again as it starts to move downward, creating a double-knock sound, which is also described as a rattling sound. If the piston pin is too tight in the piston, it will restrict piston expansion along the pin diameter. This will lead to piston scuffing. Normal piston pin clearances range from 0.0005 to 0.0007 inch (0.012 to 0.0180 millimeter).

PISTON PIN RETAINING METHODS

Full Floating It is necessary to retain or hold piston pins so that they stay centered in the piston. If piston pins are not retained, they will move endwise and groove the cylinder wall. The piston pin may be **full floating,** with some type of stop located at each end.

Full-floating piston pins in automotive engines are retained by **lock rings** located in grooves in the piston pin hole at the ends of the piston pin. See Figure 28–16. Some engines use aluminum or plastic plugs in both ends of the piston pin. These plugs touch the cylinder wall without scoring, to hold the piston pin centered in the piston.

Interference Fit The modern method of retaining the piston pin in the connecting rod is to make the connecting rod hole slightly smaller than the piston pin. The pin is installed by heating the rod to expand the hole or by pressing the pin into the rod. This retaining method will securely hold the pin. See Figure 28–17. This press or shrink fit is called an **interference fit.** Care must be taken to have the correct hole sizes, and the pin must be centered in the connecting rod. The interference fit method is the least expensive to use. It is, therefore, used in the majority of engines.

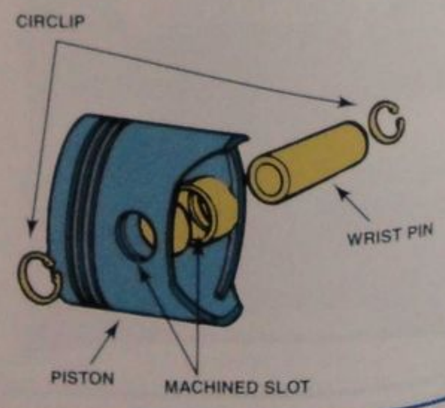


Figure 28–16 Circlips hold full-floating piston pins in place.

REAL-WORLD FIX **Big Problem, No Noise**

Sometimes the piston pin can "walk" off the center of the piston and score the cylinder wall. This scoring is often not noticed because this type of wear does not create noise. Because the piston pin is below the piston rings, little combustion pressure is lost past the rings until the groove worn by the piston pin has worn the piston rings.

Troubleshooting the exact cause of the increased oil consumption is difficult because the damage done to the oil control rings by the groove usually affects only one cylinder.

Often, compression tests indicate good compression because the cylinder seals, especially at the top. More than one technician has been surprised to see the cylinder gouged by a piston pin when the cylinder head has been removed for service. In such a case, the cost of the engine repair immediately increases far beyond that of normal cylinder head service.

PISTON RING GROOVES

Piston ring **grooves** are located between the piston head and skirt. The width of the grooves, the width of the **lands** between the ring grooves, and the number of rings are major factors in determining minimum piston height. The outside diameter of the lands is about 0.020 to 0.040 inch (0.5 to 1.0 millimeter) smaller than the **skirt** diameter.

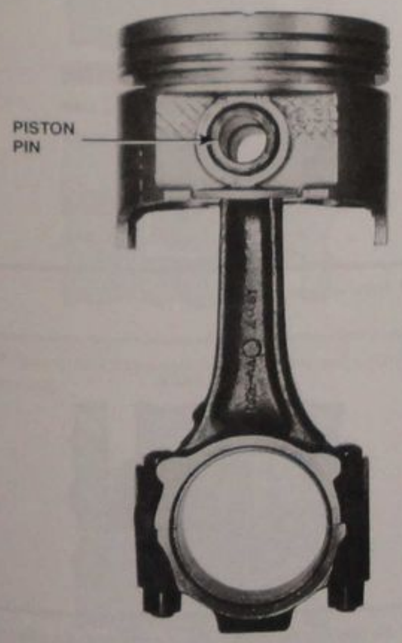


Figure 28–17 Interference fit type of piston pin.

PISTON RINGS

Piston rings serve several major functions in engines.

- They form a sliding combustion chamber seal that prevents the high-pressure combustion gases from leaking past the piston.
- They keep engine oil from getting into the combustion chamber.
- The rings transfer some of the piston heat to the cylinder wall, where it is removed from the engine through the cooling system. See Figure 28–18.

Piston rings are classified into two types: two **compression rings,** located toward the top of the piston, and one **oil control ring,** located below the compression rings. See Figure 28–19.

NOTE: Some engines, such as the Honda high-fuel-economy engines, use pistons with only two rings: one compression ring and one oil control ring.

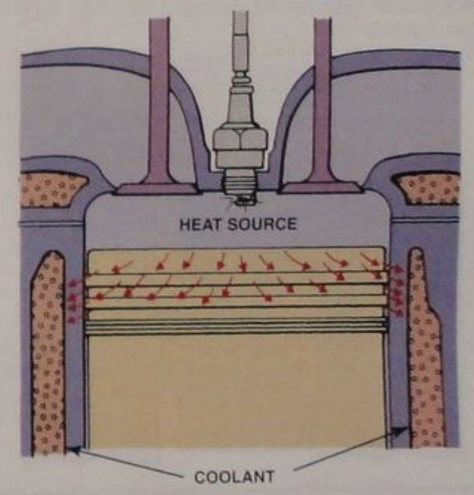


Figure 28–18 The rings conduct heat from the piston to the cylinder wall.

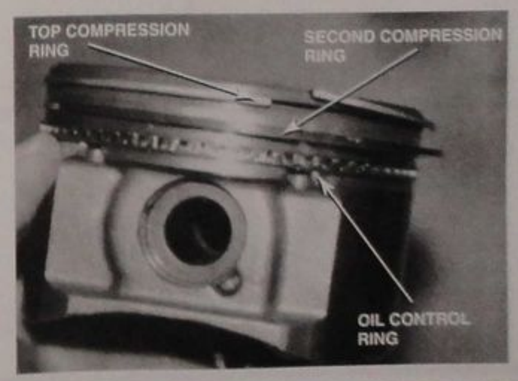


Figure 28–19 Most pistons use two compression rings and one oil control ring.

The first piston rings were made with a simple rectangular cross-section. This cross-section was modified with tapers, chamfers, counterbores, slots, rails, and expanders. Piston ring materials have also changed from plain cast iron to materials such as pearlitic and nodular iron, as well as steel. **Ductile iron,** which is very flexible and can be twisted without breaking, is also used as a piston ring material in some automotive engines.

COMPRESSION RINGS

A compression ring is designed to form a seal between the moving piston and the cylinder wall. This is necessary to get maximum power from the combustion pressure. At the same time, the compression ring must keep friction at a minimum. This is made possible by providing only enough static or built-in mechanical tension to hold the ring in contact with the cylinder wall during the intake stroke. Combustion chamber pressure during the compression, power, and exhaust strokes is applied to the top and back of the ring. This pressure will add the force on the ring that is required to seal the combustion chamber during these strokes. Figure 28–20 illustrates how the combustion chamber pressure adds force to the ring.

The space in the ring groove above the ring is called the **side clearance** and the space behind the ring is called the **back clearance.** See Figure 28–21.

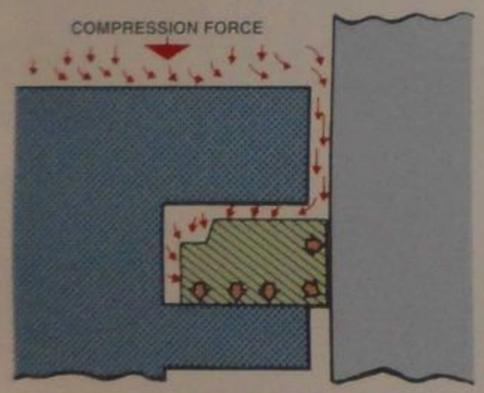


Figure 28–20 Combustion chamber pressure forces the ring against the cylinder wall and the bottom of the ring groove, effectively sealing the cylinder.

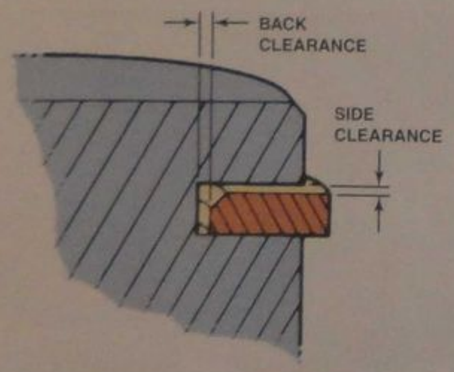


Figure 28–21 The side and back clearances must be correct for the compression rings to seal properly.

Ring Gap The piston **ring gap** will allow some leakage past the top compression ring. This leakage is useful in providing pressure on the second ring to develop a dynamic sealing force. The amount of piston ring gap is critical. Too much gap will allow excessive **blowby.** Blowby is the leakage of combustion gases past the rings. Blowby will blow oil from the cylinder wall. This oil loss is followed by piston ring scuffing. Too little gap, however, will allow the piston ring ends to butt when the engine is hot. Ring end butting increases the mechanical force against the cylinder wall, causing excessive wear and possible engine failure.

A butt-type piston ring gap is the most common type used in automotive engines. Some low-speed industrial engines and some diesel engines use a more expensive tapered or seal-cut ring gap. These gaps are necessary to reduce losses of the high-pressure combustion gases. At low speeds, the gases have more time to leak through the gap. Typical ring gaps are illustrated in Figure 28–22.

Piston Ring Cross-Sections As engine speeds have increased, inertia forces on the piston rings have also increased. As a result, engine manufacturers have found it desirable to reduce inertia forces on the rings by reducing their weight. This has been done by narrowing the piston ring from 1/4 inch (6 millimeters) to as little as 1/16 inch (1.6 millimeters).

A **taper face ring** will contact the cylinder wall at the lower edge of the piston ring. See Figure 28–23. When either a chamfer or counterbore relief is made on the *upper inside* corner of the piston ring, the ring cross-section is unbalanced. This will cause the ring to twist in the groove in a positive direction. **Positive twist** will give the same wall contact as the taper-faced ring. It will also provide a

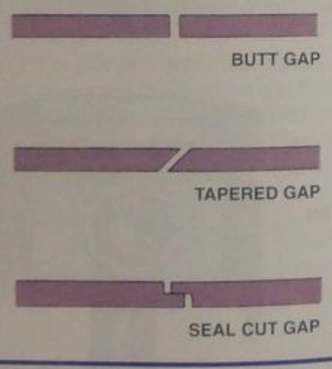


Figure 28–22 Typical ring gaps.

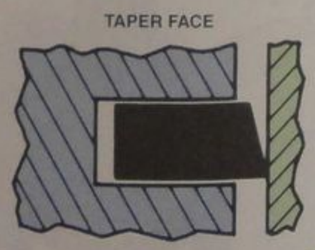


Figure 28–23 The taper face ring provides good oil control by scraping the cylinder wall. This style of ring must be installed right side up or the ring will not seal and oil will be drawn into the combustion chamber.

line contact seal on the bottom side of the groove. Sometimes, twist and a taper face are used on the same compression ring.

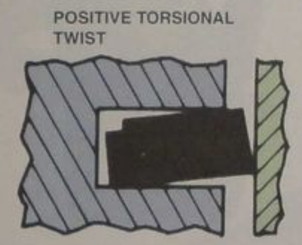
Some second rings are notched on the *outer lower* corner. This, too, provides a positive ring twist. The sharp lower outer corner becomes a scraper that helps in oil control, but this type of ring has less compression control than the preceding types.

By chamfering the ring's *lower inner* corner, a **reverse twist** is produced. This seals the lower outer section of the ring and piston ring groove, thus improving oil control. Reverse twist rings require a greater taper face or barrel face to maintain the desired ring face-to-cylinder wall contact. See Figure 28–24.

Another style of positive twist ring has a counterbore at the lower outside edge. See Figure 28–25. This ring is called a **scraper ring** because it does a good job of oil control and is usually recommended for use at the second compression ring.

Some rings replace the outer ring taper with a barrel face. The barrel is 0.0003 inch per 0.100 inch (0.0076 millimeter per 0.254 millimeter) of piston ring width. Barrel faces are found on rectangular rings and on torsionally twisted rings. See Figure 28–26.

Chromium Piston Rings A chromium facing on cast-iron rings greatly increases piston ring life, especially where abrasive materials are present in the air. During manufacture, the chromium-plated ring is slightly chamfered at the outer corners. About 0.0004 inch (0.010 millimeter) of chrome is then plated on the ring face. Chromium-faced rings are then prelapped or honed before they are packaged and shipped to the customer. The finished chromium facing is shown in a sectional view in Figure 28–27.



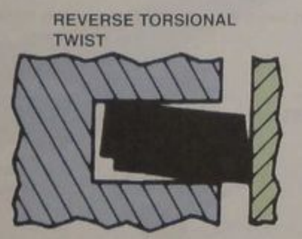


Figure 28–24 Torsional twist rings provide better compression sealing and oil control than regular taper face rings.

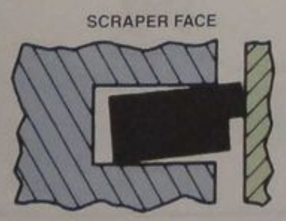


Figure 28–25 Scraper rings improve oil control.

Molybdenum Piston Rings Early in the 1960s, molybdenum piston ring faces were introduced. These rings proved to have good service life, especially under scuffing conditions. The plasma method is a spray method used to deposit molybdenum on cast iron to produce a long-wearing and low-friction piston ring. The plasma method involves an electric arc plasma (ionized gas) that generates an extremely high temperature to melt the molybdenum and spray-deposit a molten powder of it onto a piston ring. Therefore, plasma rings are molybdenum (moly) rings that have the moly coating applied by the plasma method. Most molybdenum-faced piston rings have a groove that is 0.004- to 0.008-inch (0.1- to 0.2-millimeter) deep cut into the ring face. This groove is filled with molybdenum, using a metallic (or plasma) spray method, so that there is a cast-iron edge above and below the molybdenum. This edge may be chamfered in some applications. A sectional view of a molybdenum-faced ring is shown in Figure 28–28.

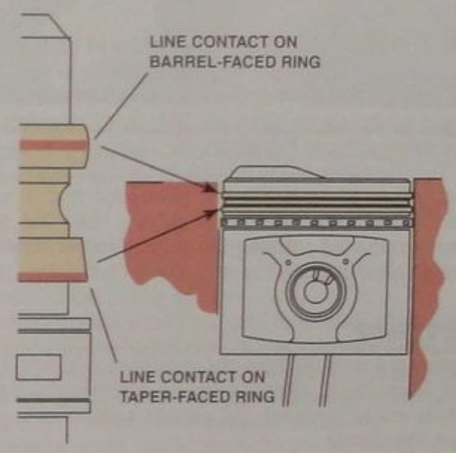


Figure 28–26 The piston rings are slightly used, so only the line contact shows. The upper, barrel-faced ring has line contact in the center. The second, taper-faced ring has line contact along the lower edge of the ring.

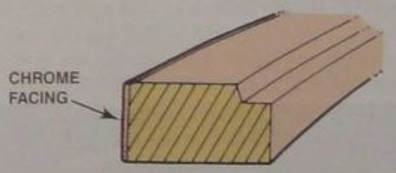


Figure 28–27 The chrome facing on this compression ring is about 0.004-inch (0.10-mm) thick.

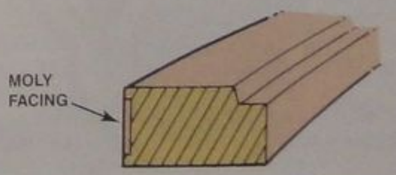


Figure 28–28 The moly facing on this compression ring is about 0.005-inch (0.13-mm) thick.

Molybdenum-faced piston rings will survive under high-temperature and scuffing conditions better than chromium-faced rings. Under abrasive wear conditions, chromium-faced rings will have a better service life. There is little measurable difference between these two facing materials with respect to blowby, oil control, break-in, and horsepower. Piston rings with either of these two types of facings are far better than plain cast-iron rings with phosphorus coatings. A molybdenum-faced ring, when used, will be found in the top groove, and a plain cast-iron or chromium-faced ring will be found in the second groove.

Moly-Chrome-Carbide Rings Rings with moly-chrome-carbide coating are also used in some original equipment (OE) and replacement applications. The coating has properties that include the hardness of the chrome and carbide combined with the heat resistance of molybdenum. Ceramic-coated rings are also being used where additional heat resistance is needed, such as in some heavy-duty, turbocharged, or supercharged engines.

Oil Control Rings The scraping action of the oil control ring allows oil to return through the ring and openings in the piston. Figure 28–29 shows how the scraping action of the oil control ring can be used to lubricate the piston pin. Steel spring expanders were placed in the ring groove behind the ring to improve static radial tension. They forced the ring to conform to the cylinder wall. Many expander designs are used. On the three-piece ring, a spacer-expander lies between the top and bottom rails. The spacer-expander keeps the rails separated and pushes them out against the cylinder wall. See Figure 28–30.

PISTON SERVICE

The pistons are removed from the rods using a special fixture shown in Figure 28–31. After cleaning, the skirts of the used industrial pistons should be resized, and a spacer is placed in the top of the upper ring grooves.

As the piston goes rapidly up and down in the cylinder, it tosses the rings to the top and to the bottom of the ring grooves. The pounding of each ring in its groove gradually increases the piston ring side clearance. Material is worn from both the ring and the groove. See Figure 28–32. Replace the piston if the ring groove is larger than factory specifications.

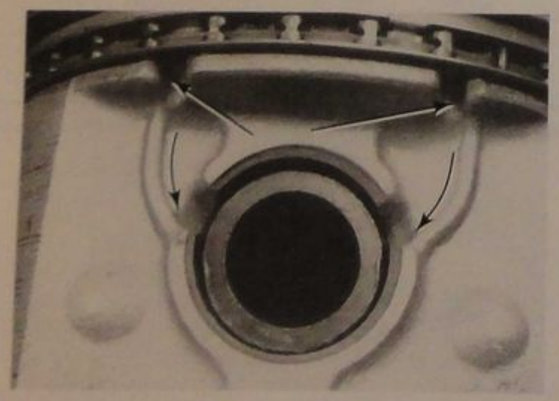


Figure 28–29 The oil scraped from the cylinder walls by the oil control ring is directed to lubricate the piston pin in this design.

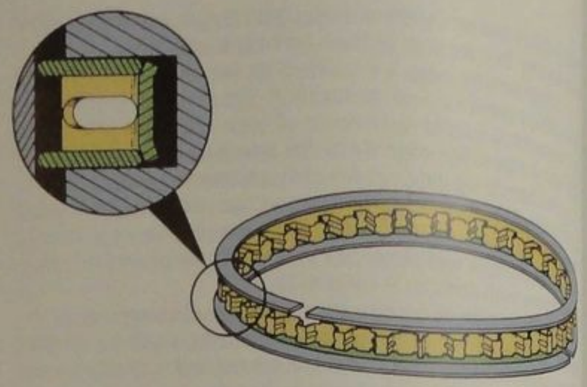


Figure 28–30 This typical three-piece oil control ring uses a hump-type stainless steel spacer-expander. The expander separates the two steel rails and presses them against the cylinder wall.



Figure 28–31 A press used to remove the connecting rod from the piston.

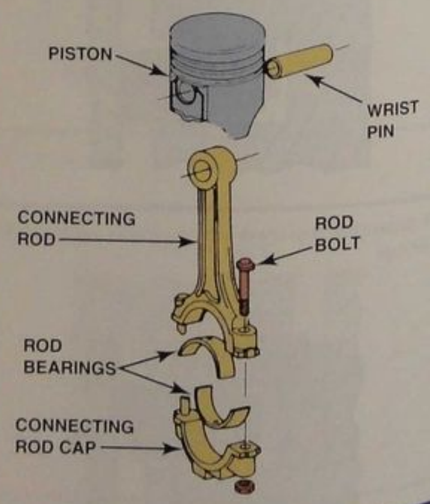


Figure 28–32 The connecting rod is the most highly stressed part of any engine because combustion pressure tries to compress it and piston inertia tries to pull it apart.

CONNECTING RODS

The connecting rod transfers the force and reciprocating motion of the piston to the crankshaft. The small end of the connecting rod reciprocates with the piston. The large end rotates with the crankpin. See Figure 28–32. These dynamic motions make it desirable to keep the connecting rod as light as possible while still having a rigid beam section. See Figure 28–33.

Connecting rods are manufactured by casting, forging, and powdered (sintered) metal processes.

Cast Connecting Rods Casting materials and processes have been improved so that they are used in most vehicle engines with high production standards. Cast connecting rods can be identified by their *narrow parting line.* A typical rough connecting rod casting is shown in Figure 28–34.

Forged Connecting Rods Forged connecting rods have been used for years. They are generally used in heavy-duty and high-performance engines. Generally, the forging method produces lighter weight and stronger, but more expensive, connecting rods. Forged connecting rods can be identified by their *wide parting line.* Many high-performance connecting rods use a bronze bushing in the small end of the rod as shown in Figure 28–35.

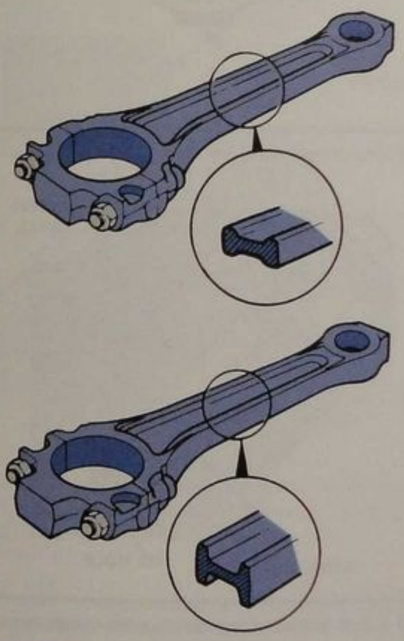


Figure 28–33 Even though different rods may have different cross-sections, most are I-beam shaped.



Figure 28–34 Rough casting for a connecting rod.



Figure 28–35 This high-performance connecting rod uses a bronze bushing in the small end of the rod and oil hole to allow oil to reach the full-floating piston pin.

Powdered Metal Connecting Rods Most new production engines, such as the General Motors Northstar and Chrysler Hemi, use powdered metal (PM) rods.

Powdered metal connecting rods have many advantages over conventional cast or forged rods including precise weight control. Each rod is created using a measured amount of material so that rod balancing, and therefore engine balancing, is now achieved without extra weighting and machining operations.

Powdered metal connecting rods start as powdered metal, which includes iron, copper, carbon, and other alloying agents. This powder is then placed in a die and compacted (forged) under a pressure of 30 to 50 tons per square inch. After the part is shaped in the die, it is taken through a sintering operation where the part is heated, without melting, to about 2000°F. During the sintering process, the ingredients are transformed into metallurgical bonds, giving the part strength. Machining is very limited and includes boring the small and big ends and drilling the holes for the rod bearing cap retaining bolts. The big end is then fractured using a large press. The uneven parting line helps ensure a perfect match when the pieces are assembled. See Figure 28–36.

CONNECTING ROD DESIGN

The big end of the connecting rod must be a perfect circle. Therefore, the rod caps must not be interchanged. Assembly bolt holes are closely reamed in both the cap and connecting rod to ensure alignment. The connecting rod bolts have **piloting surfaces** that closely fit these reamed holes. The fit of the connecting rod bolts is so tight that a press must be used to remove the bolts when they are to be replaced, as shown in Figure 28–37.

In some engines, offset connecting rods provide the most economical distribution of main bearing space and crankshaft cheek clearance.

Connecting rods are made with **balancing bosses (pads)** so that their weight can be adjusted to specifications. Some have balancing bosses only on the rod cap. Others also have a balancing



Figure 28–36 Powdered metal connecting rods feature a fractured parting line at the big end of the rod.

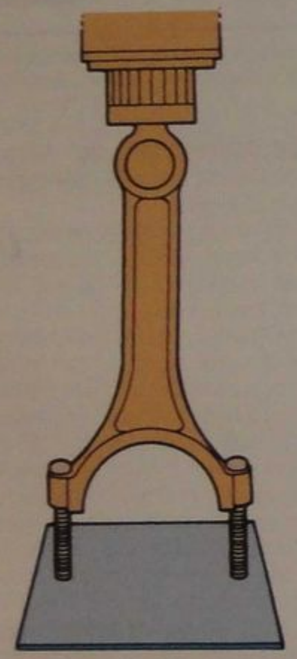


Figure 28–37 Rod bolts are quickly removed by using a press.

boss above the piston. Some manufacturers put balancing bosses on the side of the rod, near the center of gravity of the connecting rod. Typical balancing bosses can be seen in Figure 28–38. Balancing is done on automatic balancing machines as the final machining operation before the rod is installed in an engine.

Most connecting rods have a **spit hole** that bleeds some of the oil from the connecting rod journal. See Figure 28–39. On inline engines, oil is thrown up from the spit hole into the cylinder in which the rod is located. On V-type engines, it is often thrown into a cylinder in the opposite bank. The oil that is spit from the rod is aimed so that it will splash into the interior of the piston. This helps to lubricate the piston pin. A hole similar to the spit holes may be

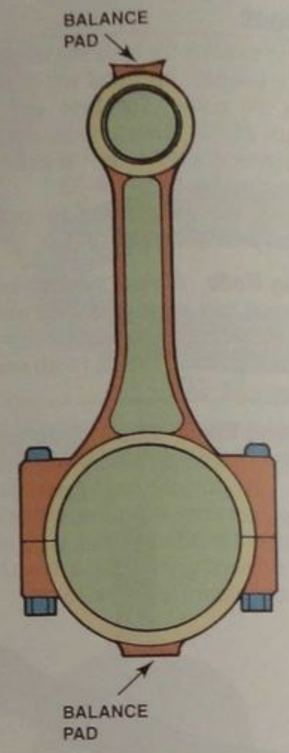


Figure 28–38 Some rods have balance pads on each end of the connecting rod.

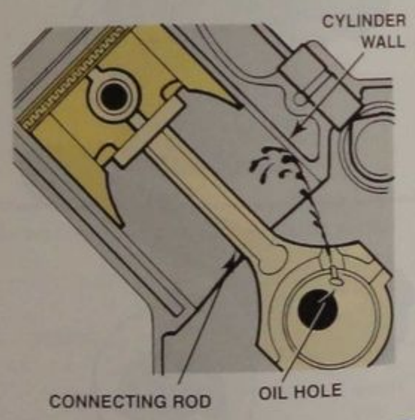


Figure 28–39 Some connecting rods have spit holes to help lubricate the cylinder wall and piston pins.

used. It is called a **bleed hole.** Its only purpose is to control the oil flow through the bearing.

ROD TWIST

During connecting rod reconditioning, the rod should be checked for twist. See Figure 28–40. In other words, the hole at the small end and the hole at the big end of the connecting rod should be parallel. No more than 0.002-inch (0.05-millimeter) twist is acceptable. See Figure 28–41 for the fixture used to check connecting rods for twist. If measured rod twist is excessive, some specialty shops can remove the twist by bending the rod cold. Both cast and

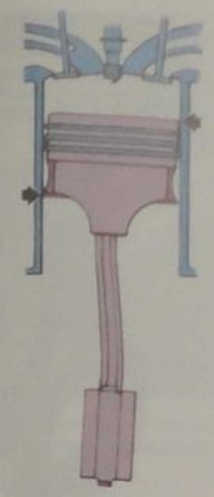


Figure 28–40 If the rod is twisted, it will cause diagonal-type wear on the piston skirt.

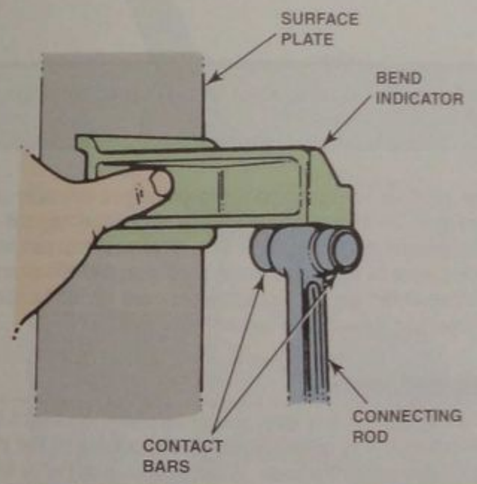


Figure 28–41 A rod alignment fixture being used to check a connecting rod to see if it is bent or twisted.

forged rods can be straightened. However, many engine builders replace the connecting rod if it is twisted.

CONNECTING ROD SERVICE

As an engine operates, the forces go through the large end of the connecting rod. This causes the crankshaft end opening of the rod (eye) to gradually deform. See Figure 28–42. The large eye of the connecting rod is resized during precision engine service.

Step #1 The parting surfaces of the rod and cap are smoothed to remove all high spots before resizing. A couple of thousandths of an inch of metal is removed from the rod cap parting surface. This is done using the same grinder that is used to remove a slight amount of metal from the parting surface of main bearing caps. The amount removed from the rod and rodcap only reduces the bore size 0.003 to 0.006 inch (0.08 to 0.15 millimeter).

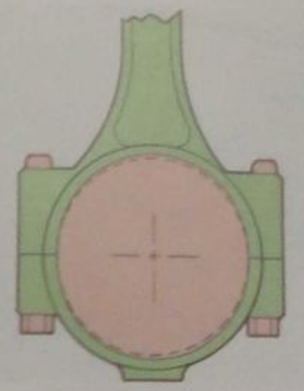


Figure 28–42 Rod bearing bores normally stretch from the top to the bottom, with most wear concentrated on the cap.



Figure 28–43 Resizing the big end of the connection rod with a hone. To help ensure a more accurate and straighter job, hone two connecting rods at a time.

NOTE: Powdered metal connecting rods cannot be reconditioned using this method. Most manufacturers recommend replacing worn powdered metal connecting rods.

Step #2 The cap is installed on the rod, and the nuts or cap screws are properly torqued. The hole is then bored or honed to be perfectly round and of the size and finish required to give the correct connecting rod bearing crush. Figure 28–43 shows the setup for resizing the rod on a typical hone used in engine reconditioning.

Even though material is being removed at the big end of the rod, the compression ratio is changed very little. The inside of the bore at the big end should have a 60- to 90-microinch finish for proper bearing contact and heat transfer.

PISTON AND ROD ASSEMBLY

To assemble the piston and rod, the piston pin is put in one side of the piston. The small end of the connecting rod should be checked for proper size. The small eye of the connecting rod is heated before the pin is installed. See Figure 28–44. This causes the rod eye to expand so that the pin can be pushed into place with little force. The pin must be rapidly pushed into the correct center position.



(a)



(b)

Figure 28–44 (a) Flame-type connecting rod heater; the type most often used by remanufacturers because of the rapid heating. The rod should not be heated to more than 700°F (370°C). (If the rod turns blue, it is too hot.) (b) An operator removing the heated connecting rod and preparing to install it on the piston. Note the fixture used to hold the piston pin, and the dial indicator (gauge) used to ensure proper positioning.

There is only one chance to get it in the right place because the rod will quickly seize on the pin as the rod eye is cooled by the pin.

Full-floating piston pins operate in a bushing in the small eye of the connecting rod. The bushing can be replaced. The bushing and the piston are honed to the same diameter. This allows the piston pin to slide freely through both. The full-floating piston pin is held in place with a lock ring at each end of the piston pin. The lock ring expands into a small groove in the pin hole of the piston.

NOTE: The lock rings should always be replaced with new rings.

Care must be taken to ensure that the pistons and rods are in the correct cylinder. They must face in the correct direction. There is usually a **notch** on the piston head indicating the *front*. Using this will correctly position the piston pin offset toward the right side of the engine. The connecting rod **identification marks** on pushrod inline engines are normally placed on the camshaft side.



Figure 28–45 Position of the notch at the front of the piston, and the connecting rod numbers.

NOTE: The camshaft side of an inline OHV engine is also the oil filter side of most engines.

The notch and numbers on a piston and rod assembly can be seen in Figure 28–45. On V-type engines, the connecting rod cylinder identification marks are on the side of the rods that can be seen from the bottom of the engine when the piston and rod assemblies are installed in the engine. The service manual should be checked for any special piston and rod assembly instructions.

PISTON RING SERVICE

Each piston ring, one at a time, should be placed backward in the groove in which it is to be run. Its side clearance in the groove should be checked with a feeler gauge, as shown in Figure 28–46. If a ring is tight at any spot, check for deposits or burrs in the ring groove. Each piston ring, one at a time, is then placed in the cylinder in which it is to operate.

After the block and cylinder bores have been reconditioned, invert the piston and push each ring into the lower quarter of the cylinder; then measure the ring gap. See Figure 28–47. It should be approximately 0.004 inch for each inch of bore diameter (0.004 millimeter for each centimeter of bore diameter). If necessary, use a file or hand-operated piston ring grinder to achieve the necessary ring gap. See Figure 28–48.

The oil rings are installed first. The expander-spacer of the oil ring is placed in the lower ring groove. One oil ring rail is carefully placed above the expander-spacer by winding it into the groove. The other rail is placed below the expander-spacer. The ring should be rotated in the groove to ensure that the expander-spacer ends have not overlapped. If they have, the ring must be removed and reassembled correctly.

Installing the compression rings requires the use of a piston ring expander tool that will only open the ring gap enough to slip the ring on the piston. See Figure 28–49. Be careful to



Figure 28–46 The side clearance of the piston ring is checked with a thickness (feeler) gauge.

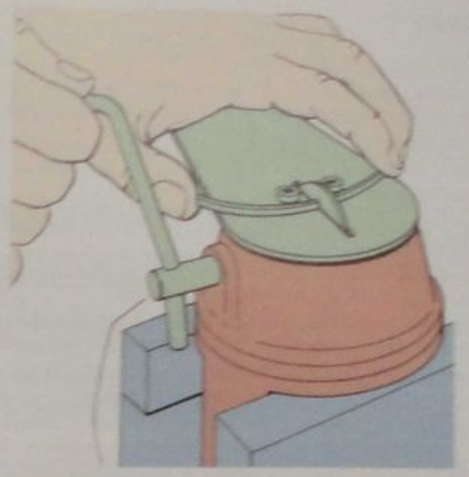


Figure 28–48 A hand-operated piston ring end gap grinder being used to increase the end gap of a piston ring in order to bring it to within factory specifications before installation on the piston.

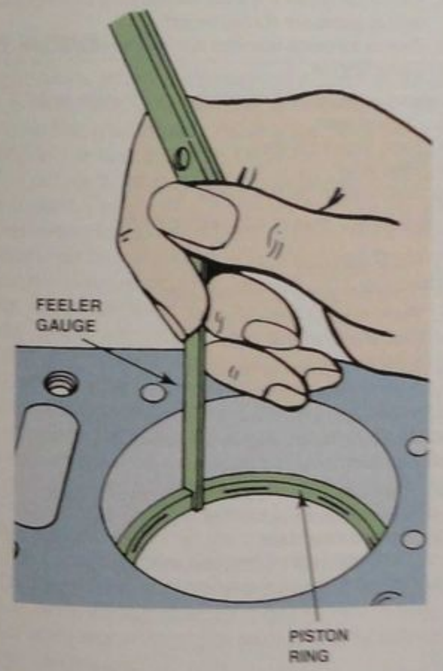


Figure 28–47 The ring gap is measured with a feeler gauge.

install the ring with the correct side up. The top of the compression ring is marked with a dot, the letter *T*, or the word *top*. See Figure 28–50. After the rings are installed, they should be rotated in the groove to ensure that they move freely, and checked to ensure that they will go fully into the groove so that the ring face is flush with the surface of the piston ring lands. Usually, the rings are placed on all pistons before any pistons are installed in the cylinders.



Figure 28–49 A typical ring expander being used to install a piston ring.



Figure 28–50 Identification marks used to indicate the side of the piston ring to be placed toward the head.

SUMMARY

1. The connecting rods should be marked before disassembly.
2. Pistons are cam ground so that when operating temperature is reached, the piston will have expanded enough across the piston pin area to become round.
3. Replacement pistons should weigh the same as the original pistons to maintain proper engine balance.
4. Some engines use an offset piston pin to help reduce piston slap when the engine is cold.
5. Piston rings usually include two compression rings at the top of the piston and an oil control ring below the compression rings.
6. If the ring end gap is excessive, blowby gases can travel past the rings and into the crankcase.
7. Many piston rings are made of coated cast iron to provide proper sealing.
8. If the connecting rod is twisted, diagonal wear will be noticed on the piston skirt.
9. Powdered metal connecting rods are usually broken at the big end parting line. Because of this rough junction, powdered metal connecting rods cannot be reconditioned—they must be replaced if damaged or worn.
10. The piston and the connecting rod must be correctly assembled according to identifying notches or marks.

REVIEW QUESTIONS

1. Describe the procedure for correctly removing the piston and rod assembly from the engine.
2. What methods are used to control piston heat expansion?
3. Why are some piston skirts tin plated?
4. Describe the effect of the piston pin offset as it controls piston slap.
5. Why is it important to keep the connecting rod cap with the rod on which it was originally used, and to install it in the correct way?
6. What causes the piston ring groove clearance to widen in service?
7. Describe how connecting rods are reconditioned.
8. How is the piston pin installed in the piston and rod assembly?

CHAPTER QUIZ

1. Connecting rod caps should be marked (if they were not marked at the factory) before the piston and connecting rod assembly is removed from the engine _____.
   a. Because they are balanced together
   b. Because they are machined together
   c. To make certain that the heavier rod is matched to the heavier piston
   d. To make certain that the lighter rod is matched to the lighter piston
2. Many aluminum piston skirts are plated with _____.
   a. Tin
   b. Lead
   c. Antimony
   d. Terneplate
3. A hypereutectic piston has _____.
   a. A higher weight than a eutectic piston
   b. A higher silicon content
   c. A higher tin content
   d. A higher nickel content
4. The purpose of casting steel struts into an aluminum piston is to _____.
   a. Provide increased strength
   b. Provide increased weight at the top part of the piston where it is needed for stability
   c. Provide increased heat transfer from the piston head to the piston pin
   d. Control thermal expansion
5. Full-floating piston pins are retained by _____.
   a. Lock rings
   b. A drilled hole with roll pin
   c. An interference fit between rod and piston pin
   d. An interference fit between piston and piston pin
6. When balancing pistons _____.
   a. Choose the heaviest and add weight to the others
   b. Choose the heaviest and grind weight off until it matches the *average* of all the others
   c. Choose the lightest and grind material from the other pistons until all pistons are of equal weight
   d. Balance the piston only after it is assembled with the connecting rod
7. A misaligned connecting rod causes what type of engine wear?
   a. Cylinder taper
   b. Barrel-shaped cylinders
   c. Ridge wear
   d. Angle wear on the piston skirt
8. Side clearance is a measure taken between the _____ and the _____.
   a. Piston (side skirt); cylinder wall
   b. Piston pin; piston pin retainer (clip)
   c. Piston ring; piston ring groove
   d. Compression ring; oil control ring
9. Piston ring gap should only be measured _____.
   a. After all cylinder work has been performed
   b. After installing the piston in the cylinder
   c. After installing the rings on the piston
   d. Both a and c
10. Piston damage is most likely to be caused by _____.
    a. Valves hitting the piston head
    b. Abnormal combustion
    c. Lugging the engine during operation
    d. High engine speeds that can break piston heads

CHAPTER 29

Engine Blocks, Crankshafts, and Bearings

OBJECTIVES: After studying Chapter 29, the reader will be able to: Prepare for Engine Repair (A1) ASE certification test content area "C" (Engine Block Diagnosis and Repair). • Describe the types of engine blocks and how they are manufactured. • List the machining operations required on most engine blocks. • List the steps necessary to prepare an engine block for assembly. • Describe the purpose and function of a crankshaft. • Explain how crankshafts are machined and polished. • Discuss engine bearing construction and installation procedures.

KEY TERMS: aluminum • amplitude • Babbitt • ball-type deglazing hone • bank • bearing crown • bearing shell • bedplate • block deck • bores • case hardening • compacted graphite iron (CGI) • conformability • cooling jacket • copper-lead alloy • core plugs • corrosion resistance • counterweights • crankshaft centerline • crosshatch finish • crush • decking the block • deglazing hone • dry cylinder sleeve • elastomer • electroplating • embedability • fatigue life • flying web • freeze plugs • frequency • frost plugs • full round bearings • fully counterweighted • grit size • half-shell bearings • hub • inertia ring • left-hand dipstick • monoblock • nitriding • oil gallery • oil gallery plugs • overlay • plain bearing • plateau hone • precision insert-type bearing shells • rebore • resonate • saddles • score resistance • Siamese cylinder bores • sizing hone • sleeve bearing • sleeving • splay angle • split-type bearings • spread • spun bearing • tuftriding • wet cylinder sleeve • work hardened

ENGINE BLOCKS

The engine block, which is the supporting structure for the entire engine, is made from gray cast iron or from cast or die-cast aluminum alloy. The gray color is a result of the 3% carbon in the form of graphite in the cast iron. The liquid cast iron is poured into a mold. The carbon in the cast iron allows for easy machining, often without coolant. The graphite in the cast iron also has lubricating properties. Newer blocks use thinner walls to reduce weight. Cast iron is strong for its weight and usually is magnetic. All other engine parts are mounted on or in the block. This large casting supports the crankshaft and camshaft and holds all the parts in alignment. Blocks are often of the **monoblock** design, which means that the cylinder, water jacket, main bearing supports (saddles), and oil passages are all cast as one structure for strength and quietness. Large-diameter holes in the block casting form the cylinders to guide the pistons. The cylinder holes are called **bores** because they are made by a machining process called *boring*. Combustion pressure loads are carried from the head to the crankshaft bearings through the block structure. The block has webs, walls, and drilled passages to contain the coolant and lubricating oil and to keep them separated from each other. See Figure 29–1. Mounting pads or lugs on the block transfer the engine torque reaction to the vehicle frame through attached engine mounts. A large mounting surface at the rear of the engine block is used for fastening a bell housing or transmission.

The cylinder head(s) attaches to the block. The attaching joints are sealed so that they do not leak. Gaskets are used in the joints to take up differences that are created by machining irregularities and that result from different pressures and temperatures.

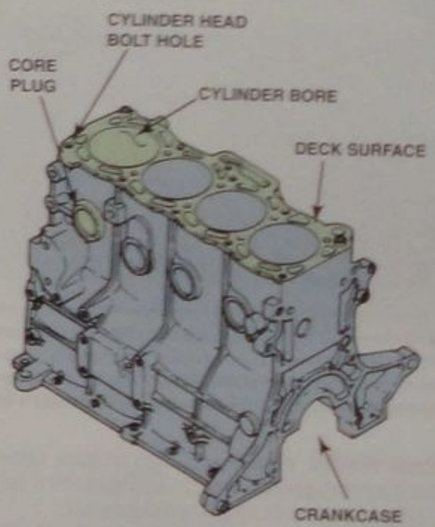


Figure 29–1 The cylinder block usually extends from the oil pan walls at the bottom to the deck surface at the top.

Block Manufacturing Cast-iron cylinder block casting technology continues to be improved. The trend is to make blocks with larger cores, using fewer individual pieces. Oil-sand cores are forms that shape the internal openings and passages in the engine block. Before casting, the cores are supported within a core box. The core box also has a liner to shape the outside of the block. Special alloy cast iron is poured into the box. It flows between the cores and the core box liner. As the cast iron cools, the core breaks up. When the cast iron has hardened, it is removed from the core box, and the pieces of sand core are removed through the openings in the block by vigorously shaking the casting. These openings in the block are plugged with **core plugs.** Core plugs are also called **freeze plugs** or **frost plugs.** Although the name seems to imply that the plugs would be pushed outward if the coolant in the passages were to freeze, they seldom work this way. See Figure 29–2.

One way to keep the engine weight as low as possible is to make the block with minimum wall thickness. The cast iron used with thin-wall casting techniques has higher nickel content and is harder than the cast iron previously used. Engine designers have used foundry techniques to make engines lightweight by making the cast-iron block walls and bulkheads only as heavy as necessary to support their required loads.



Figure 29–2 An expansion plug is used to block the opening in the cylinder head or block the holes where the core sand was removed after the part was cast.

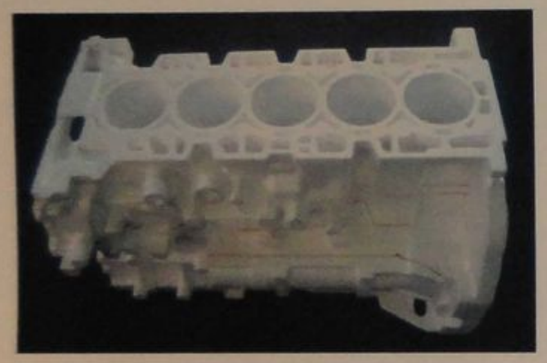


Figure 29–3 A Styrofoam casting mold used to make the five-cylinder engine blocks for the Chevrolet Colorado and the Hummer H2. The brown lines are glue used to hold the various parts together. Sand is packed around the mold and molten aluminum is poured into the sand, which instantly vaporizes the Styrofoam. The aluminum then flows and fills the area of the mold.

Aluminum Blocks Aluminum is used for some cylinder blocks and is nonmagnetic and lightweight. See Figure 29–3 for an example of a core used to sand-cast an aluminum block.

Aluminum blocks may have one of several different types of cylinder walls:

- Cast-aluminum blocks may have steel cylinder liners (Saturn, Northstar, and Ford modular V-8s and V-6s). The cast-iron cylinder sleeves are either cast into the aluminum block during manufacturing or pressed into the aluminum block. These sleeves are not in contact with the coolant passages and are called **dry cylinder sleeves.** See Figure 29–4.
- Another aluminum block design has the block die cast from silicon-aluminum alloy with no cylinder liners. Pistons with zinc-copper-hard iron coatings are used in these aluminum bores (some Porsche engines).
- Some engines have die-cast aluminum blocks with replaceable cast-iron cylinder sleeves. The sleeves are sealed at the block deck and at their base. Coolant flows around the cylinder sleeve, so this type of sleeve is called a **wet cylinder sleeve** (Cadillac 4.1-, 4.5-, and 4.9-L V-8 engines). See Figure 29–5.

Cast-iron main bearing caps are used with aluminum blocks to give the required strength.

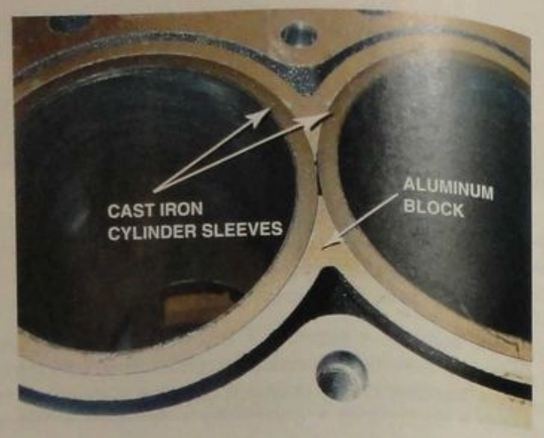


Figure 29–4 Cast-iron dry sleeves are used in aluminum blocks to provide a hard surface for the rings.

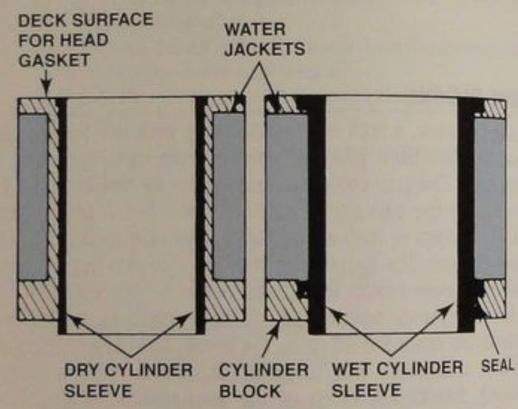


Figure 29–5 A dry sleeve is supported by the surrounding cylinder block. A wet sleeve must be thicker to be able to withstand combustion pressures without total support from the block.

FREQUENTLY ASKED QUESTION ???

What Is Compacted Graphite Iron?

Compacted graphite iron (CGI) has increased strength, ductility, toughness, and stiffness as compared to gray iron. If no magnesium is added, the iron will form gray iron when cooled, with the graphite present in flake form. If a very small amount of magnesium is added, the shape of the graphite begins to change to compacted graphite forms. Compacted graphite iron is used for bedplates and many diesel engine blocks. Its enhanced strength has been shown to permit reduced weight while still reducing noise vibration and harshness.

Bedplate Design Blocks A **bedplate** is a structural member that attaches to the bottom of the block and supports the crankshaft. Under the bedplate is the oil pan, which in most cases is also part of the structure and support for the block assembly. See Figure 29–6.

Casting Numbers Whenever an engine part such as a block is cast, a number is put into the mold to identify the casting. These



Figure 29–6 A bedplate is a structural part of the engine that is attached between the block and the oil pan and supports the crankshaft.

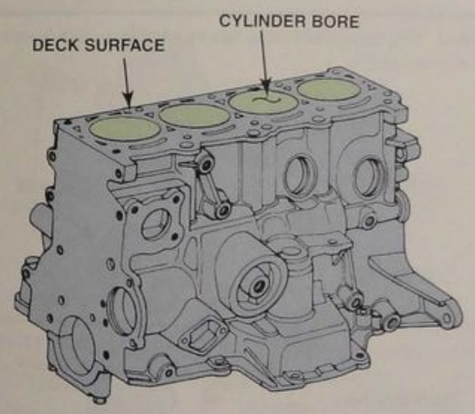


Figure 29–7 The deck is the machined top surface of the block. Note all of the passages and holes that are part of the typical block.

casting numbers can be used to check dimensions such as the cubic inch displacement and other information, such as year of manufacture. Sometimes changes are made to the mold, yet the casting number is not changed. Most often the casting number is the best piece of identifying information that the service technician can use.

Block Deck The cylinder head is fastened to the top surface of the block. This surface is called the **block deck.** The deck has a smooth surface to seal *against* the head gasket. Bolt holes are positioned around the cylinders to form an even holding pattern. Four, five, or six head bolts are used around each cylinder in automobile engines. These bolt holes go into reinforced areas within the block that carry the combustion pressure load to the main bearing bulkheads. Additional holes in the block are used to transfer coolant and oil, as seen in Figure 29–7.

Cooling Passages Cylinders are surrounded by cooling passages. These coolant passages around the cylinders are often called the **cooling jacket.** In most skirtless cylinder designs, the cooling passages extend nearly to the bottom of the cylinder. In extended skirt cylinder designs, the cooling passages are limited to the upper portion of the cylinder.

Some engines are built with **Siamese cylinder bores** where the cylinder walls are cast together without a water jacket (passage) between the cylinders. While this design improves the strength of the block and adds stability to the cylinder bores, it can reduce the cooling around the cylinders. Figure 29–8 is a typical V-8 engine cutaway that shows the coolant jackets and some of the lubrication holes.

FREQUENTLY ASKED QUESTION ???

What Is an Oil Jet?

Some turbocharged gasoline engines and many diesel engines have an oil jet that directs a shot of oil directly to the underside of the piston crown. See Figure 29–9.

The spray of oil not only lubricates, but helps reduce piston temperatures. Combustion chamber temperatures are always higher in turbocharged and diesel engines.

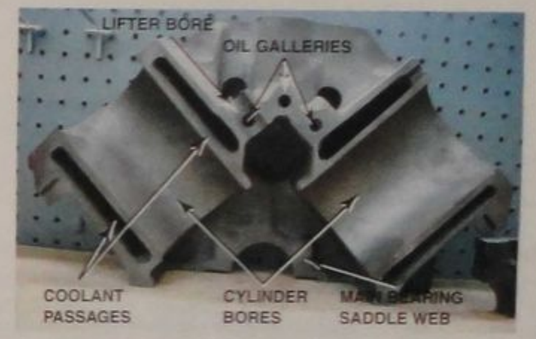


Figure 29–8 Cutaway of a Chevrolet V-8 block showing all of the internal passages.

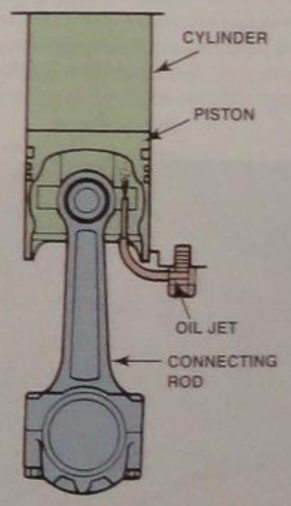


Figure 29–9 Oil jets are often used in some turbocharged, and many diesel, engines to cool the pistons.

Lubricating Passages An engine block has many oil holes that carry lubricating oil to the required locations. During manufacture, all oil holes, called the **oil gallery,** are drilled from outside the block. When a curved passage is needed, intersecting drilled holes are used. In some engines, plugs are placed in the oil holes to direct oil to another point before it comes back to the original hole, on the opposite side of the plug. After oil holes are drilled, the unneeded open ends may be capped by pipe plugs, steel balls, or cup-type soft plugs, often called **oil gallery plugs.** These end plugs in the oil passages can be a source of oil leakage in operating engines. See Figure 29–10.

TECH TIP ✓ **What Does LHD Mean?**

The abbreviation LHD means **left-hand dipstick,** which is commonly used by rebuilders and remanufacturers in their literature describing Chevrolet small-block V-8 engines. Before about 1980, most small-block Chevrolet V-8s used an oil dipstick pad on the left side (driver's side) of the engine block. Starting in about 1980, when oxygen sensors were first used on this engine, the dipstick was relocated to the right side of the block.

Therefore, to be assured of ordering or delivering the correct engine, knowing the dipstick location is critical. An LHD block cannot be used with the exhaust manifold setup that includes the oxygen sensor without major refitting or the installing of a different style of oil pan that includes a provision for an oil dipstick. Engine blocks with the dipstick pad cast on the right side are, therefore, coded as right-hand dipstick (RHD) engines.

NOTE: Some blocks cast around the year 1980 are cast with both right- and left-hand oil dipstick pads, but only one is drilled for the dipstick tube. See Figure 29–11.

Main Bearing Caps The main bearing caps are cast separately from the block. They are machined and then installed on the block for a final bore finishing operation. With caps installed, the main bearing bores and cam bearing bores are machined to the correct size and alignment. On some engines, these bores are honed to a very fine finish and exact size. Main bearing caps are not interchangeable or reversible because they are individually finished in place. Main bearing caps may have cast numbers indicating their position on the block. If not, they should be marked.

Standard production engines usually use two bolts to hold the main bearing cap in place. See Figure 29–12. Heavy-duty and high-performance engines often use additional main bearing support bolts.

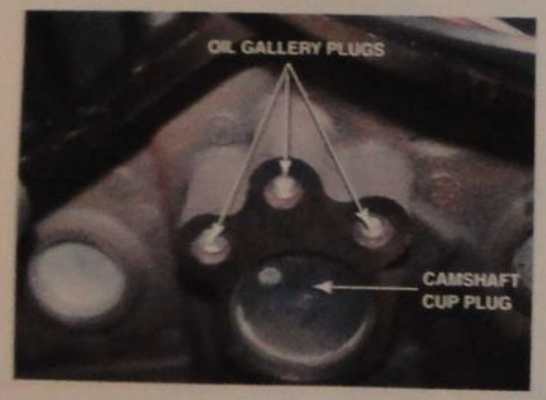


Figure 29–10 Typical oil gallery plugs on the rear of a Chevrolet small-block V-8 engine.



Figure 29–11 Small-block Chevrolet block. Note the left-hand dipstick hole and a pad cast for a right-hand dipstick.

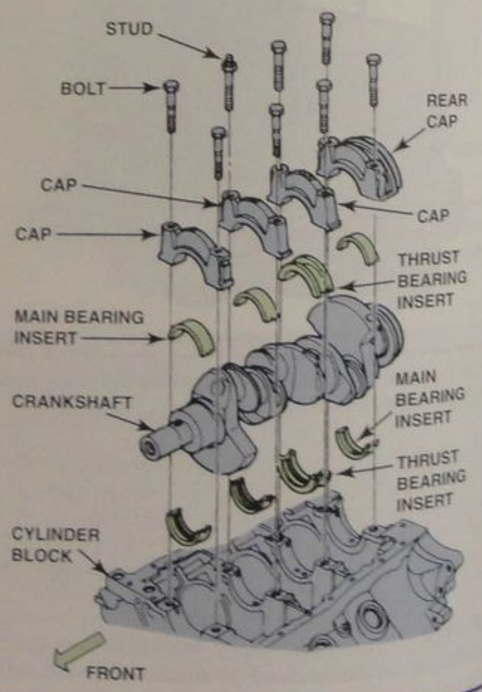


Figure 29–12 Two-bolt main bearing caps provide adequate bottom end strength for most engines.

A four-bolt, and even six-bolt, main cap can be of a cross-bolted design in a deep skirt block or of a parallel design in a shallow skirt block. See Figures 29–13 and 29–14. Expansion force of the combustion chamber gases will try to push the head off the top and the crankshaft out the bottom of the block. The engine is held together with the [illegible]

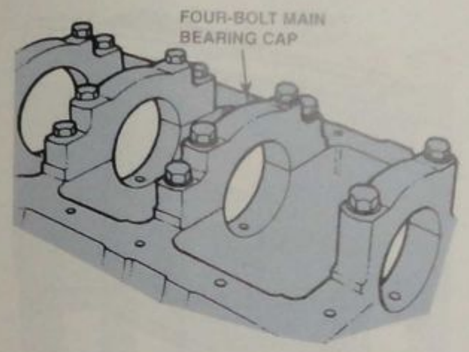


Figure 29–13 High-performance and truck engines often use four-bolt main bearing caps for greater durability.

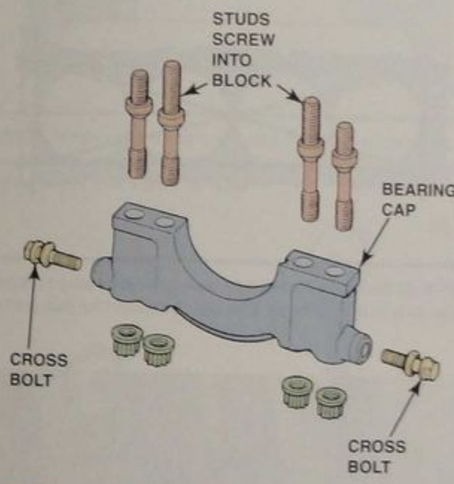


Figure 29–14 Some engines add to the strength of a four-bolt main bearing cap by also using cross bolts through the bolt on the sides of the main bearing caps.

bolts and main bearing cap bolts screwed into bolt bosses and ribs in the block. The extra bolts on the main bearing cap help to support the crankshaft when there are high combustion pressures and mechanical loads, especially during high-engine speed operation.

ENGINE BLOCK SERVICE

The engine block is the foundation of the engine. All parts of the block must be of the correct size and they must be aligned. The parts must also have the proper finishes if the engine is to function dependably for a normal service life. Blueprinting is the reconditioning of all the critical surfaces and dimensions so that the block is actually like new.

After a thorough cleaning, the block should be inspected for cracks or other flaws before machine work begins. If the block is in serviceable condition, the block should be prepared in the following sequence:

Operation 1	Align boring or honing main bearing saddles and caps
Operation 2	Machining the block deck surface parallel to the crankshaft
Operation 3	Cylinder boring and honing

Main Bearing Housing Bore Alignment The main bearing journals of a straight crankshaft are in alignment. If the main bearing housing bores in the block are not in alignment, the crankshaft will bend as it rotates. This will lead to premature bearing failure and it could lead to a broken crankshaft. The original stress in the block casting is gradually relieved as the block is used. Some slight warpage may occur as the stress is relieved. In addition, the continued pounding caused by combustion will usually cause some stretch in the main bearing caps. See Figure 29–15. The main bearing bores gradually bow from the cylinder head and elongate vertically. This means that the bearing bore becomes smaller at the center line as the block distorts, pinching the bore inward at the sides. See Figure 29–16.

The first step in determining the condition of the main bearing bores is to determine if the bore alignment in the block is straight. These bores are called the **saddles.** A precision ground straightedge and a feeler gauge are used to determine the amount of warpage. The amount of variation along the entire length of the block should not exceed 0.0015 inch (0.038 mm).

CAUTION: When performing this measurement, be sure that the block is resting on a flat surface. If the engine is mounted to an engine stand, the weight of the block on the unsupported end can cause an error in the measurement of the main bearing bores and saddle alignment.

If the block saddles exceed one-and-a-half thousandth of an inch distortion, then align honing is required to restore the block. If

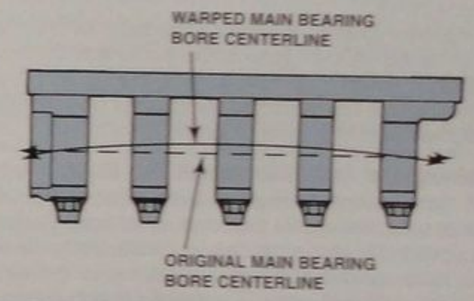


Figure 29–15 The main bearing bores of a warped block usually bend into a bowed shape. The greatest distortion is in the center bores.

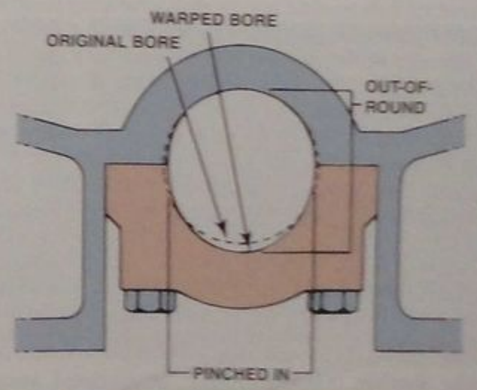


Figure 29–16 When the main bearing caps bow downward, they also pinch in at the parting line.



Figure 29–17 The main bearing bores can be checked using a precision straightedge and a feeler gauge.

the block saddles are straight, the bores should be measured to be sure that the bearing caps are not distorted. The bearing caps should be installed and the retaining bolts tightened to the specified torque before measuring the main bearing bores.

Using a telescoping gauge, measure each bore in at least two directions. Check the service information for the specified main bearing bore diameter. The bearing bore should vary by more than one-half of a thousandth of an inch or 0.0005 inch (0.0127 mm). See Figure 29–17.

A dial bore gauge is often used to measure the main bearing bore. Set up the dial bore gauge in the fixture with the necessary extensions to achieve the nominal main bearing bore diameter. Check the service information for the specified main bearing bore diameter and determine the exact middle of the range.

Machining the Deck Surface of the Block An engine should have the same combustion chamber size in each cylinder. For this to occur, each piston must come up an equal distance from the block deck. The connecting rods are attached to the rod bearing journals of the crankshaft. Pistons are attached to the connecting rods. As the crankshaft rotates, the pistons come to the top of the stroke. When all parts are sized equally, all the pistons will come up to the same level. This can only happen if the block deck is parallel to the main bearing bores. See Figure 29–18.

The block deck must be resurfaced in a surfacing machine that can control the amount of metal removed when it is necessary to match the size of the combustion chambers. This procedure is called **decking the block.** The block is set up on a bar located in the main bearing saddles, or set up on the oil pan rails of the block. The bar is parallel to the direction of cutting head movement. The block is leveled sideways, and then the deck is resurfaced in the same manner as the head is resurfaced. Figure 29–19 shows a block deck being resurfaced by grinding. The surface finish should be 60 to 100 Ra (65 to 110 RMS) for cast iron and 50 to 60 Ra (55 to 65 RMS) for aluminum block decks to be assured of a proper head gasket surface. The surface finish is determined by the type of grinding stone used, as well as the speed and coolant used in the finishing operation.

Cylinder Boring Cylinders should be measured across the engine (perpendicular to the crankshaft), where the greatest wear occurs. Most wear will be found just below the ridge, and the least amount of wear will occur below the lowest ring travel. See

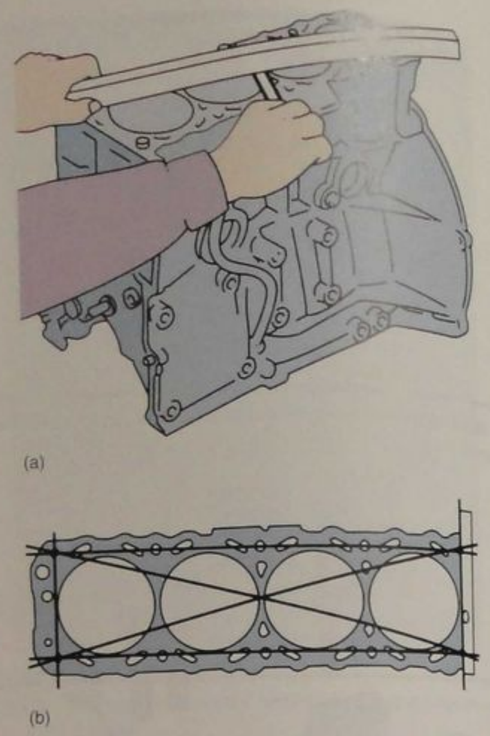


Figure 29–18 (a) Checking the flatness of the block deck surface using a straightedge and a feeler gauge. (b) To be sure that the top of the block is flat, check the block in six locations as shown.



Figure 29–19 Grinding the deck surface of the block.

Figure 29–20. The cylinder should be checked for out-of-round and taper. See Figure 29–21. Most cylinders are serviceable if:

- Maximum of 0.003 inch (0.076 millimeter) out-of-round
- No more than 0.005 inch (0.127 millimeter) taper
- Have no deep scratches in the cylinder wall

NOTE: Always check the specifications for the engine being surfaced. For example, the General Motors 5.7-L, LS-1, V-8 has a maximum out-of-round of only 0.0003 (3/10 of one thousandths of an inch). Normally this specification is about three times that dimension or about 0.001 inch.

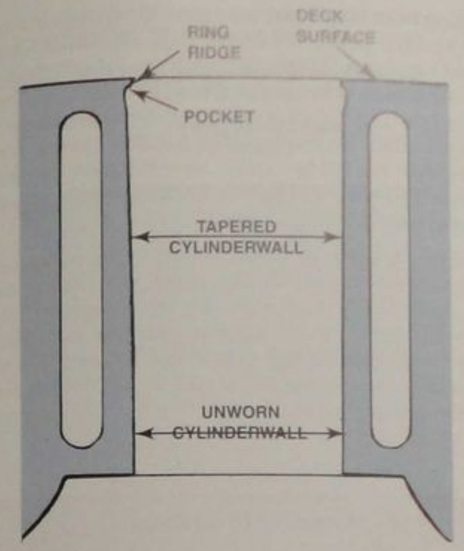


Figure 29–20 Cylinders wear in a taper, with most of the wear occurring at the top of the cylinder where the greatest amount of heat is created. The ridge is formed because this very top part of the cylinder is not worn by the rings.

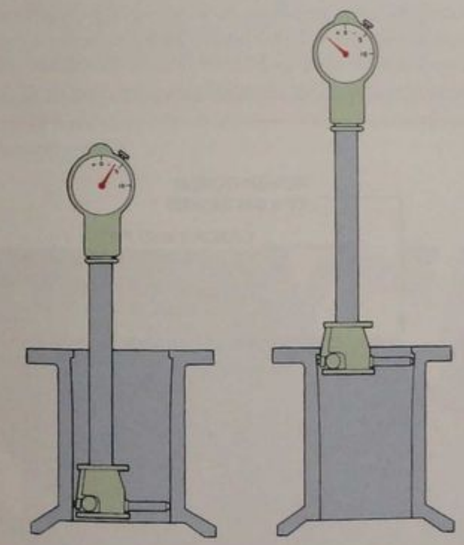


Figure 29–21 Using a dial bore gauge to measure the bore diameter at the top just below the ridge and at the bottom below the ring travel. Take the measurements in line with the crankshaft and then repeat the measurements at right angles to the center line of the block in each cylinder.

The most effective way to correct excessive cylinder out-of-round, taper, or scoring is to **rebore** the cylinder. The rebored cylinder requires the use of a new, oversize piston.

The maximum bore oversize is determined by two things: the cylinder wall thickness and the size of the available oversize pistons. If in doubt as to the amount of overbore that is possible without causing structural weakness, an ultrasonic test should be performed on the block to determine the thickness of the cylinder walls. All cylinders should be tested. Variation in cylinder wall thickness occurs because of core shifting (moving) during the casting of the block. For best results, cylinders should be rebored to the smallest size possible.

FREQUENTLY ASKED QUESTION ???

How Do I Determine What Oversize Bore Is Needed?

An easy way to calculate oversize piston size is to determine the amount of taper, double it, and add 0.010 inch (Taper × 2 + 0.010 in. = OS piston). Common oversize measurements include 0.020 inch, 0.030 inch, 0.040 inch, and 0.060 inch. Use caution when boring for an oversize measurement larger than 0.030 inch.

HINT: The pistons that will be used should always be in hand *before* the cylinders are rebored. The cylinders are then bored and honed to match the exact size of the pistons.

The cylinder must be perpendicular to the crankshaft for normal bearing and piston life. If the block deck has been aligned with the crankshaft, it can be used to align the cylinders. Portable cylinder boring bars are clamped to the block deck. Heavy-duty production boring machines support the block on the main bearing bores.

Main bearing caps should be torqued in place when cylinders are being rebored. In precision boring, a torque plate is also bolted on in place of the cylinder head while boring cylinders. In this way, distortion is kept to a minimum. The general procedure used for reboring cylinders is to set the boring bar up so that it is perpendicular to the crankshaft. It must be located over the center of the cylinder. The cylinder center is found by installing centering pins in the bar. The bar is lowered so that the centering pins are located near the bottom of the cylinder, where the least wear has occurred. This locates the boring bar over the original cylinder center. Once the boring bar is centered, the boring machine is clamped in place to hold it securely. This will allow the cylinder to be rebored on the original centerline, regardless of the amount of cylinder wear. A sharp, properly ground cutting tool is installed and adjusted to the desired dimension. Rough cuts remove a great deal of metal on each pass of the cutting tool. The rough cut is followed by a fine cut that produces a much smoother and more accurate finish. Different-shaped tool bits are used for rough and finish boring. The last cut is made to produce a diameter that is at least 0.002 inch (0.05 millimeter) smaller than the required diameter. See Figure 29–22.



Figure 29–22 A cylinder boring machine is used to enlarge cylinder bore diameter so a replacement oversize piston can be used to restore a worn engine to useful service or to increase the displacement of the engine in an attempt to increase power output.

Sleeving the Cylinder Sometimes, cylinders have a gouge so deep that it will not clean up when the cylinder is rebored to the maximum size. This could happen if the piston pin moved endways and rubbed on the cylinder wall. Cylinder blocks with deep gouges can be salvaged by **sleeving** the cylinder. This is done by boring the cylinder to a dimension that is greatly oversize to almost match the outside diameter of the cylinder sleeve. The sleeve is pressed into the rebored block, then the center of the sleeve is bored to the diameter required by the piston. The cylinder can be sized to use a standard-size piston when it is sleeved. See Figure 29–23.

Cylinder Honing It is important to have the proper surface finish on the cylinder wall for the rings to seat against. Some ring manufacturers recommend breaking the hard surface glaze on the cylinder wall with a hone before installing new piston rings. Honing the cylinder removes the fractured metal that is created by boring. The cylinder wall should be honed to straighten the cylinder when the wall is wavy or scuffed. If honing is being done with the crankshaft remaining in the block, the crankshaft should be protected to keep honing chips from getting on the shaft.

Two types of hones are used for cylinder service.

- A **deglazing hone** removes the hard surface glaze remaining in the cylinder. It is a flexible hone that follows the shape of the cylinder wall, even when the wall is wavy. It cannot be used to straighten the cylinder. A brush-type **(ball-type)** deglazing hone is shown in Figure 29–24.



Figure 29–23 A dry cylinder sleeve can also be installed in a cast-iron block to repair a worn or cracked cylinder.



Figure 29–24 An assortment of ball-type deglazing hones. This type of hone does not straighten wavy cylinder walls.

- A **sizing hone** can be used to straighten the cylinder and to provide a suitable surface for the piston rings. The cylinders must be honed a minimum of 0.002 inch (0.050 mm) after boring to cut below the rough surface and provide an adequate finish. Honing leaves a plateau surface that can support the oil film for the rings and piston skirt. This plateau surface is achieved by first using a coarse stone followed by a smooth stone to achieve the desired surface. The process of using both coarse and fine stones is called **plateau honing.** See Figure 29–25.

The honing stones are held in a rigid fixture with an expanding mechanism to control the size of the hone. The sizing hone can be used to straighten the cylinder taper by honing the lower cylinder diameter more than the upper diameter. As it rotates, the sizing hone only cuts the high spots so that cylinder out-of-round is also reduced. The cylinder wall surface finish is about the same when the cylinder is refinished with either type of hone. See Figure 29–26.

TECH TIP ✔ Always Use Torque Plates

Torque plates are thick metal plates that are bolted to the cylinder block to duplicate the forces on the block that occur when the cylinder head is installed. Even though not all machine shops use torque plates during the boring operation, the use of torque plates during the final dimensional honing operation is very beneficial. Without torque plates, cylinders can become out-of-round (up to 0.003 inch) and distorted when the cylinder heads are installed and torqued down. Even though the use of torque plates does not eliminate all distortion, their use helps to ensure a truer cylinder dimension. See Figure 29–27.

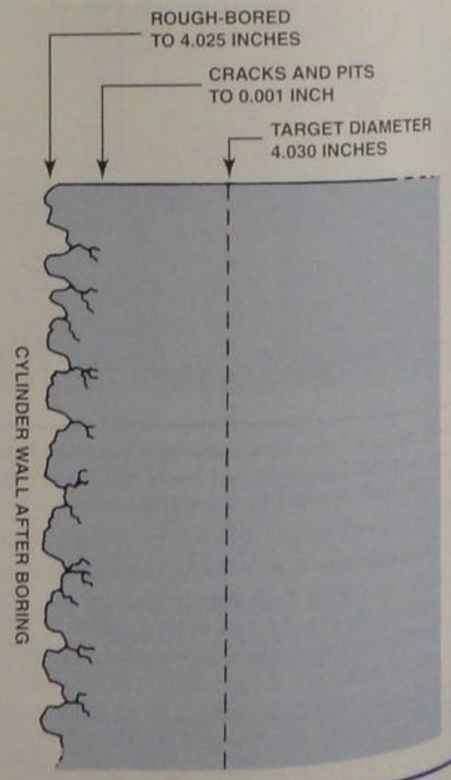


Figure 29–25 After boring, the cylinder surface is rough, pitted, and fractured to a depth of about 0.001 inch.

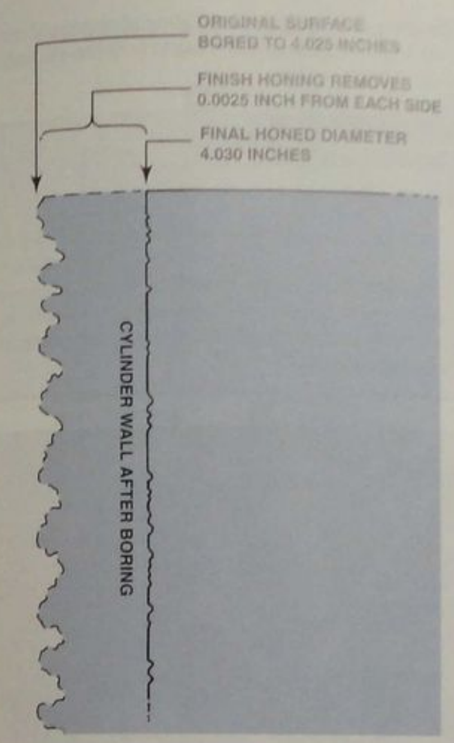


Figure 29–26 Honing enlarges the cylinder bore to the final size and leaves a plateau surface finish that retains oil.

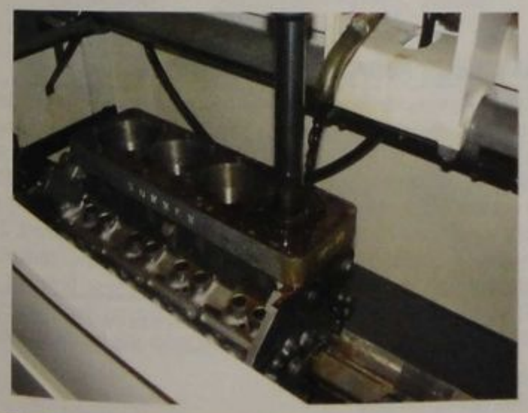


Figure 29–27 A torque plate being used during a cylinder honing operation. The thick piece of metal is bolted to the block and simulates the forces exerted on the block by the head bolts when the cylinder head is attached.

The hone is stroked up and down in the cylinder as it rotates. This produces a **crosshatch finish** on the cylinder wall. A typical honed cylinder is pictured in Figure 29–28. The angle of the crosshatch should be between 20 and 60 degrees. Higher angles are produced when the hone is stroked more rapidly in the cylinder.

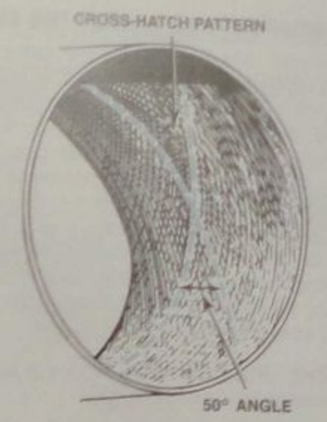


Figure 29–28 The crosshatched pattern holds oil to keep the rings from wearing excessively, and also keeps the rings against the cylinder wall for a gas-tight fit.

TECH TIP ✔ Bore to Size, Hone for Clearance

Many engine rebuilders and remanufacturers bore the cylinders to the exact size of the oversize pistons that are to be used. After the block is bored to a standard oversize measurement, the cylinder is honed. The rigid hone stones, along with an experienced operator, can increase the bore size by 0.001 to 0.003 inch (1 to 3 thousandths of an inch) for the typical clearance needed between the piston and the cylinder walls.

For example:

Actual piston diameter	= 4.028 in.
Bore diameter	= 4.028 in.
Diameter after honing	= 4.030 in.
Amount removed by honing	= 0.002 in.

NOTE: The minimum amount recommended to be removed by honing is 0.002 inch to remove the fractured metal in the cylinder wall caused by boring.

Cylinder Surface Finish The size of the abrasive particles in the grinding and honing stones controls the surface finish. The size of the abrasive is called the **grit size.** The abrasive is sifted through a mesh screen to sort out the grit size. A coarse-mesh screen has few wires in each square inch, so large pieces can fall through the screen. A fine-mesh screen has many wires in each square inch so that only small pieces can fall through. The screen is used to separate the different grit sizes. The grit size is the number of wires in each square inch of the mesh. A low-numbered grit has large pieces of abrasive material; a high-numbered grit has small pieces of abrasive material. The higher the grit number, the smoother the surface finish.

A given grit size will produce the same finish as long as the cutting pressure is constant. With the same grit size, light cutting pressure produces fine finishes, and heavy cutting pressure produces rough finishes.

The surface finish should match the surface required for the type of piston rings to be used. Typical grit and surface finish standards include the following:

- Chrome—#180 grit (25 to 35 microinches)
- Cast iron—#200 grit (20 to 30 microinches)
- Moly—#220 grit (18 to 25 microinches)

BLOCK CLEANING AND PREPARATION FOR ASSEMBLY

After the cylinders have been honed and before the block is cleaned, use a sandpaper cone to chamfer the top edge of the cylinder. Cleaning the honed cylinder wall is an important part of the honing process. If any grit remains on the cylinder wall, it will rapidly wear the piston rings. This wear will cause premature failure of the reconditioning job. Degreasing and decarbonizing procedures will only remove the honing oil. They will *not* remove the abrasive. The *best* way to clean the honed cylinders is to scrub the cylinder wall with a brush using a mixture of *soap* or *detergent* and *water*. The block is scrubbed until it is absolutely clean. This can be determined by wiping the cylinder wall with a clean cloth. The cloth will pick up no soil when the cylinder wall is clean.

Block Detailing Before the engine block can be assembled, a final detailed cleaning should be performed.

1. All oil passages (galleries) should be cleaned by running a long bottle-type brush through all holes in the block.
2. All tapped holes should be chamfered and cleaned with the correct size of thread chaser to remove any dirt and burrs. See Figures 29–29 and 29–30.



Figure 29–29 Notice on this cutaway engine block that some of the head bolt holes do not extend too far into the block and dead end. Debris can accumulate at the bottom of these holes and it must be cleaned out before final assembly.

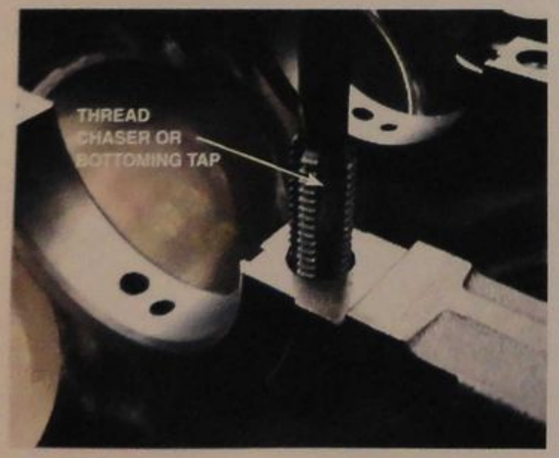


Figure 29–30 A thread chaser or bottoming tap should be used in all threaded holes before assembling the engine.

3. Coat the newly cleaned block with fogging oil to prevent rust. Cover the block with a large plastic bag to keep out dirt until it is time to assemble the engine.

HIGH-PERFORMANCE TIP

Install Lifter Bore Bushings

Lifter bores in a block can be out-of-square with the camshaft, resulting in premature camshaft wear and variations in the valve timing from cylinder to cylinder. To correct for this variation, the lifter bores are bored and reamed oversize using a fixture fastened to the block deck to ensure proper alignment. Bronze lifter bushings are then installed and finish honed to achieve the correct lifter-to-bore clearance. See Figure 29–31.



Figure 29–31 High-performance engine builders will often install bronze sleeves in the valve lifter bores.

CRANKSHAFT PURPOSE AND FUNCTION

Power from expanding gases in the combustion chamber is delivered to the crankshaft through the piston, piston pin, and connecting rod. The connecting rods and their bearings are attached to a bearing journal on the crank throw. The crank throw is offset from the **crankshaft centerline.** The combustion force is applied to the crank throw after the crankshaft has moved past top center. This produces the turning effort or torque, which rotates the crankshaft. The crankshaft rotates on the main bearings. These bearings are split in half so that they can be assembled around the crankshaft main bearing journals. The crankshaft includes the following parts:

- Main bearing journals
- Rod bearing journals
- Crankshaft throws
- Counterweights
- Keyways
- Oil passages

See Figure 29–32.

MAIN BEARING JOURNALS

The crankshaft rotates in the cylinder block on main bearings. See Figure 29–33. The bearings support the crankshaft and allow it to rotate easily without excessive wear. The number of cylinders usually determines the number of main bearings.

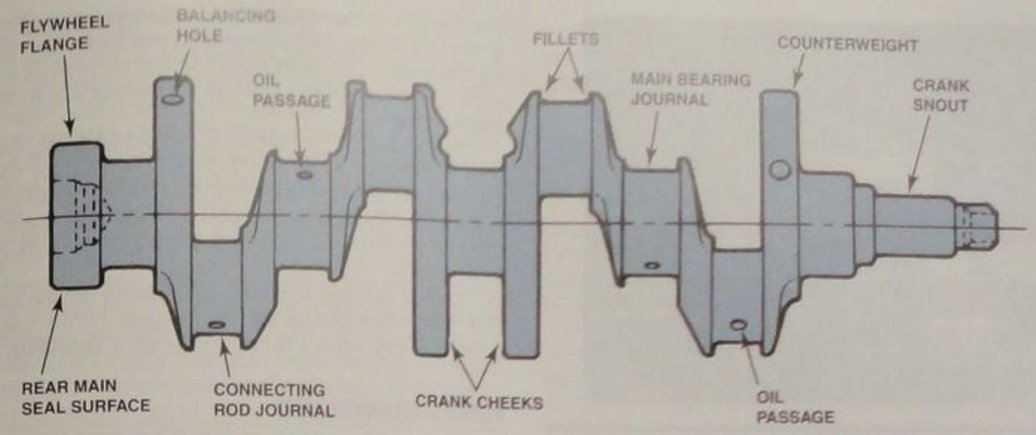


Figure 29–32 Typical crankshaft with main journals that are supported by main bearings in the block. Rod journals are offset from the crankshaft centerline.

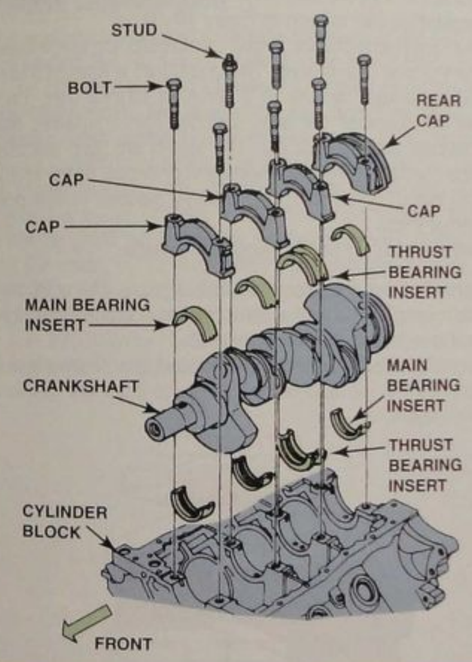


Figure 29–33 The crankshaft rotates on main bearings. Longitudinal (end-to-end) movement is controlled by the thrust bearing.

- Four-cylinder engines and V-8 engines usually have five main bearings.
- Inline 6-cylinder engines usually have seven main bearings.
- V-6 engines normally have only four main bearings.

See Figure 29–34.

The crankshaft also has to be able to absorb thrust loads from the clutch on a manual transmission vehicle or the torque converter on a vehicle equipped with an automatic transmission. Thrust loads are forces that push and pull the crankshaft forward and rearward in the engine block. A thrust bearing supports these loads and maintains the front-to-rear position of the crankshaft in the block. See Figure 29–35. The thrust surface is usually located at the middle on one of the end main bearings. On most engines, the bearing insert for the main bearing is equipped with thrust bearing flanges that ride against the thrust surface.

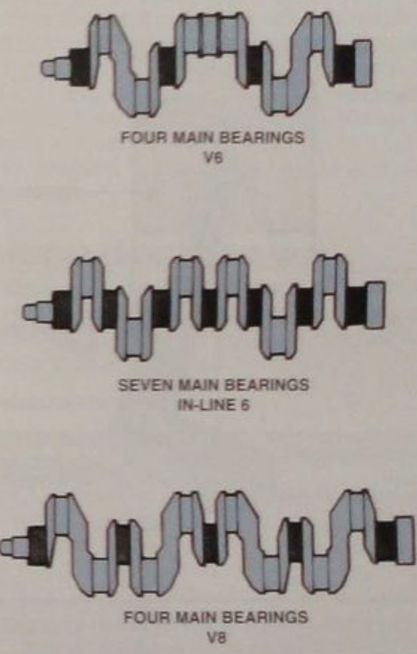


Figure 29–34 The longer the crankshaft, the more main bearing journals are needed.

ROD BEARING JOURNALS

The rod bearing journals, also called crankpins, are offset from the centerline of the crank. Insert-type bearings fit between the big end of the connecting rod and the crankpin of the crankshaft.

The amount of offset of the rod bearing journal determines the stroke of the engine. The crankshaft with throws that measure one-half of the stroke has a direct relationship to the displacement of the engine. See Figure 29–36.

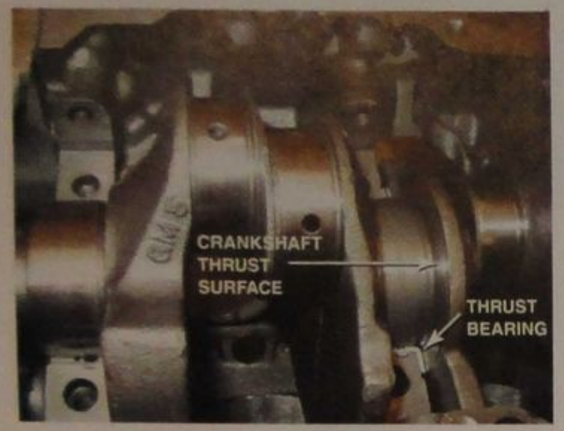


Figure 29–35 A ground surface on one of the crankshaft cheeks next to a main bearing supports thrust loads on the crank.

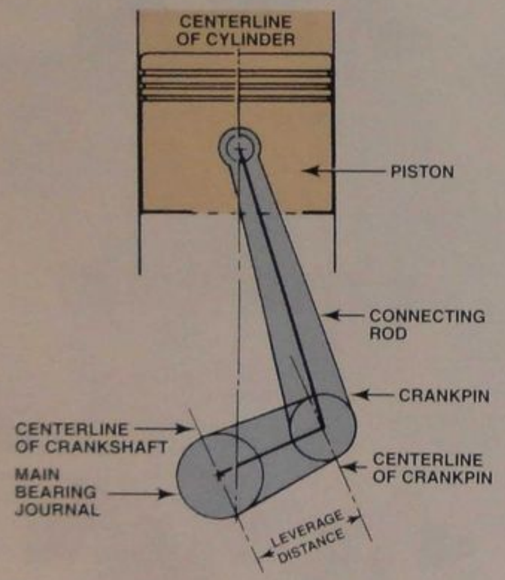


Figure 29–36 The distance from the crankpin centerline to the centerline of the crankshaft determines the stroke, which is the leverage available to turn the crankshaft.

SURFACE FINISH

All crankshaft journals are ground to a very smooth finish. Surface finish is measured in micro-inches and the smaller the number, the smoother the surface. Where the surface finish of a machined block deck or cylinder head may range from 60 to 100 RA (roughness average), the typical specification for main and rod crankshaft journals is between 10 and 20 RA. This very smooth surface finish is achieved by polishing the crank journals after the grinding operation.

JOURNAL HARDNESS

To improve wear resistance, some manufacturers harden the crankshaft journals. One method used is called **case hardening,** where only the outer portion of the surface is hardened. Case hardening involves heating the crankshaft and adding carbon to the journals where it causes the outer surface to become harder than the rest of the crankshaft. If the entire crankshaft was hardened, it would become too brittle to be able to absorb the torsional stresses of normal engine operation.

Another form of case hardening is called **nitriding.** The crankshaft is heated to about 1000°F (540°C) in a furnace filled with ammonia gas, and then allowed to cool. The process adds nitrogen (from the ammonia) into the surface of the metal-forming hard nitrides in the surface of the crankshaft to a depth of about 0.003 inch (0.8 mm).

Another variation of this process involves heating the crankshaft in a molten cyanide salt bath. General Motors Corporation uses this process referred to by the trade name **Tuftriding.**

FORGED CRANKSHAFTS

Crankshafts used in high-production automotive engines may be either forged or cast. Forged crankshafts are stronger than the cast crankshaft, but they are more expensive. Forged crankshafts have a wide separation line, as seen in Figure 29–37.

Most high-performance forged crankshafts are made from SAE 4340 or a similar type of steel. The crankshaft is formed from a hot steel billet through the use of a series of forging dies. Each die changes the shape of the billet slightly. The crankshaft blank is finally formed with the last die. The blanks are then machined to finish the crankshaft. Forging makes a very dense, tough crankshaft with the metal's grain structure running parallel to the principal direction of stress.

Two methods are used to forge crankshafts.

- One method is to forge the crankshaft *in place.* This is followed by straightening. The forging in place method is primarily used with forged four- and six-cylinder crankshafts.
- A second method is to forge the crankshaft in a *single plane.* It is then twisted in the main bearing journal to index the throws at the desired angles.

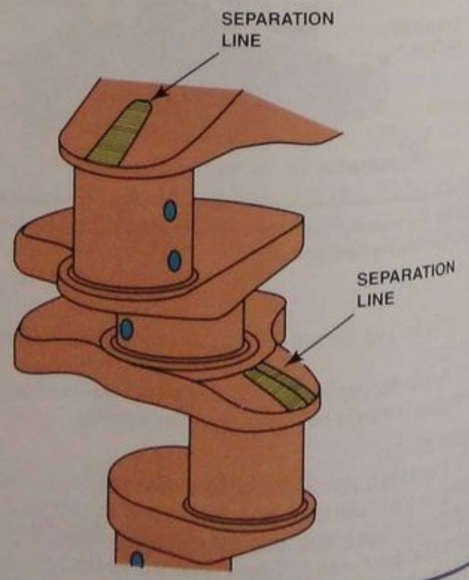


Figure 29–37 Wide separation lines where the flashings have been removed from the forged crankshaft show that it has been twisted to index the crank throws.

CAST CRANKSHAFTS

Casting materials and techniques have improved cast crankshaft quality so that cast crankshafts are used in most production automotive engines. Automotive crankshafts may be cast in steel, nodular iron, or malleable iron. The major advantage of the casting process is that crankshaft material and machining costs are less than they are with forging. The reason is that the crankshaft can be made close to the required shape and size, including all complicated counterweights. The only machining required on a carefully designed cast crankshaft is the grinding of bearing journal surfaces and the finishing of front and rear drive ends. Metal grain structure in the cast crankshaft is uniform and random throughout; thus, the shaft is able to handle loads from all directions. Counterweights on cast crankshafts are slightly larger than counterweights on a forged crankshaft because the cast shaft metal is less dense and therefore somewhat lighter. The narrow mold parting surface lines can be seen on the cast crankshaft pictured in Figure 29–38.

V-8 ENGINE CRANKSHAFTS

The V-8 engine has four inline cylinders in each of the two blocks that are placed at a 90-degree angle to each other. Each group of four inline cylinders is called a **bank.** The crankshaft for the V-8 engine has four throws. The connecting rods from two cylinders are connected to each throw, one from each bank. This arrangement results in a condition of being only minimally unbalanced. The V-8 engine crankshaft has two planes, so there is one throw every 90 degrees. A plane is a flat surface that cuts through the part. These planes could be seen if the crankshaft were cut lengthwise through the center of the main bearing and crankpin journals. Looking at the front of the crankshaft with the first throw at 360 degrees (up), the second throw is at 90 degrees (to the right), the third throw is at 270 degrees (to the left), and the fourth throw is at 180 degrees (down). In operation with this arrangement, one piston reaches top center at each 90 degrees of crankshaft rotation so that the engine operates smoothly with even firing at each 90 degrees of crankshaft rotation.

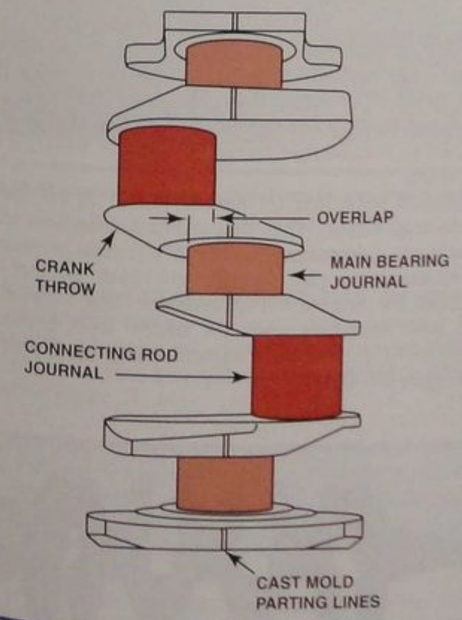


Figure 29–38 Cast crankshaft showing the bearing journal overlap and a straight, narrow cast mold parting line.

FOUR-CYLINDER ENGINE CRANKSHAFTS

The crankshaft used on four-cylinder inline engines has four throws on a single plane. There is usually a main bearing journal between each throw, making it a five-main-bearing crankshaft. Pistons also move as pairs in this engine. Pistons in #1 and #4 cylinders move together, and pistons #2 and #3 move together. Each piston in a pair is 360 degrees out-of-phase with the other piston in the 720-degree four-stroke cycle. With this arrangement, the four-cylinder inline engine fires one cylinder at each 180 degrees of crankshaft rotation.

A four-cylinder opposed engine and a 90-degree V-4 engine have crankshafts that look like that of the four-cylinder inline engine.

FIVE-CYLINDER ENGINE CRANKSHAFTS

The inline five-cylinder engine has a five-throw crankshaft with one throw at each 72 degrees. Six main bearings are used on this crankshaft. The piston in one cylinder reaches top center at each 144 degrees of crankshaft rotation. The throws are arranged to give a firing order of 1-2-4-5-3. Dynamic balancing has been one of the major problems with this engine design, yet the vibration was satisfactorily dampened and isolated on both the Audi and Acura five-cylinder engines.

THREE-CYLINDER ENGINE CRANKSHAFTS

A three-cylinder engine uses a 120-degree three-throw crankshaft with four main bearings. This engine requires a balancing shaft that turns at crankshaft speed, but in the opposite direction, to reduce the vibration to an acceptable level.

REAL WORLD FIX **The Mysterious Engine Vibration**

A Buick-built, 3.8-liter V-6 engine vibrated the whole car after a new short block had been installed. The technician who had installed the replacement engine did all of the following:

1. Checked the spark plugs
2. Checked the spark plug wires
3. Disconnected the torque converter from the flex plate (drive plate) to eliminate the possibility of a torque converter or automatic transmission pump problem
4. Removed all accessory drive belts one at a time

Yet the vibration still existed.

Another technician checked the engine mounts and found that the left (driver's side) engine mount was out of location, ripped, and cocked. The transmission mount was also defective. After the technician replaced both mounts and made certain that all mounts were properly set, the vibration was eliminated. The design and location of the engine mounts are critical to the elimination of vibration, especially on 90-degree V-6 engines.

ODD-FIRING 90-DEGREE V-6 ENGINE CRANKSHAFTS

The 90-degree V-6 engine uses a three-throw crankshaft with four main bearings. The throws are 120 degrees apart. As in typical V-type engines, each crank throw has two connecting rods attached, one

from each bank. This V-6 engine design does not have even-firing impulses because the pistons, connected to the 120-degree crankpins, do not reach top center at even intervals. The engine has a firing pattern of 150°–90°–150°–90°–150°–90°, as illustrated in Figure 29–39. This firing pattern produces unequal pulses that have to be isolated with engine mounts that have been carefully designed.

EVEN-FIRING 90-DEGREE V-6 ENGINE CRANKSHAFTS

The crank throws for an even-firing V-6 engine are split, making separate crankpins for each cylinder. The split throw can be seen in Figure 29–40. This angle between the crankpins on the crankshaft throws is called a **splay angle.** A flange was left between the split crankpin journals. This provides a continuous fillet or edge for machining and grinding operations. It also provides a normal flange for the rod and bearing. This flange between the splayed crankpin journals is sometimes called a **flying web.**

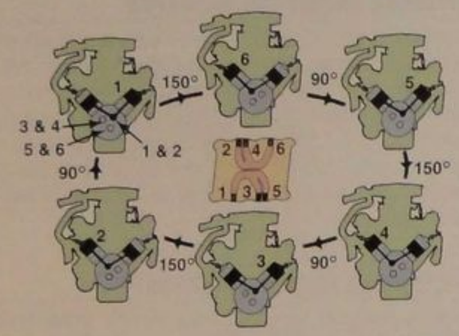


Figure 29–39 The firing impulses of this odd-fire V-6 are unequally spaced because two cylinders share a common crankpin.

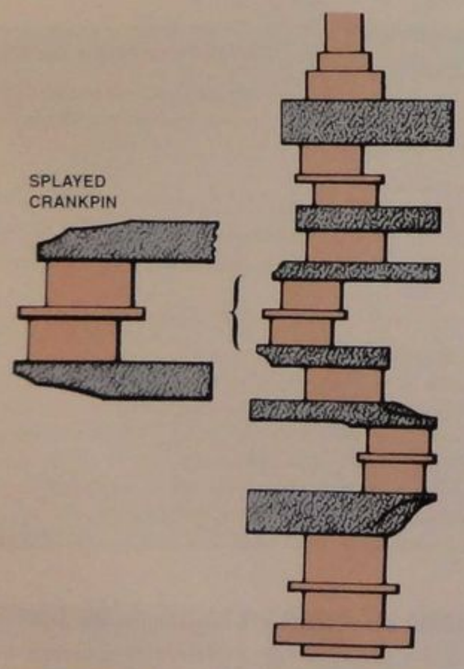


Figure 29–40 A splayed crankshaft design is used to create an even-firing 90-degree V-6.

60-DEGREE V-6 ENGINE CRANKSHAFTS

The 60-degree V-6 engine is similar to the even-firing 90-degree V-6 engine. The adjacent pairs of crankpins on the crankshaft used in the 60-degree V-6 engine have a splay angle of 60 degrees. With this large 60-degree splay angle, the flange or flying web between the splayed crankpins is made heavier than on crankshafts with smaller splay angles. This is necessary to give strength to the crankshaft. The crankshaft of the 60-degree V-6 engine also uses four main bearings.

COUNTERWEIGHTS

Crankshafts are balanced by **counterweights,** which are cast or forged as part of the crankshaft. A crankshaft that has counterweights on both sides of each connecting rod journal is called **fully counterweighted.** See Figure 29–41.

A fully counterweighted crankshaft is the smoothest running and most durable design, but it is also the heaviest and most expensive to manufacture. Most vehicle manufacturers do not use fully counterweighted crankshafts in an effort to lighten the rotating mass of the engine. An engine with a light crankshaft allows the engine to accelerate quicker.

FREQUENTLY ASKED QUESTION ???

What Is an Offset Crankshaft?

To reduce side loads, some vehicle manufacturers offset the crankshaft from center. For example, if an engine rotates clockwise as viewed from the front, the crankshaft may be offset to the left to reduce the angle of the connecting rod during the power stroke. See Figure 29–42.

The offset usually varies from 1/16 inch to 1/2 inch, depending on make and model. Most gasoline engines used in hybrid gasoline/electric vehicles use an offset crankshaft.

VIBRATION DAMAGE

Each time combustion occurs, the force deflects the crankshaft as it transfers torque to the output shaft. This deflection occurs in two ways, to bend the shaft sideways and to twist the shaft in torsion. The crankshaft must be rigid enough to keep the deflection forces to a minimum.

Crankshaft deflections are directly related to the operating roughness of an engine. When back-and-forth deflections occur at the same vibration **frequency** (number of vibrations per second) as that of another engine part, the parts will vibrate together. When this happens, the parts are said to **resonate.** These vibrations may become great enough to reach the audible level, producing a thumping sound. If this type of vibration continues, the part may fail. See Figure 29–43.



Figure 29–41 A fully counterweighted four-cylinder crankshaft.

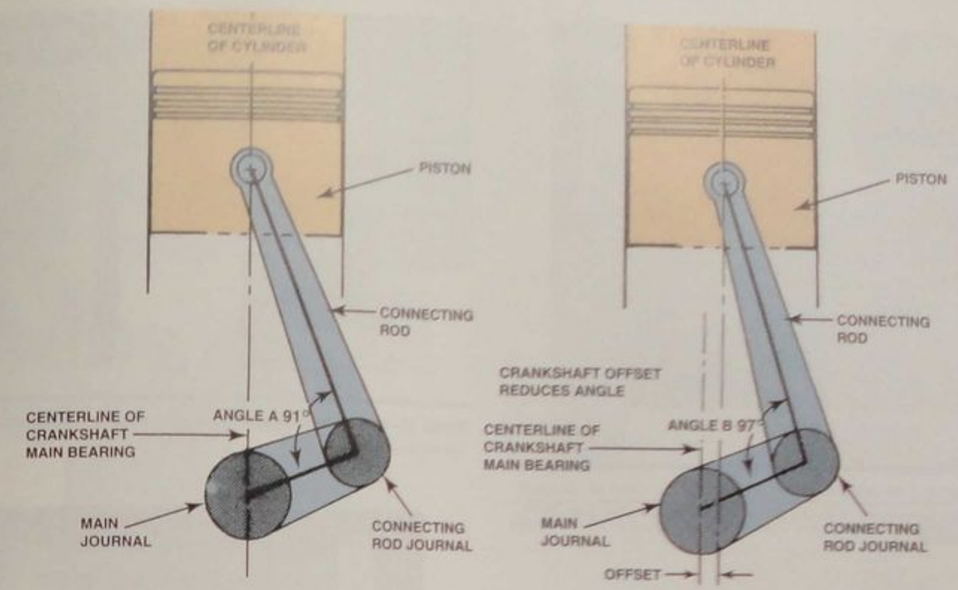


Figure 29–42 The crank throw is halfway down on the power stroke. The piston on the left without an offset crankshaft has a sharper angle than the engine on the right with an offset crankshaft.

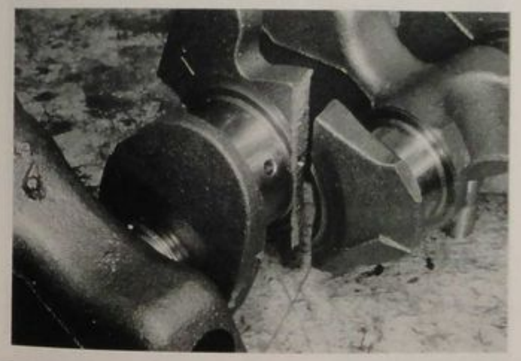


Figure 29–43 A crankshaft broken as a result of using the wrong torsional vibration damper.

Harmful crankshaft twisting vibrations are dampened with a torsional vibration damper. It is also called a harmonic balancer. This damper or balancer usually consists of a cast-iron **inertia ring** mounted to a cast-iron **hub** with an **elastomer** sleeve. An example is shown in Figure 29–44.

HINT: Push on the rubber (elastomer sleeve) of the vibration damper with your fingers or a pencil. *If the rubber does not spring back, replace the damper.*

Elastomers are actually synthetic, rubber-like materials. The inertia ring size is selected to control the **amplitude** of the crankshaft vibrations for each specific engine model. See Figure 29–45.



Figure 29–44 This Chevy V-8 harmonic balancer also has a line cut into the outer ring that is used to indicate top dead center to set the ignition timing on engines that are equipped with a distributor ignition.

HIGH-PERFORMANCE TIP

High-Engine Speeds Require High-Performance Parts

Do not go racing with stock parts. The harmonic balancer shown in Figure 29–46 came apart and the resulting vibration broke the crankshaft when the owner attempted to race with his stock engine.

The owner had made some engine modifications, but he did not change the stock harmonic balancer even though the other changes allowed the engine to rev to much higher speeds than stock parts normally would permit.

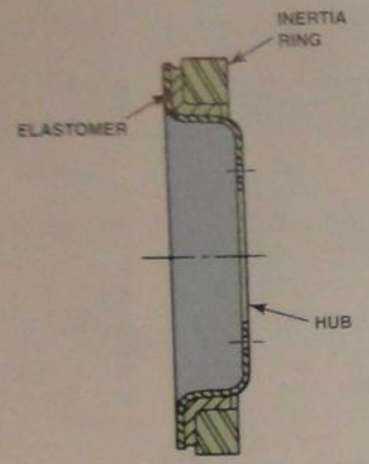


Figure 29–45 The hub of the harmonic ballancer is attached to the front of the crankshaft. The elastomer (rubber) between the inertia ring and the center hub allows the absorption of crankshaft firing impulses.



Figure 29–46 Harmonic balancer that separated at high-engine speed.

EXTERNALLY AND INTERNALLY BALANCED ENGINES

Most crankshaft balancing is done during manufacture. Holes are drilled in the counterweight to lighten it to improve balance. Sometimes these holes are drilled after the crankshaft is installed in the engine. Some manufacturers are able to control casting quality so closely that counterweight machining for balancing is not necessary.

There are two ways engine manufacturers balance an engine:

- **Externally balanced.** Weight is added to the harmonic balancer (vibration damper) and flywheel or the flex plate.
- **Internally balanced.** All rotating parts of the engine are individually balanced, including the harmonic balancer and flywheel (flex plate).

For example, the 350-cubic-inch Chevrolet V-8 is internally balanced, whereas the 400-cubic-inch Chevrolet V-8 uses an externally balanced crankshaft. The harmonic balancer used on an externally balanced engine has additional weight.

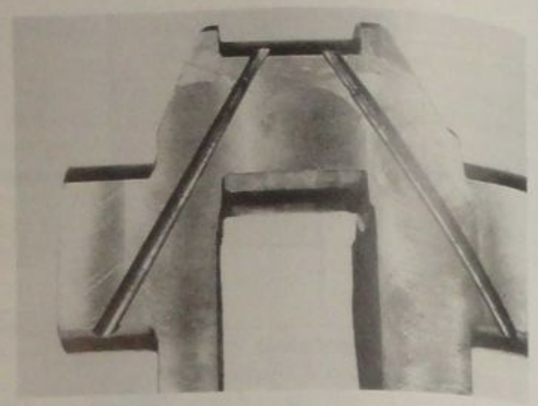


Figure 29–47 Crankshaft sawed in half, showing drilled oil passages between the main and rod bearing journals.

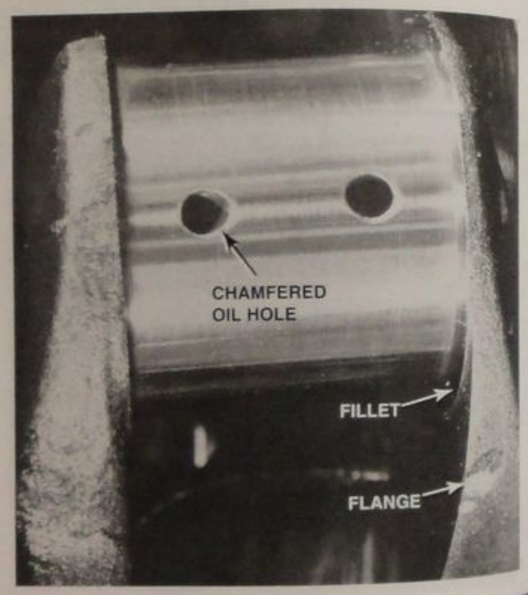


Figure 29–48 Typical chamfered hole in a crankshaft bearing journal.

CRANKSHAFT OILING HOLES

The crankshaft is drilled, as shown in Figure 29–47, to allow oil from the main bearing oil groove to be directed to the connecting rod bearings. The oil on the bearings forms a hydrodynamic oil film to support bearing loads. Some of the oil may be sprayed out through a spit or bleed hole in the connecting rod. The rest of the oil leaks from the edges of the bearing. It is thrown from the bearing against the inside surfaces of the engine. Some of the oil that is thrown from the crankshaft bearings will land on the camshaft lobes to lubricate the lobes. A part of the throw-off oil splashes on the cylinder wall to lubricate the piston and rings.

Stress tends to concentrate at oil holes drilled through the crankshaft journals. These holes are usually located where the crankshaft loads and stresses are the lowest. The edges of the oil holes are carefully chamfered to relieve as much stress concentration as possible. Chamfered oil holes are shown in Figure 29–48.

FREQUENTLY ASKED QUESTION ???

What Does "a Cross-Drilled Crankshaft" Mean?

A cross-drilled crankshaft means that there are two instead of only one oil hole leading from the main bearing journal to the rod bearing journal. Oil is supplied to the main bearing journals through oil galleries in the block. A cross-drilled crankshaft has two outlet holes for oil to reach the drilled passage that supplies oil to the rod journal. See Figure 29–49.

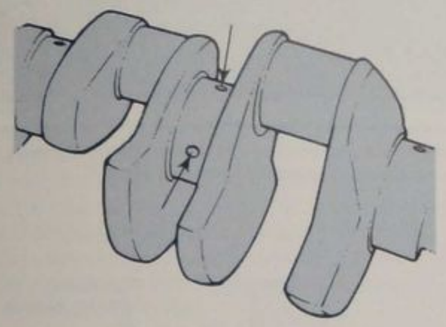


Figure 29–49 A cross-drilled crankshaft is used on some production engines and is a common racing modification.

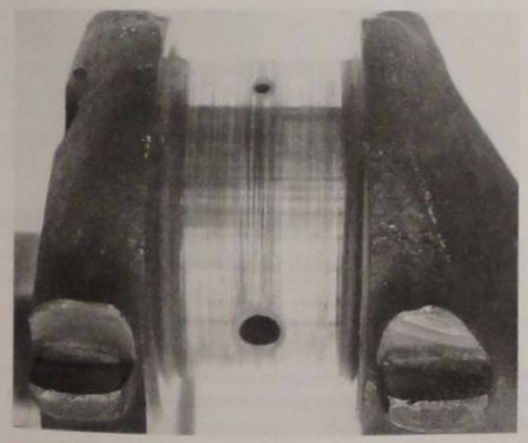


Figure 29–50 Scored connecting rod bearing journal.

CRANKSHAFT INSPECTION

Shaft damage includes scored bearing journals, bends or warpage, and cracks. Damaged shafts must be reconditioned or replaced.

The crankshaft is one of the most highly stressed engine parts. *The stress on the crankshaft increases by four times every time the engine speed doubles.* Any sign of a crack is a cause to reject the crankshaft. Most cracks can be seen during a close visual inspection. Crankshafts should also be checked with Magnaflux, which will highlight tiny cracks that would lead to failure.

Bearing journal scoring is a common crankshaft defect. Scoring appears as scratches around the bearing journal surface. Generally, there is more scoring near the center of the bearing journal, as shown in Figure 29–50.

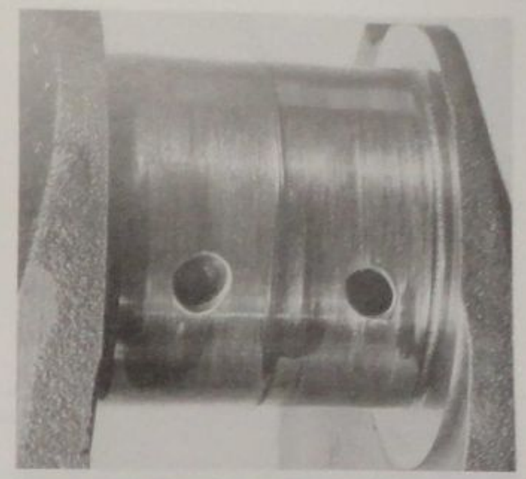


Figure 29–51 Connecting rod journal badly worn from lack of lubrication.

Crankshaft journals should be inspected for nicks, pits, or corrosion. Roughness and slight bends in journals can be corrected by grinding the journals.

HINT: If your fingernail catches on a groove when rubbed across a bearing journal, the journal is too rough to reuse and must be reground. Another test is to rub a copper penny across the journal. If any copper remains on the crankshaft, it must be reground.

CRANKSHAFT GRINDING

Crankshaft journals that have excessive scoring, out-of-round, or taper should be reground. See Figure 29–51. Crankshafts may require straightening before grinding.

Both crankshaft ends are placed in rotating heads on one style of crankshaft grinder. The main bearing journals are ground on the centerline of the crankshaft. The crankshaft is then offset in the two rotating heads just enough to make the crankshaft main bearing journal centerline rotate around the centerline of the crankpin. The crankshaft will then be rotating around the crankpin centerline. The journal on the crankpin is reground in this position. The crankshaft must be repositioned for each different crankpin center.

In another type of crankshaft grinder, the crankshaft always turns on the main bearing centerline. The grinding head is programmed to move in and out as the crankshaft turns to grind the crankpin bearing journals. The setup time is reduced when this type of grinder is used. Figure 29–52 shows a crankshaft being ground. Crankshafts are usually ground to the following undersize:

- 0.010 inch
- 0.020 inch
- 0.030 inch

The finished journal should be accurately ground to size with a smooth-surface finish. The radius of the fillet area on the sides of the journal should also be the same as the original. The journal is polished after grinding, using a 320-grit polishing cloth and oil to remove the fine metal "fuzz" remaining on the journal. See



Figure 29–52 A crankshaft being ground.



Figure 29–53 All crankshafts should be polished after grinding. Both the crankshaft and the polishing cloth are being revolved.

Figure 29–53. This fuzz feels smooth when the shaft turns in its direction. As the shaft turns in the opposite direction, the fuzz feels like a fine milling cutter. Polishing removes this fuzz. The crankshaft is rotated in its normal direction of rotation so that the polishing cloth can remove the fuzz. This leaves a smooth shaft with the proper surface finish. *Most crankshaft grinders grind in the direction opposite of rotation and then polish in the same direction as rotation.* The oil hole chamfer in the journal should be smoothed so that no sharp edge remains to cut the bearing. Finally, the crankshaft oil passages are thoroughly cleaned. The reground journals are coated with oil to keep them from rusting until they are to be cleaned for assembly.

WELDING A CRANKSHAFT

Sometimes it is desirable to salvage a crankshaft by building up a bearing journal and then grinding it to the original journal size. This is usually done by either electric arc welding or a metal spray.



Figure 29–54 An excessively worn crankshaft can be restored to useful service by welding the journals, and then machining them back to the original size.

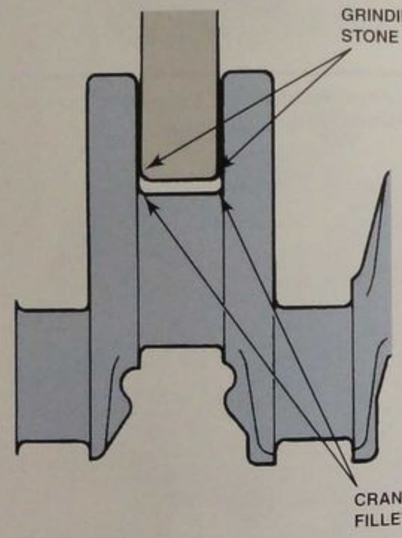


Figure 29–55 The rounded fillet area of the crankshaft is formed by the corners of the grinding stone.

See Figure 29–54. Sometimes the journal is chrome plated. Chrome plating makes an excellent bearing surface when the chrome is well bonded. If the bonding loosens, it will cause an immediate bearing failure.

RELIEVING STRESS ON THE CRANKSHAFT

The greatest area of stress on a crankshaft is the fillet area. See Figure 29–55.

Stress relief is achieved by blasting the fillet area of the journals with #320 steel shot. This strengthens the fillet area and helps to prevent the development of cracks in this area. Gray duct tape is commonly used to cover the journal to prevent damage to the rest of it. Stress relief procedures are usually performed after the grinding and polishing of the crankshaft.

TECH TIP ✓ **The Knock of a Flex Plate**

The source of a knocking noise in an engine is often difficult to determine without disassembling the engine. Generally, a deep engine knocking noise means that serious damage has occurred to the rods or main bearings and related parts. A flex plate (drive plate) is used on automatic transmission-equipped engines to drive the torque converter and provide a ring gear for the starter motor to crank the engine. Two common flex plate-related noises and their causes are as follows:

- Torque converter attaching bolts or nuts can loosen (this is most common in four-cylinder engines, where vibration is more severe than in six- or eight-cylinder engines). The torque converter can then pound on the holes of the flex plate, causing a loud knocking sound. However, if there is a load on the engine, as when the transmission is in drive or while driving under load, the sound should stop. At idle in park or neutral, the noise will be loudest, because the torque converter can float and will hit the sides of the holes in the flex plate.
- If the flex plate is cracked, the resulting noise is very similar to a connecting rod or main bearing knock. The noise also seems to change at times, leading many technicians to believe that it involves a moving internal part that is lubricated, such as a rod or main bearing. The drive belts can also make a similar noise when they are loose, and belt-driven accessories can also produce similar noises.

Diagnosis should proceed as follows:
During the diagnostic procedure, the technician should disconnect one drive belt at a time (if there is more than one) and then start the engine in an attempt to isolate the noise. Noises can be transmitted throughout the entire length of the engine through the crankshaft, making the source of the noise more difficult to isolate. If the flex plate is cracked, the noise is most noticeable when there is a change in engine speed or load. To help diagnose a cracked flex plate, raise engine speed to a high idle (1500 to 2000 RPM), then turn the ignition switch off. Before the engine stops, turn the ignition back on. If a knocking noise is heard when the engine restarts, the flex plate is cracked.

ENGINE BEARINGS

Engine bearings are the main supports for the major moving parts of any engine. Engine bearings are important for the following reasons:

1. The clearance between the bearings and the crankshaft is a major factor in maintaining the proper oil pressure throughout the entire engine. Most engines are designed to provide the maximum protection and lubrication to the engine bearings above all else.
2. Engine durability relies on bearing life. Bearing failure usually results in immediate engine failure.
3. Engine bearings are designed to support the operating loads of the engine and, with the lubricant, provide minimum friction. This must be achieved at all designed engine speeds. The bearings must be able to operate for long periods of time, even when small foreign particles are in the lubricant.

Most engine bearings are of the **plain** or **sleeve bearing** type. See Figure 29–56. Most bearing halves, or shells, do not have uniform thickness. The wall thickness of most bearings is largest in the center, called the **bearing crown.** The bearing thickness then tapers to a thinner measurement at each parting line. See Figure 29–57. The tapered wall keeps bearing clearances close at the top and bottom of the bearing, which are the more loaded areas and allow more oil flow at the sides of the bearing. Both need a constant flow of lubricating oil. In automotive engines, the lubricating system supplies oil to each bearing continuously when the engine runs. Bearings and journals *only* wear when the parts come in contact with each other or when foreign particles are present.

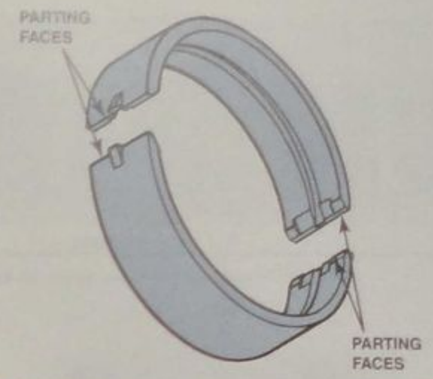


Figure 29–56 The two halves of a plain bearing meet at the parting faces.

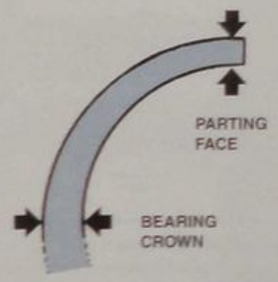


Figure 29–57 Bearing manufacturers refer to this bearing wall shape as an eccentric wall.

Oil enters the bearing through the oil holes and grooves. It spreads into a smooth wedge-shaped oil film that supports the bearing load.

BEARING LOADS

It is important that the engine have large enough bearings that the bearing load is within the strength limits of the bearings. Bearing load capacity is calculated by dividing the bearing load in pounds by the projected area of the bearing. The projected area is the bearing length multiplied by the bearing diameter. The load on engine bearings is determined by developing a polar bearing load diagram that shows the amount and direction of the instantaneous bearing loads. Bearing load diagrams are shown in Figure 29–58.

The forces on the engine bearings vary with engine speed and load. On the intake stroke, the inertia force is opposed by the force of drawing in the air–fuel mixture. On the compression and power strokes, there is also an opposing force on the rod bearings. On the exhaust stroke, however, there is no opposing force to counteract the inertia force of the piston coming to a stop at TDC. The result is a higher force load on the *bottom* rod bearing due to inertia at TDC of the exhaust stroke. These forces tend to stretch the big end of the rod in the direction of rod movement.

1. As engine speed (RPM) increases, rod bearing loads decrease because of the balancing of inertia and opposing loads.
2. As engine speed (RPM) increases, the main bearing loads increase.

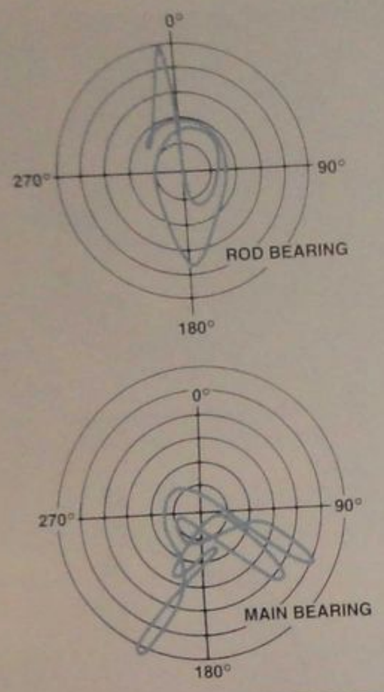


Figure 29–58 Typical rod and main bearing load diagrams. The circles on these polar diagrams indicate the amount of force on the bearing as it rotates. Notice that most of the forces on the connecting rod bearing are vertical (up and down), as you would expect; most of the forces on the main bearing are downward, again as expected.

NOTE: This helps explain why engine blocks with four-bolt main bearing supports are really only needed for high-engine speed stability.

3. Because the loads on bearings vary and affect both rod and main bearings, it is generally recommended that *all* engine bearings be replaced at one time.

BEARING FATIGUE

Bearings tend to flex or bend slightly under changing loads. This is especially noticeable in reciprocating engine bearings. Bearing metals, like other metals, tend to fatigue and break after being flexed or bent a number of times. Flexing starts fatigue, which shows up as fine cracks in the bearing surface because the bearing material became **work hardened.** These cracks gradually deepen almost to the bond between the bearing metal and the backing metal. The cracks then cross over and intersect with each other, as illustrated in Figure 29–59. In time, this will allow a piece of bearing material to fall out. The length of time before fatigue will cause failure is called the **fatigue life** of the bearing. Bearings must have a long fatigue life for normal engine service. The harder the bearing material, the longer its fatigue life. Soft bearings have a short fatigue life and low bearing load strength. They are generally low in cost and can only be used where the bearing requirements are low. See Figures 29–60 and 29–61.

BEARING CONFORMABILITY

The ability of bearing materials to creep or flow slightly to match shaft variations is called **conformability.** The bearing conforms to

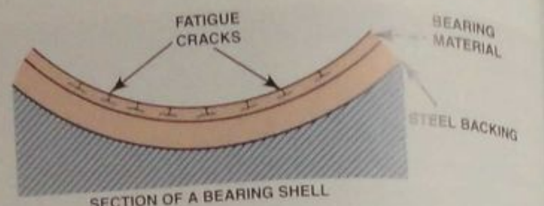


Figure 29–59 Shape of fatigue cracks in a bearing. If the bearing is subjected to continued high loads, the cracks expand and eventually cause the bearing material to flake off from the steel backing.



Figure 29–60 Bearing material missing from the shell as a result of fatigue.



Figure 29–61 Bearing material missing from the bearing as a result of fatigue failure.

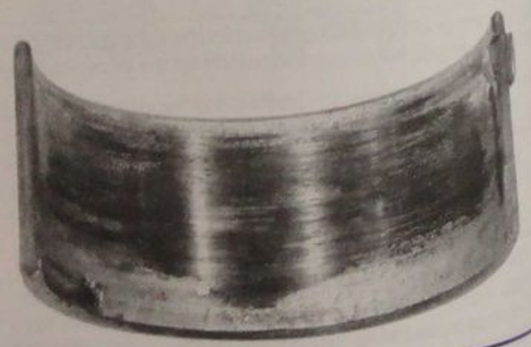


Figure 29–62 Bearing wear caused by a misaligned journal. A bent connecting rod could also cause similar bearing wear.

the shaft during the engine break-in period. In modern automobile engines, there is little need for bearing conformability or break-in because automatic processing has achieved machining tolerances that keep the shaft very close to the designed size. See Figure 29–62.

BEARING EMBEDABILITY

Engine manufacturers have designed engines to produce minimum crankcase deposits. This has been done by providing them with oil

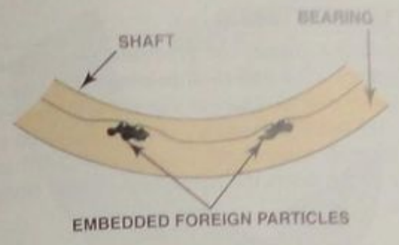


Figure 29–63 Bearing material covers foreign material as it embeds into the bearing.



Figure 29–64 Foreign particles such as dirt embedded in the bearing material.

filters, air filters, and closed crankcase ventilation systems that minimize contaminants. Still, some foreign particles get into the bearings. The bearings must be capable of embedding these particles into the bearing surface so that they will not score the shaft. To fully embed the particle, the bearing material gradually works across the particle, completely covering it. The bearing property that allows it to do this is called **embedability.** Embedability is illustrated in Figures 29–63 and 29–64.

BEARING DAMAGE RESISTANCE

Under some operating conditions, the bearing will be temporarily overloaded. This will cause the oil film to break down and allow the shaft metal to come in contact with the bearing metal. As the rotating crankshaft contacts the bearing high spots, the spots become hot from friction. The friction causes localized hot spots in the bearing material that seize or weld to the crankshaft. The crankshaft then breaks off particles of the bearing material and pulls the particles around with it, scratching or scoring the bearing surface. See Figures 29–65 and 29–66. Bearings have a characteristic called **score resistance.** It prevents the bearing materials from seizing to the shaft during oil film breakdown.

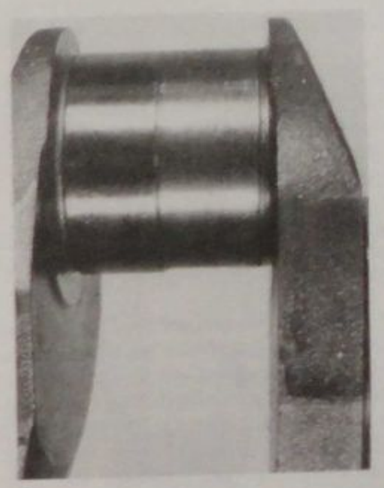
By-products of combustion form acids in the oil. The bearings' ability to resist attack from these acids is called **corrosion resistance.** Corrosion can occur over the entire surface of the bearing. This will remove material and increase the oil clearance. It can also leach or eat into the bearing material, dissolving some of the bearing material alloys. Either type of corrosion will reduce bearing life.

BEARING MATERIALS

Three materials are used for automobile engine bearings: **babbitt, copper-lead alloy,** and **aluminum.** A layer of the bearing materials 0.010 to 0.020 inch (0.25 to 0.50 millimeter) thick is applied over a



Figure 29–65 Bearing material starting to leave the steel backing.



(a)



(b)

Figure 29–66 Typical results of oil pressure loss: (a) extreme wear of the connecting rod journal, (b) overheating finally leading to failure of the bearing.

low-carbon steel backing. An engine bearing is called a **bearing shell,** which is a steel backing with a surface coating of bearing material. The steel provides support needed for the shaft load. The bearing material meets the rest of the bearing operating requirements.

Babbitt Babbitt is the oldest automotive bearing material. Isaac Babbitt (1799–1862) first formulated this material in 1839. An excellent bearing material, it was originally made from a combination of lead, tin, and antimony. Lead and tin are alloyed with small quantities of copper and antimony to give it the required strength. Babbitt is still used in applications in which material is required for soft shafts running under moderate loads and speeds. It will work with occasional borderline lubrication and oil starvation without failure.

Tri-Metal Copper-lead alloy is a stronger and more expensive bearing material than babbitt. It is used for intermediate- and high-speed applications. Tin, in small quantities, is often alloyed with the copper-lead bearings. This bearing material is most easily damaged by corrosion from acid accumulation in the engine oil. Corrosion results in bearing journal wear as the bearing is eroded by the acids.

Many of the copper-lead bearings have an **overlay,** or third layer, of metal. This overlay is usually of babbitt. Babbitt-overlayed bearings have high fatigue strength, good conformity, good embeddability, and good corrosion resistance. The overplated bearing is a premium bearing. It is also the most expensive because the overplating layer, from 0.0005 to 0.001 inch (0.0125 to 0.025 millimeter) thick, is put on the bearing with an **electroplating** process. The layers of bearing material on a bearing shell are illustrated in Figure 29–67.

Aluminum Aluminum was the last of the three materials to be used for automotive bearings. Automotive bearing aluminum has small quantities of tin and silicon alloyed with it. This makes a stronger but more expensive bearing than either babbitt or copper-lead alloy.

Most of its bearing characteristics are equal to or better than those of babbitt and copper-lead. Aluminum bearings are well suited to high-speed, high-load conditions and do not contain lead, which is a benefit to the environment both at the manufacturing plant and for the technician who may be exposed to the bearings.

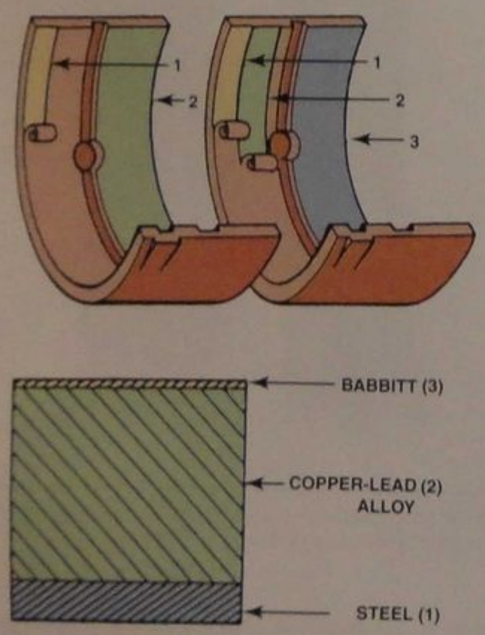


Figure 29–67 Typical two-layer and three-layer engine bearing insert showing the relative thickness of the various materials.

BEARING MANUFACTURING

Modern automotive engines use **precision insert-type bearing shells,** sometimes called **half-shell bearings.** The bearing is manufactured to very close tolerance so that it will fit correctly in each application. The bearing, therefore, must be made from precisely the correct materials under closely controlled manufacturing conditions. Figure 29–68 shows the typical bearing shell types found in most engines.

BEARING SIZES

Bearings are usually available in standard (std) size, and in measurements of 0.010, 0.020, and 0.030 inch *undersize.* See Figure 29–69.

Even though the bearing itself is thicker for use on a machined crankshaft, the bearing is referred to as undersize because the crankshaft journals are undersize. Factory bearings may be available in 0.0005 or 0.001 inch undersize for precision fitting of a production crankshaft.

Before purchasing bearings, be sure to use a micrometer to measure *all* main and connecting rod journals.

BEARING CLEARANCE

The bearing-to-journal clearance may be from 0.0005 to 0.0025 inch (0.025 to 0.060 millimeter), depending on the engine. Doubling the

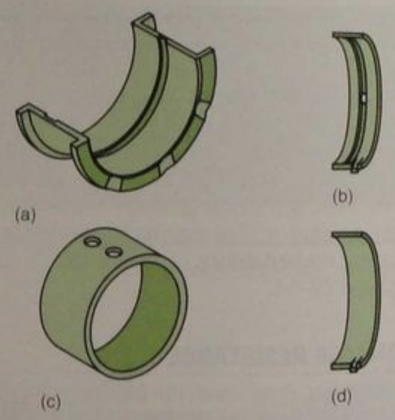


Figure 29–68 Typical bearing shell types found in modern engines: (a) half-shell thrust bearing, (b) upper main bearing insert, (c) lower main bearing insert, (d) full round-type camshaft bearing.

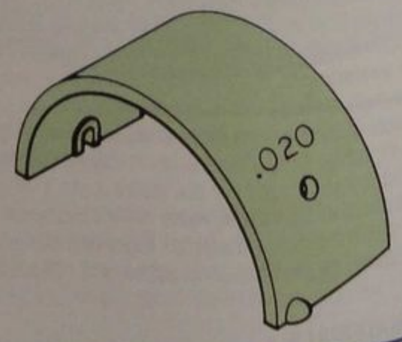


Figure 29–69 Bearings are often marked with an undersize dimension. This bearing is used on a crankshaft with a ground journal that is 0.020 inch smaller in diameter than the stock size.

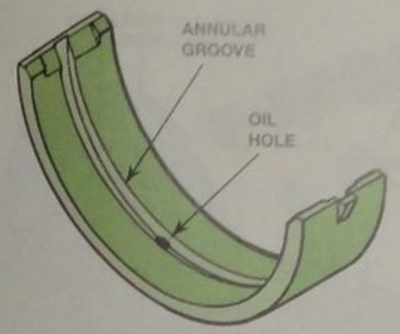


Figure 29–70 Many bearings are manufactured with a groove down the middle to improve the oil flow around the main journal.

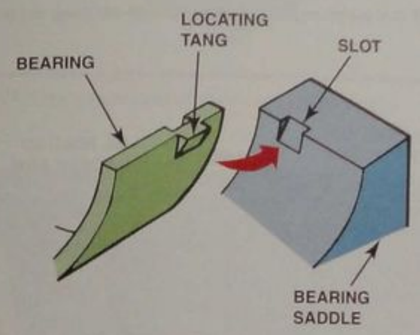


Figure 29–71 The tang and slot help index the bearing in the bore.

journal clearance will allow more than *four* times as much oil to flow from the edges of the bearing. The oil clearance must be large enough to allow an oil film to build up, but small enough to prevent excess oil leakage, which would cause loss of oil pressure. A large amount of oil leakage at one of the bearings would starve other bearings farther along in the oil system. This would result in the failure of the oil-starved bearings. See Figure 29–70.

BEARING SPREAD AND CRUSH

A lip or tang locates the bearing shell in the housing, as shown in Figure 29–71. The bearing design also includes bearing **spread** and **crush,** as illustrated in Figure 29–72.

The bearing shell has a slightly larger arc than does the bearing housing. This difference is called bearing spread and it makes the shell 0.005 to 0.020 inch (0.125 to 0.500 millimeter) wider than the housing bore. Spread holds the bearing shell in the housing while the engine is being assembled. When the bearing is installed, each end of the bearing shell is slightly above the parting surface. When the bearing cap is tightened, the ends of the two bearing shells touch and are forced together. This force is called bearing crush. Crush holds the bearing in place and keeps the bearing from turning when the engine runs. Crush must exert a force of at least 12,000 PSI (82,740 kPa) at 250°F (121°C) to hold the bearing securely in place. A stress of 40,000 PSI (275,790 kPa) is considered maximum to avoid damaging the bearing or housing. See Figure 29–73. Bearing shells that do not have enough crush may rotate with the shaft. The result is called a **spun bearing,** as pictured in Figure 29–74.

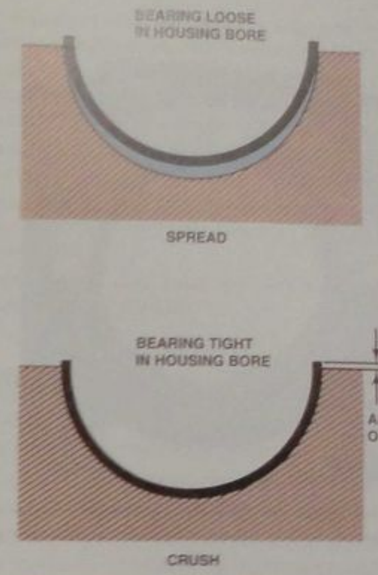


Figure 29–72 Bearing spread and crush.

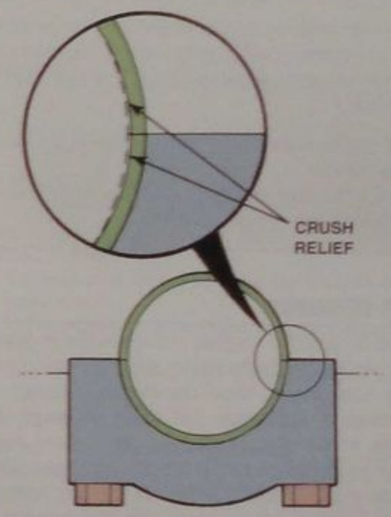


Figure 29–73 Bearings are thinner at the parting line faces to provide crush relief.

Replacement bearings should be of a quality as good as or better than that of the original bearings. The replacement bearings must also have the same oil holes and grooves.

CAUTION: Some bearings may have oil holes in the top shell only. If these are incorrectly installed, no oil will flow to the connecting rods or main rods, which will result in instant engine failure.

Modified engines have more demanding bearing requirements and therefore usually require a higher-quality bearing to provide satisfactory service.

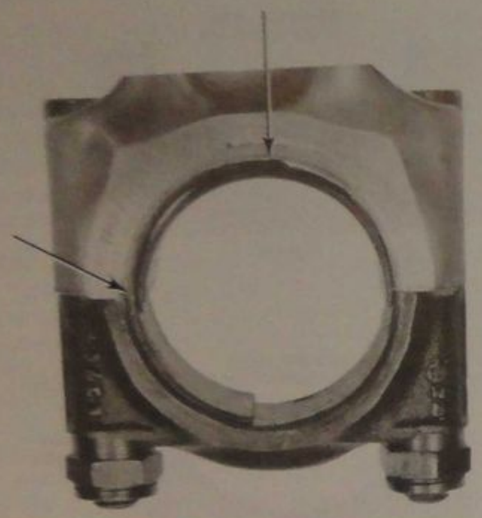


Figure 29–74 Spun bearing. The lower cap bearing has rotated under the upper rod bearing.

TECH TIP ✔ **Count Your Blessings and Your Pan Bolts!**

Replacing cam bearings can be relatively straightforward or can involve keeping count of the number of oil pan bolts! For example, Buick-built V-6 engines use different cam bearings depending on the number of bolts used to hold the oil pan to the block.

- Fourteen bolts in the oil pan. The front bearing is special, but the rest of the bearings are the same.
- Twenty bolts in the oil pan. Bearings #1 and #4 use two oil feed holes. Bearings #2 and #3 use single oil feed holes.

CAMSHAFT BEARINGS

The camshaft in pushrod engines rotates in sleeve bearings that are pressed into bearing bores within the engine block. Overhead camshaft bearings may be either sleeve-type bushings called **full round bearings** or **split-type** (half-shell) **bearings,** depending on the design of the bearing supports. In pushrod engines, the cam bearings are installed in the block. See Figure 29–75. The best rule of thumb to follow is to replace the cam bearings whenever the main bearings are replaced. The replacement cam bearings must have the correct outside diameter to fit snugly in the cam bearing bores of the block. They must have the correct oil holes and be positioned correctly. See Figure 29–76. Cam bearings must also have the proper inside diameter to fit the camshaft bearing journals.

In many engines, each cam bearing is a different size—the largest is in the front and the smallest is in the rear. The cam bearing journal size must be checked and each bearing identified before assembly is begun. The location of each new cam bearing can be marked on the outside of the bearing with a felt-tip marker to help avoid mixing up bearings. Marking in this way will not affect the bearing size or damage the bearing in any way. Cam bearings should be installed "dry" (not oiled) to prevent the cam bearing from moving (spinning) after installation. If the cam bearing were oiled, the rotation of the camshaft could cause the cam bearing to rotate and block oil holes that lubricate the camshaft.

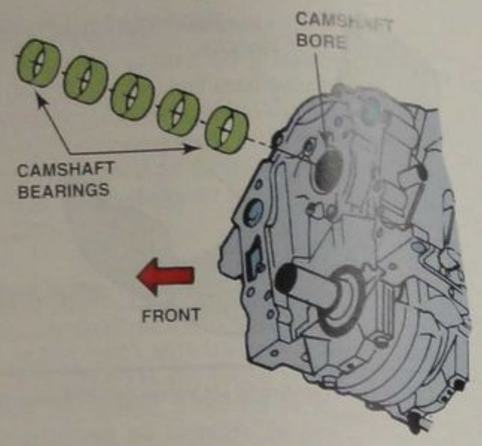


Figure 29–75 Cam-in-block engines support the camshaft with sleeve-type bearings.

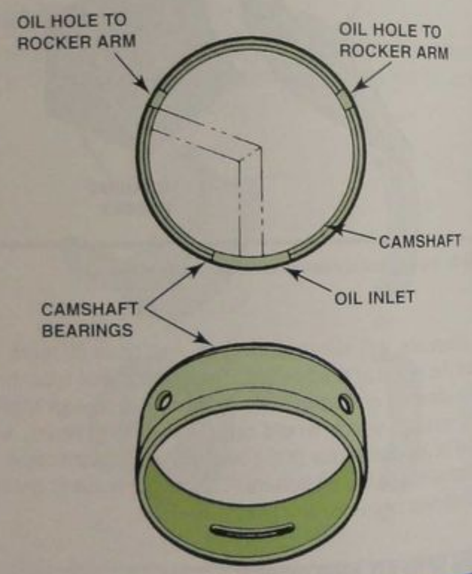


Figure 29–76 Camshaft bearings must be installed correctly so that oil passages are not blocked.

Camshaft bearings used on overhead camshaft engines may be either full round or split depending on the engine design. See Figure 29–77.

TECH TIP ✔ **Do No Harm**

All engine parts should be stored in a safe location to help avoid damage prior to being installed in an engine. All camshafts and crankshafts should be stored vertically to avoid causing bending or warpage of these parts that could cause difficulty when the engine is being assembled. See Figure 29–78 for one method of safely storing crankshafts.

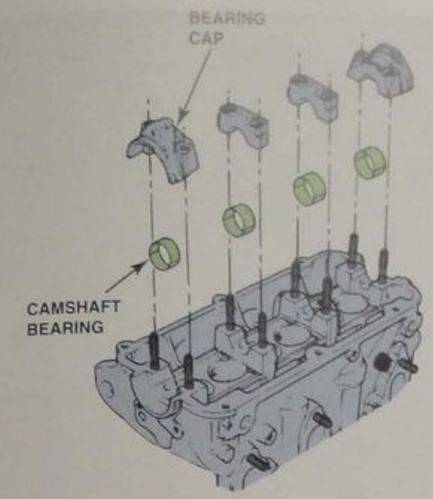


Figure 29–77 Some overhead camshaft engines use split bearing inserts.



Figure 29–78 Crankshafts should be stored vertically to prevent possible damage or warpage. This clever bench-mounted tray for crankshafts not only provides a safe place to store crankshafts but it is out-of-the-way and cannot be accidentally tipped.

SUMMARY

1. Engine blocks are either cast iron or aluminum.
2. Cores are used inside a mold to form water jackets and cylinder bores. After the cast iron has cooled, the block is shaken, which breaks up the cores so that they fall out of openings in the side of the block. Core plugs are used to fill the holes.
3. The block deck is the surface to which the cylinder head attaches. This surface must be flat and true for proper engine operation.
4. All bolt holes should be chamfered and cleaned with a thread chaser before assembly.
5. Forged crankshafts have a wide separation line.
6. Cast crankshafts have a narrow mold parting line.
7. Even-firing 90-degree V-6 engines require that the crankshaft be splayed to allow for even firing.
8. Lubrication to the main bearings is fed through the main oil gallery in the block. Oil for the rod bearings comes from holes in the crankshaft drilled between the main journal and the rod journal.

9. A vibration damper, also known as a harmonic balancer, is used to dampen harmful twisting vibrations of the crankshaft.
10. Most engines are internally balanced. This means that the crankshafts and vibration damper are both balanced. Other engines use the vibration damper to balance the crankshaft and are called externally balanced engines.
11. Most crankshafts can be reground to be 0.010, 0.020, or 0.030 inch undersize.
12. Most engine bearings are constructed with a steel shell for strength and are covered with a copper-lead alloy. Many bearings also have a thin overlay of babbitt.
13. Bearings should have spread and crush to keep them from spinning when the crankshaft rotates.

REVIEW QUESTIONS

1. What does "decking the block" mean?
2. Explain what "microinch finish" means.
3. What is the difference between deglazing and honing a cylinder?
4. What is the best method to use to clean an engine block after honing?
5. How many degrees of crankshaft rotation are there between cylinder firings on an inline four-cylinder engine, an inline six-cylinder engine, and a V-8 engine?
6. List four engine bearing properties.
7. Describe bearing crush and bearing spread.

CHAPTER QUIZ

1. The block deck is the _____.
   a. Bottom (pan rail) of the block
   b. Top surface of the block
   c. Valley surface of a V-type engine
   d. Area where the engine mounts are attached to the block
2. The standard measurement for surface finish is the microinch. Which of the following is correct?
   a. The rougher the surface, the higher the microinch finish measurement.
   b. The smoother the surface, the higher the microinch finish measurement.
   c. The rougher the surface, the lower the microinch finish measurement.
   d. Both b and c.
3. A four-cylinder engine fires one cylinder at every _____ degrees of crankshaft rotation.
   a. 270
   b. 180
   c. 120
   d. 90
4. A splayed crankshaft is a crankshaft that _____.
   a. Is externally balanced
   b. Is internally balanced
   c. Has offset main bearing journals
   d. Has offset rod journals
5. The thrust bearing surface is located on one of the main bearings to control thrust loads caused by _____.
   a. Lugging the engine
   b. Torque converter or clutch release forces
   c. Rapid deceleration forces
   d. Both a and c
6. If any crankshaft is ground, it must also be _____.
   a. Shot peened
   b. Chrome plated
   c. Polished
   d. Externally balanced

7. If bearing-to-journal clearance is doubled, how much oil will flow?
   a. One-half as much
   b. The same amount if the pressure is kept constant
   c. Double the amount
   d. Four times the amount
8. Typical journal-to-bearing clearance is _____.
   a. 0.00015 to 0.00018 inch
   b. 0.0005 to 0.0025 inch
   c. 0.150 to 0.250 inch
   d. 0.020 to 0.035 inch
9. A bearing shell has a slightly larger arc than the bearing housing. This difference is called _____.
   a. Bearing crush
   b. Bearing tang
   c. Bearing spread
   d. Bearing saddle
10. Bearing _____ occurs when a bearing shell is slightly above the parting surface of the bearing cap.
   a. Overlap
   b. Crush
   c. Cap lock
   d. Interference fit

CHAPTER 30 Engine Blueprinting and Assembly

OBJECTIVES: After studying Chapter 30, the reader will be able to: Prepare for Engine Repair (A1) ASE certification test content area "C" (Engine Block Diagnosis and Repair). • List the steps for assembling an engine. • Describe how to measure bearing oil clearance using plastic gauging material. • Explain how to check for crankshaft end play and connecting rod side clearance. • Discuss how to fit pistons to individual cylinder bores. • Describe how to test for proper oil pressure before starting the engine.

KEY TERMS: acetic acid • amine-type silicone • armor • braided fabric seals • cork-rubber gasket • crankshaft end play • fire ring • last • multilayered steel (MLS) • no-retorque gasket • piston ring compressor • room-temperature vulcanization (RTV) • strip feeler gauge • torque-angle • torque-to-yield • welsh plugs • wet holes

All parts are attached to the engine block. The block, therefore, must be prepared before assembly can begin. The key to proper assembly of any engine is cleanliness. The work area and the workbench space must be clean to prevent dirt or other engine-damaging particles from being picked up and causing possible serious engine damage.

BLUEPRINTING

The term *blueprinting* means that all of the components of an engine have been carefully measured and checked that they match the specifications listed by the manufacturer. The engine manufacturer builds a new engine to the dimensions and tolerances specified on the blueprint, which is the engineering drawing of the parts and assembly. Therefore, to "blueprint" an engine is to make sure that all component parts and dimensions are within the range specified by the engine manufacturer.

BLOCK PREPARATION

All surfaces of the block should also be checked for damage resulting from the machining processes. Items that should be done before assembly begins include the following:

1. The block, including the oil gallery passages, should be thoroughly cleaned. See Figures 30–1 and 30–2.
2. All threaded bolt holes should be chamfered.
3. All threaded holes should be cleaned with a tap. See Figure 30–3.



Figure 30–1 The best way to clean cylinders is to use soap (detergent) and water and thoroughly clean using a large washing brush. This method floats the machining particles off of the block and washes them away.

INSTALLING CUPS AND PLUGS

Oil gallery plugs should be installed using sealant on the threads. Core holes left in the external block wall are machined and sealed with soft core plugs or expansion plugs (also called freeze plugs or **welsh plugs**).



Figure 30–2 All oil galleries should be cleaned using soap (detergent) and water using a long oil gallery cleaning brush.



Figure 30–3 All threaded holes should be cleaned using a thread chaser or a bottoming tap.

CAUTION: Avoid using Teflon tape on the threads of oil gallery plugs. The tape is often cut by the threads, and thin strips of the tape are then free to flow through the oil galleries where the tape can cause a clog, thereby limiting lubricating engine oil to important parts of the engine.

Soft plugs are of two designs:

- **Convex type.** The core hole is counter bored with a shoulder. The convex soft plug is placed in the counter bore, convex side out. It is driven in and upset with a fitted seating tool. This causes the edge of the soft plug to enlarge to hold it in place. Figure 30–4 shows an installed convex soft plug. A convex plug should be driven in until it reaches the counter bore of the core plug hole.
- **Cup type.** This most common type fits into a smooth, straight hole. The outer edge of the cup is slightly bell mouthed. The bell mouth causes it to tighten when it is driven into the hole to the correct depth with a seating tool. An installed cup-type soft plug is shown in Figure 30–5. A cup plug is installed about 0.020 to 0.050 inch (0.5 to 1.3 millimeters) below the surface of the block, using sealant to prevent leaks. See Figure 30–6.

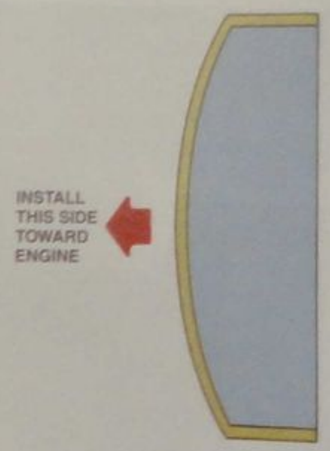


Figure 30–4 Cup plugs have a deep tapered flange. The flange should be coated with water-resistant sealer before being driven into the block.



Figure 30–5 This engine uses many cup plugs to block off coolant and oil passages as well as a large plug over the end of the camshaft bore.

INSTALLING CAM BEARINGS

A cam bearing installing tool is required to insert the new cam bearing without damaging the bearing. A number of tool manufacturers design and sell cam bearing installing tools. Their common feature is a shoulder on a bushing that fits inside the cam bearing, with a means of keeping the bearing aligned as it is installed. Figure 30–7 shows a camshaft bearing on the removing and installing tool. The bearing is placed on the bushing of the tool and rotated to properly align the oil hole. The bearing is then forced into the bearing bore of the block by

either a pulling screw or a slide hammer. A pulling screw type of tool is illustrated in Figure 30–8. The installed bearing must be checked to make sure that it has the correct depth and that the oil hole is indexed with the oil passage in the block. No additional service is required on cam bearings that have been properly installed. The opening at the back of the camshaft is closed with an expansion plug.



Figure 30–6 Sealer should be used on the cup plug before being driven into the block.

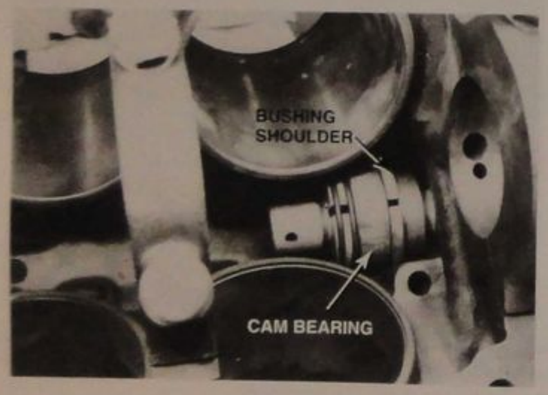


Figure 30–7 Cam bearing tool being used to remove a used cam bearing.

CAUSES OF PREMATURE BEARING FAILURE

According to a major manufacturer of engine bearings, the main causes of premature (shortly after installation) bearing failure include the following:

Dirt (45%)
Misassembly (13%)
Misalignment (13%)
Lack of lubrication (11%)
Overloading or lugging (10%)
Corrosion (4%)
Other (4%)

Many cases of premature bearing failure may result from a combination of several of these items. Therefore, to help prevent bearing failure, *keep everything as clean as possible.*

MEASURING MAIN BEARING CLEARANCE

The engine is assembled from the inside out. Checks are made during assembly to ensure correct fits and proper assembly of the parts.

The main bearings are properly fit before the crankshaft is lubricated or turned. The oil clearance of both main and connecting rod bearings is set by selectively fitting the bearings. In this way the oil clearance can be adjusted to within 0.0005 inch of the desired clearance.

CAUTION: Avoid touching bearings with bare hands. The oils on your fingers can start corrosion of the bearing materials. Always wear protective cloth or rubber gloves to avoid the possibility of damage to the bearing surface.

Bearings are usually made in 0.010, 0.020, and 0.030 inch undersize for use on reground journals. See Figure 30–9 for a typical main bearing set.

The crankshaft bearing journals should be measured with a micrometer to select the required bearing size. Remember that each of the main bearing caps will only fit one location and the caps must be positioned correctly. The correct-size bearings should be placed in the block and cap, making sure that the bearing tangs

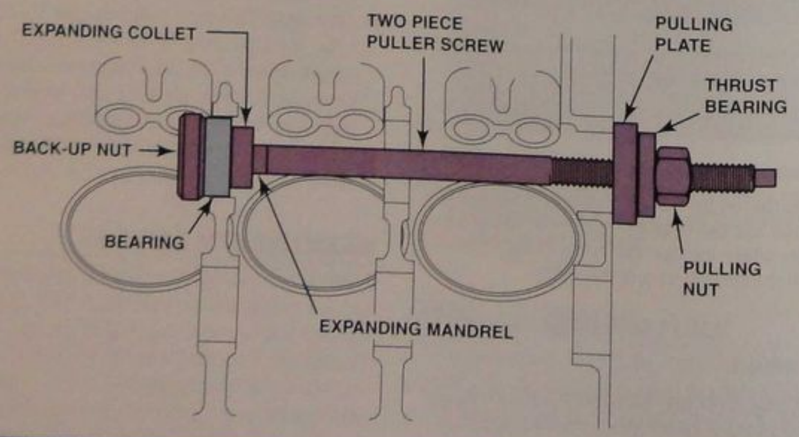


Figure 30–8 Screw-type puller being used to install a new cam bearing. Most cam bearings are crush fit. The full, round bearing is forced into the cam bearing bore.

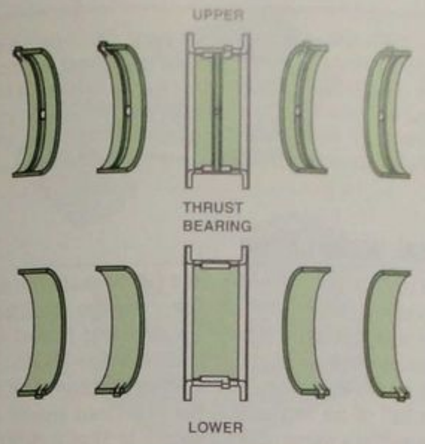


Figure 30–9 Typical main bearing set. Note that the upper halves are grooved for better oil flow and the lower halves are plain for better load support. This bearing set uses the center main bearing for thrust control.

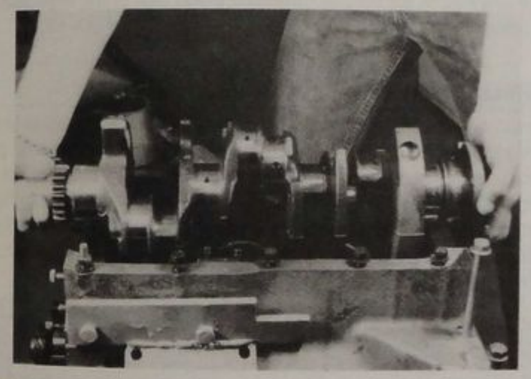


Figure 30–10 Crankshaft being carefully lowered into place.

locks into its slot. The upper main bearing has an oil feed hole. Carefully rest the clean crankshaft in the block on the upper main bearings. Lower it squarely, as shown in Figure 30–10, so that it does not damage the thrust bearing. Place a strip of Plastigage (gauging plastic) on each main bearing journal. Install the main bearing caps and tighten the bolts to specifications. Remove each cap and check the width of the Plastigage with the markings on the gauge envelope, as shown in Figure 30–11. This will indicate the oil clearance. If the shaft is out-of-round, the oil clearance should be checked at the point that has the *least* oil clearance.

CORRECTING BEARING CLEARANCE

The oil clearance can be reduced by 0.001 inch by replacing both bearing shells with bearing shells that are 0.001 inch undersize. The clearance can be reduced by 0.0005 inch by replacing only one of the bearing shells with a bearing shell that is 0.001 inch smaller. This smaller bearing shell should be placed in the engine-block side of the bearing (the upper shell). Oil clearance can be adjusted accurately using this procedure. Never mismatch the bearing shells by more than a 0.001 inch difference in size. Oil clearances normally run from 0.0005 to 0.002 inch.



Figure 30–11 Checking the width of the plastic gauging strip to determine the oil clearance of the main bearing. An alternate method of determining oil clearance includes careful measurement of the crankshaft journal and bearings after they are installed and the main housing bore caps are torqued to specifications.

The crankshaft is removed once the correct oil clearance has been established. The rear oil seal is installed in the block and cap; then the crankshaft journals are lubricated with assembly lubricant.

TECH TIP ✔ **"One to Three"**

When engine technicians are talking about clearances and specifications, the unit of measure most often used is thousandths of an inch (0.001 inch). Therefore, a clearance expressed as "one to three" would actually be a clearance of 0.001 to 0.003 inch. The same applies to parts of a thousandth of an inch. For example, a specification of 0.0005 to 0.0015 inch would be spoken of as simply being "one-half to one and one-half." The unit of a thousandth of an inch is assumed, and this method of speaking reduces errors and misunderstandings.

HINT: Most engine clearance specifications fall within one-to three-thousandths of an inch. The written specification could be a misprint; therefore, if the specification does not fall within this general range, double-check the clearance value using a different source.

LIP SEAL INSTALLATION

Seals are always used at the front and rear of the crankshaft. Overhead cam engines may also have a seal at the front end of the camshaft and at the front end of an auxiliary accessory shaft. Either a lip seal or a rope seal is used in these locations. See Figure 30–12. The rear crankshaft oil seal is installed after the main bearings have been properly fit.

The lip seal may be molded in a steel case or it may be molded around a steel stiffener. The counter bore or guide that supports the

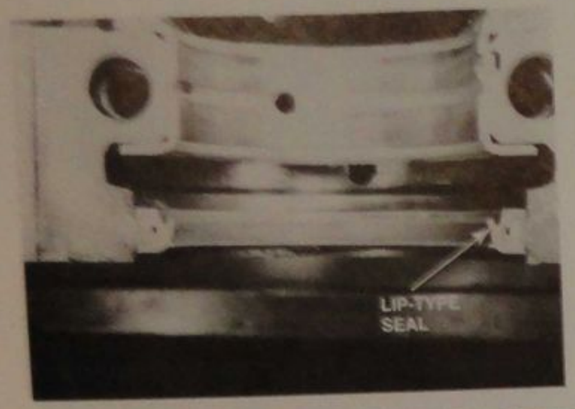


Figure 30–12 Lip-type rear main bearing seal in place. The crankshaft is removed.

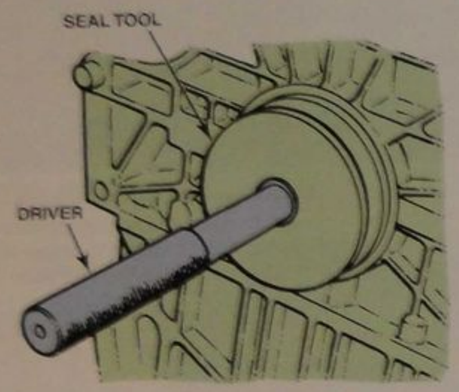


Figure 30–13 Always use the proper driver to install a main seal. Never pound directly on the seal.

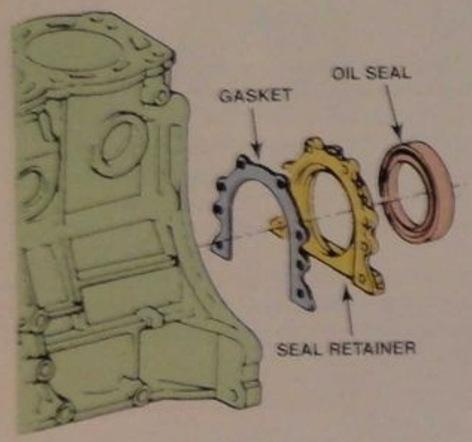


Figure 30–14 The rear seal for this engine mounts to a retainer plate. The retainer is then bolted to the engine block.

seal must be thoroughly clean. In most cases, the back of the lip seal is dry when it is installed. Occasionally, a manufacturer will recommend the use of sealants behind the seal. The engine service manual should be consulted for specific sealing instructions. The lip of the seal should be well lubricated before the shaft and cap are installed. See Figures 30–13 and 30–14.

CAUTION: Teflon seals should not be lubricated. This type of seal should be installed dry. When the engine is first started, some of the Teflon transfers to the crankshaft so a Teflon-to-Teflon surface is created. Even touching the seal with your hands could remove some of the outer coating on the seal and could cause a leak. Carefully read, understand, and follow the installation instructions that should come with the seal.

ROPE SEAL INSTALLATION

Rope-type seals, usually called **braided fabric seals,** are sometimes used as rear crankshaft oil seals. Some engines manufactured by Buick use rope-type seals at both the front and rear of the crankshaft. Rope-type oil seals must be compressed tightly into the groove so that no oil can leak behind them. With the crankshaft removed, the upper half of the rope seal is put in a clean groove and compressed by rolling a round object against it to force it tightly into the groove. A piece of pipe, a large socket, or even a hammer handle can be used for this, as shown in Figure 30–15. When the seal is fully seated in the groove, the ends that extend above the parting surface are cut to be flush with the surface using a sharp single-edge razor blade or a sharp tool specially designed to cut the seal. The same procedures are used to install the lower half of the rope seal in the rear main bearing cap or seal retainer. See Figure 30–16.

INSTALLING THE CRANKSHAFT

The main bearing saddles, the caps, and the back of all the main bearing shells should be wiped clean; the bearing shells can then be put in place. It is important that each bearing tang line up with the slot in the bearing support. The bearing shells must have some spread to hold them in the bearing saddles and caps during assembly. The surface of the bearings is then given a thin coating of assembly lubricant to provide initial lubrication for engine start-up. See Figure 30–17.

The crankshaft with lubricant on the journals is carefully placed in the bearings to avoid damage to the thrust bearing surfaces. The bearing caps are installed with their identification numbers correctly positioned. The caps were originally machined in place, so they can only fit correctly in their original position. The main bearing cap bolts are tightened finger-tight, and the crankshaft is rotated. It should rotate freely.

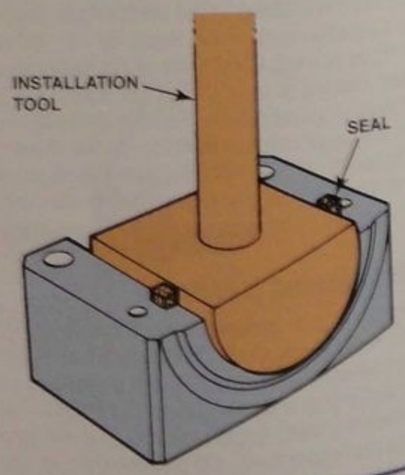


Figure 30–15 Use a special tool or other round object like a hammer handle to roll the seal to the bottom of the groove.

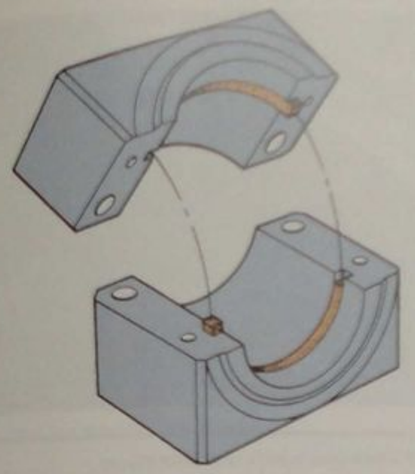


Figure 30–16 Many engine builders prefer to stagger the parting lines of a split seal.



Figure 30–17 Engine assembly lubricant is best to use because it contains additives that provide protection to engine parts during the critical original start-up phase.

MEASURING THRUST BEARING CLEARANCE

Pry the crankshaft forward and rearward to align the cap half of the thrust bearing with the block saddle half. Most engine specifications for thrust bearing clearance (also called **crankshaft end play**) can range from 0.002 to 0.012 inch (0.02 to 0.3 millimeter). This clearance or play can be measured with a feeler gauge (Figure 30–18) or a dial indicator (Figure 30–19).

If the clearance is too great, oversize main thrust bearings may be available for the engine. Semifinished bearings may have to be purchased and machined to size to restore proper tolerance.

TIGHTENING PROCEDURE FOR THE MAIN BEARING

Tighten the main bearing caps to the specified assembly torque, and in the specified sequence. Many manufacturers require that the crankshaft be pried forward or rearward during the main bearing tightening process. The crankshaft should turn freely after all main bearing cap bolts are fully torqued. See Figure 30–20. It should never require over 5 pound-feet (6.75 Newton-meters [N-m]) of torque to rotate the crankshaft. An increase in the torque needed to rotate the crankshaft is often caused by a foreign particle that was not removed during cleanup. It may be on the bearing surface, on the crankshaft journal, or between the bearing and saddle.

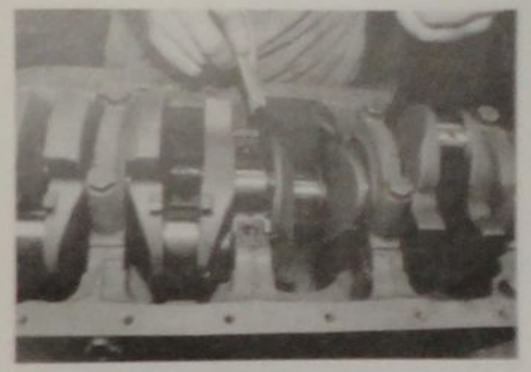


Figure 30–18 Checking crankshaft thrust bearing clearance with a feeler gauge. The technician in this photo has not yet installed the thrust bearing cap; this allows a better view of the actual movement and clearance as the crankshaft is pried back and forth.



Figure 30–19 A dial indicator is being used to check the crankshaft end play (also known as thrust bearing clearance). Always follow the manufacturer's recommended testing procedures.



Figure 30–20 Measuring the crankshaft turning torque after each main bearing cap is properly tightened. An abnormal increase in torque indicates a problem that should be corrected before additional assembly.

INSTALLING TIMING CHAINS AND GEARS

On pushrod engines, the timing gears or chain and sprocket can be installed after the crankshaft. The timing marks should be aligned according to the factory-specified marks. See Figure 30–21. When



Figure 30–21 Timing chain and gears can be installed after the crankshaft and camshaft have been installed. The technician is rotating the crankshaft using the harmonic balancer bolt to check for proper rotating torque and to confirm that the timing marks are aligned.

used, the replaceable fuel-pump eccentric is installed as the cam sprocket is fastened to the cam. The crankshaft should be rotated several times to see that the camshaft and timing gears or chain rotate freely. The timing mark alignment should be rechecked at this time. If the engine is equipped with a slinger ring, it should also be installed on the crankshaft, in front of the crankshaft gear.

It is assumed that the front oil seal is installed in the cover. The timing cover and gasket are placed over the timing gears and/or chain and sprockets. The attaching bolts are loosely installed to allow the damper hub to align with the cover as it fits in the seal. The damper is installed on the crankshaft. On some engines, it is a press-fit and on others it is held with a large center bolt. After the damper is secured, the attaching bolts on the timing cover can be tightened to the specified torque.

PISTON FITTING

After thorough block cleaning, the piston-to-cylinder clearance should be checked to ensure that the piston properly fits the cylinder in which it is to operate. The fit can be checked by determining the difference in the measured size of the piston and cylinder. A **strip feeler gauge** placed between the piston and the cylinder can be used to measure the piston-to-cylinder clearance. The gauge thickness is the desired clearance measurement. Typical piston clearances range from about 0.0005 in. (1/2 thousandth of an inch) to .0025 in. (2 1/2 thousandths of an inch) (0.02 to 0.06 millimeter).

The cylinders and pistons, without rings, should be wiped thoroughly clean to remove any excess protective lubricant and dust that may have accumulated on the surface. The strip thickness (feeler) gauge is placed in the cylinder along the thrust side. The piston is inserted in the cylinder upside down, with the piston thrust surface against the thickness (feeler) gauge. The piston is held in the cylinder with the connecting rod as the strip gauge is withdrawn. A moderate pull (from 5 to 10 pounds) on the gauge indicates that the clearance is the same as the gauge thickness. A light pull indicates that the clearance is greater than the gauge thickness, whereas a heavy pull indicates that the clearance is smaller than the gauge thickness.

All pistons should be tested in all cylinder bores. Even though all cylinders were honed to the exact same dimension and all pistons were machined to the same diameter, some



Figure 30–22 A feeler gauge is used to check piston ring gap.

variation in dimensions will occur. *Each piston should be selectively fitted to each cylinder.* This procedure helps to prevent mismatched assembled components and results in a better-performing and longer-lasting engine. By checking all cylinders, the technician is also assured that the machining of the block was done correctly.

Ring End Gap The bottom of the combustion chamber is sealed by the piston rings. They have to fit correctly in order to seal properly. Piston rings are checked both for side clearance and for gap. See Figure 30–22. Typical ring gap clearances are about 0.004 inch per inch of cylinder bore, or as follows:

Piston Diameter	Ring Gap
2 to 3 inches	0.007 to 0.018 inch
3 to 4 inches	0.010 to 0.020 inch
4 to 5 inches	0.013 to 0.023 inch

NOTE: If the gap is greater than recommended, some engine performance is lost. However, too small a gap will result in scuffing because of ring butting during operation, which forces the rings to scrape the cylinders.

If the ring gap is too large, the ring should be replaced with one having the next oversize diameter. If the ring gap is too small, the ring should be removed and filed to make the gap larger.

INSTALLING PISTON AND ROD ASSEMBLIES

Be sure to note which piston/rod assembly goes into which cylinder. Double-check the following:

1. Be sure the piston notch "front" or arrow points toward the front of the engine.
2. Be sure that the valve reliefs end up closest to the lifter valley on a V-type OHV engine.
3. Be sure that the larger valve reliefs always match the intake valve.



Figure 30–23 On V-type engines that use paired rod journals, the side of the rod with the large chamfer should face toward the crank throw (outward).

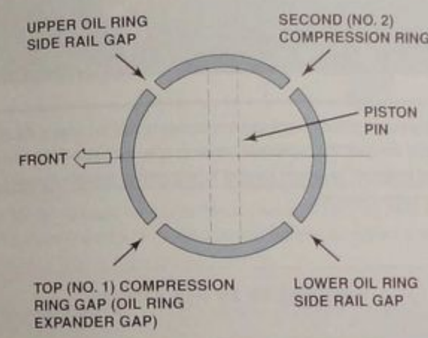


Figure 30–24 One method of piston ring installation showing the location of ring gaps. Always follow the manufacturer's recommended method for the location of ring gaps and for ring gap spacing.

4. Make sure the connecting rod has been installed on the piston correctly—the chamfer on the side of the big end should face outward (toward the crank throw). See Figure 30–23.
5. Be sure the piston ring gaps are set according to the manufacturer's recommendations. See Figure 30–24.

The cylinder is wiped with a lintless cleaning cloth. It is then given a liberal coating of clean engine oil. This oil is spread over the entire cylinder wall surface by hand.

The connecting rod bearings are prepared for assembly in the same way, as are the main bearings. The piston can be dipped in a bath of clean engine oil to lubricate the piston pin as well as the piston rings. See Figure 30–25.

NOTE: Some overlapping (gapless) piston rings are installed dry, without oil. See Figure 30–26. Some manufacturers recommend oiling only the oil control ring. Always check the piston ring instruction sheet for the exact procedure.

When the piston is lifted from the oil, it is held and let drip for a few seconds. This allows the largest part of the oil to run out of the piston and ring grooves. The **piston ring compressor** is then put on the piston to hold the rings in their grooves. See Figures 30–27 and 30–28.

The bearing cap is removed from the rod, and protectors are placed over the rod bolts. See Figure 30–29. The crankshaft is



Figure 30–25 Dipping the piston, with rings installed, into a container of engine oil is one method that can be used to ensure proper lubrication of pistons during installation in the engine cylinder. This method also ensures that the piston pin will be well lubricated.

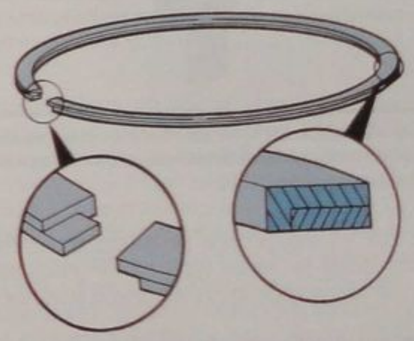


Figure 30–26 A gapless ring is made in two pieces that overlap.

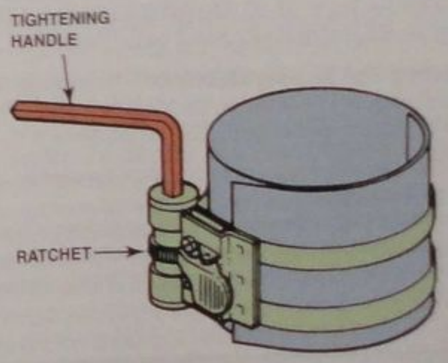


Figure 30–27 This style of ring compressor uses a ratchet to contract the spring band and compress the rings into their grooves.

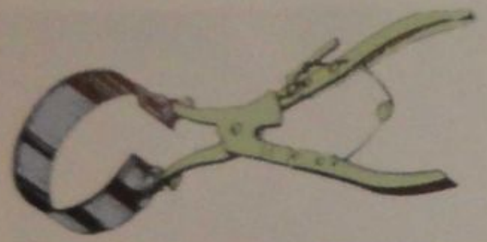


Figure 30–28 This pliers-like tool is used to close the metal band around the piston to compress the rings. An assortment of bands are available to service different size pistons.



Figure 30–29 When threaded onto the rod bolts, these guides not only help align the rod but they also protect the threads and hold the bearing shell in place. The soft ends also will not damage the crankshaft journals.

rotated so that the crankpin is at the bottom center. The upper rod bearing should be in the rod, and the piston should be turned so that the notch on the piston head is facing the front of the engine.

The piston and rod assembly is placed in the cylinder through the block deck. The ring compressor must be kept tightly against the block deck as the piston is pushed into the cylinder. The ring compressor holds the rings in their grooves so that they will enter the cylinder. See Figure 30–30. The piston is pushed into the cylinder until the rod bearing is fully seated on the journal.

Connecting Rod Bearing Clearance The rod cap, with the bearing in place, is put on the rod. There are two methods that can be used to check for proper connecting rod clearance:

- Use Plastigage following the same procedure discussed for main bearing clearance.
- Measure the assembled connecting rod big end devices with the bearing installed and the caps torqued to specification. Subtract the diameter of the rod journal to determine the bearing clearance. See Figure 30–31.

NOTE: Be certain to check for piston-to-crankshaft counterweight clearance. Most manufacturers specify a minimum 0.060 inch (1.5 millimeters).



Figure 30–30 Installing a piston using a ring compressor to hold the rings in the ring grooves of the piston and then using a hammer handle to drive the piston into the bore. Connecting rod bolt protectors have been installed to help prevent possible damage to the crankshafts during piston installation.

TECH TIP ✔ **Tightening Tip for Rod Bearings**

Even though the bearing clearances are checked, it is still a good idea to check and record the torque required to rotate the crankshaft with all piston rings dragging on the cylinder walls. Next, the retaining nuts on one bearing should be torqued; then the torque required to rotate the crankshaft should be rechecked and recorded. Follow the same procedure on all rod bearings. If tightening any one of the rod bearing caps causes a large increase in the torque required to rotate the crankshaft, immediately stop the tightening process. Determine the cause of the increased rotating torque using the same method, as used on the main bearings. Rotate the crankshaft for several revolutions to make sure that the assembly is turning freely and that there are no tight spots.

The rotating torque of the crankshaft with all connecting rod cap bolts fully torqued should be as follows:

- **four-cylinder engine.** 20 pound-feet maximum (88 Newton-meters)
- **six-cylinder engine.** 25 pound-feet maximum (110 Newton-meters)
- **eight-cylinder engine.** 30 pound-feet maximum (132 Newton-meters)

Connecting Rod Side Clearance The connecting rod should be checked to make sure that they still have the correct side clearance. This is measured by fitting the correct thickness of feeler gauge between the connecting rod and the crankshaft cheek of the bearing journal. See Figure 30–32.

A dial gauge can also be set up to measure the connecting rod side clearance.

- *If the side clearance is too great,* excessive amounts of oil may escape that can cause lower-than-normal oil pressure. To correct excessive clearance:
  1. Weld and regrind or replace the crankshaft
  2. Carefully measure all connecting rods and replace those that are too thin or mismatched.

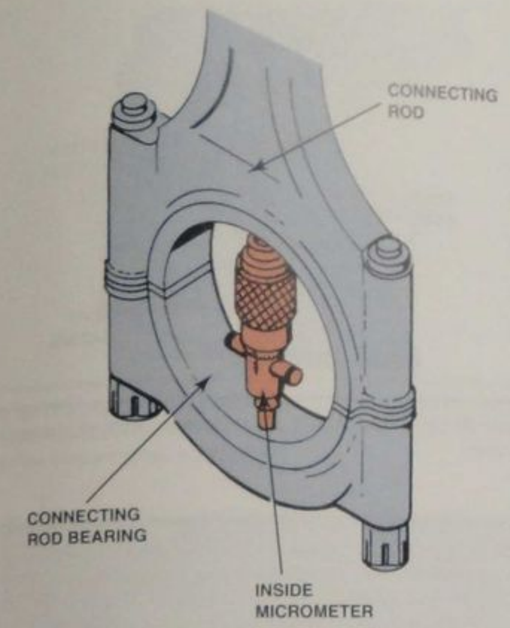


Figure 30–31 An inside micrometer can be used to measure the inside diameter of the big end of the connecting rod with the bearings installed. This dimension subtracted from the rod journal diameter is equal to the bearing clearance.



Figure 30–32 The connecting rod side clearance is measured with a feeler gauge.

- *If the side clearance is too small,* there may not be enough room for heat expansion. To correct a side clearance that is too small:
  1. Regrind the crankshaft
  2. Replace the rods

INSTALLING THE CAMSHAFT FOR OVERHEAD CAM ENGINES

The camshaft is usually installed on overhead cam engines before the head is fastened to the block deck. Some engines have the camshaft located directly over the valves. The cam bearings on these engines can be either one piece or split. The cam bearings and journals are lubricated before assembly. In other engine types, the camshaft bearings are split to allow the camshaft to be installed without the valves being depressed. The caps are tightened evenly to avoid bending the camshaft. The valve clearance or lash is checked with the overhead camshaft in place. Some engines use shims under a follower disk as shown in Figure 30–33. On these, the camshaft is turned so that the follower is on the base circle of the cam. The clearance of each bucket follower can then be checked with a feeler gauge. The amount of clearance is recorded and compared with the specified clearance, and then a shim of the required thickness is put in the top of the bucket followers, as shown in Figure 30–34.

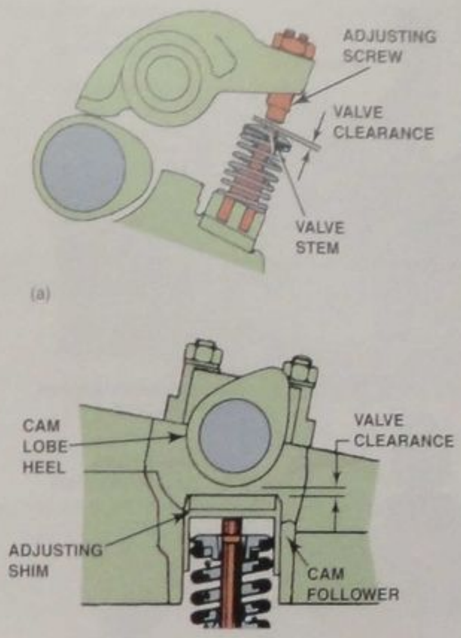


Figure 30–33 Valve clearance allows the metal parts to expand and maintain proper operation, both when the engine is cold or at normal operating temperature. (a) Adjustment is achieved by turning the adjusting screw. (b) Adjustment is achieved by changing the thickness of the adjusting shim.

HEAD GASKETS

The head gasket is under the highest clamping loads. It must seal passages that carry coolant with antifreeze and often is required to seal a passage that carries hot engine oil. The most demanding job of the head gasket is to seal the combustion chamber. As a rule of thumb, about 75% of the head bolt clamping force is used to seal the combustion chamber. The remaining 25% seals the coolant and oil passages. See Figure 30–35.

The gasket must seal when the temperature is as low as 40° below zero and as high as 400°F (204°C). The combustion pressures can get up to 1,000 PSI (6,900 kPa) on gasoline engines.

Cylinder head bolts are tightened to a specified torque, which stretches the bolt. The combustion pressure tries to push the head upward and the piston downward on the power stroke. This puts additional stress on the head bolts and it reduces the clamping load on the head gasket just when the greatest seal is needed. On a normally aspirated engine (without turbocharging), a partial vacuum on the intake stroke tries to pull the head more tightly against

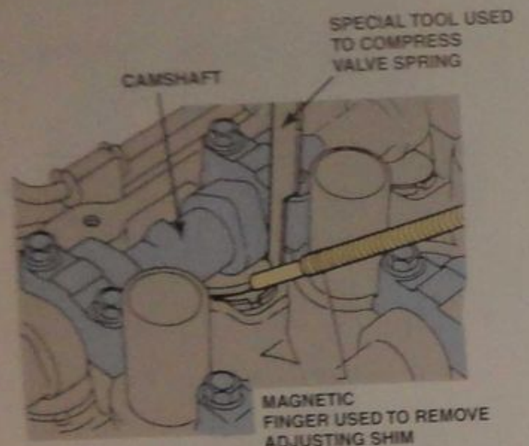




Figure 30–34 Some overhead camshaft engines use valve lash adjusting shims to adjust the valve lash. A special tool is usually required to compress the valve spring so that a magnet can remove the shim.

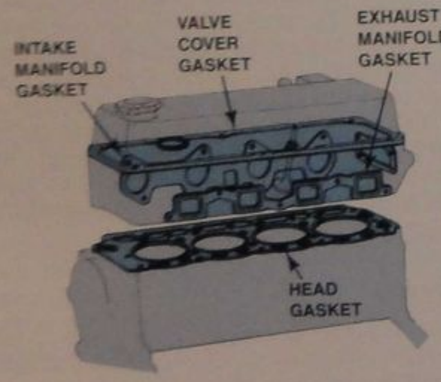


Figure 30–35 Gaskets help prevent leaks between two surfaces.

the gasket. As the crankshaft rotates, the force on the head changes from pressure on the combustion stroke to vacuum on the intake stroke, then back to pressure. Newer engines have lightweight thin-wall castings. The castings are quite flexible, so that they move as the pressure in the combustion chamber changes from high pressure to vacuum. The gasket must be able to compress and recover fast enough to maintain a seal as the pressure in the combustion chamber changes back and forth between pressure and vacuum. As a result, head gaskets are made of several different materials assembled in numerous ways, depending on the engine.

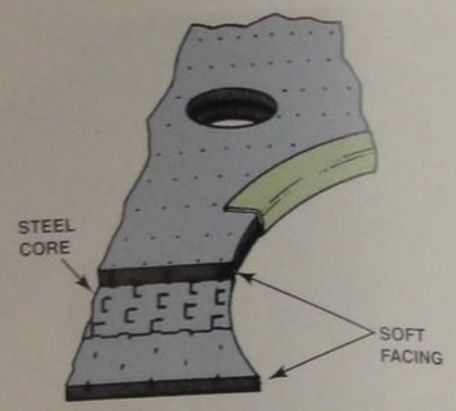


Figure 30–36 A typical perforated steel core head gasket with a graphite or composite facing material.

NOTE: Older gasket designs often contained asbestos and required that the head bolts be retorqued after the engine had been run to operating temperature. Head gaskets today are dense and do not compress like those older-style gaskets. Therefore, most gaskets are called **no-retorque** type gaskets, meaning the cylinder head bolts do not have to be retorqued after the engine has run. New gaskets do not contain asbestos.

TECH TIP ✔ **Wow — I Can't Believe a Cylinder Can Deform That Much!**

An automotive instructor used a dial bore gauge in a four-cylinder, cast-iron engine block cylinder to show students how much a block can deform. Using just one hand, the instructor was able to grasp both sides of the block and squeeze. The dial bore gauge showed that the cylinder deflected about 0.0003 in. (3/10,000 of an inch) just by squeezing the block with one hand—and that was with a cast-iron block!

After this demonstration, the students were more careful during engine assembly and always used a torque wrench on each and every fastener that was installed in or on the engine block.

Perforated Steel-Core Gaskets A perforated steel-core gasket uses a wire-mesh core with fiber facings. Another design has rubber-fiber facings cemented to a solid steel core with an adhesive. See Figures 30–36 and 30–37. The thickness of the gasket is controlled by the thickness of the metal core. The facing is thick enough to compensate for minor warpage and surface defects.

The fiber facing is protected around the combustion chamber with a metal **armor** (also called **fire ring**). See Figure 30–38. The metal also increases the gasket thickness around the cylinder so that it uses up to 75% of the clamping force and forms a tight combustion seal.

Multilayered Steel Gaskets Multilayered steel (MLS) gaskets are being used from the factory on many newer engine designs such as the overhead camshaft Ford V-8s. The many layers of thin steel reduce bore and overhead camshaft distortion with less clamping force loss than previous designs. See Figure 30–39. The use of multilayered steel gaskets also reduces the torque requirement and, therefore, reduces the stresses on the fastener and engine block.

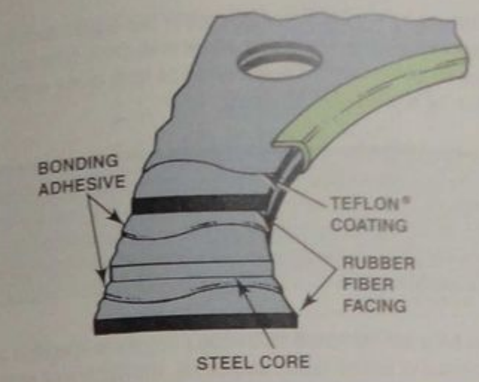


Figure 30–37 A solid steel core head gasket with a non-stick coating, which allows some movement between the block and the head, which is especially important on engines that use cast-iron blocks with aluminum cylinder heads.

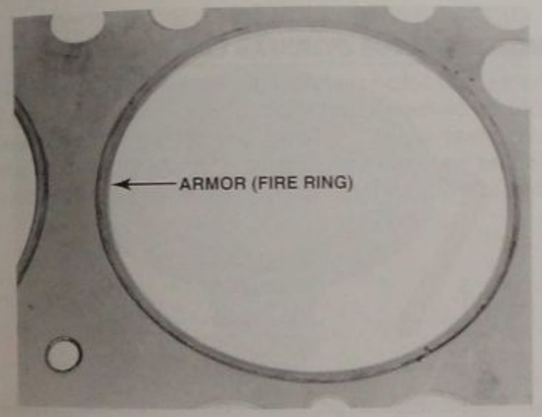


Figure 30–38 Head gasket with armor.



Figure 30–39 Multilayer steel (MLS) gaskets are used on many newer all-aluminum engines as well as engines that use a cast block with aluminum cylinder heads. This type of gasket allows the aluminum to expand without losing the sealing ability of the gasket.

INSTALLING THE HEAD GASKET

The block deck and head surfaces should be rechecked for any handling nicks that could cause a gasket leak. All tapped holes should be cleaned with the correct-size thread chaser. Also check the block and cylinder head surfaces for any dirt or burrs. There are usually alignment pins or dowels at the front and rear of the block deck to position the gasket and head. Care should be taken to properly

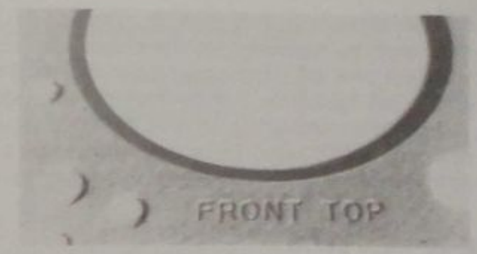


Figure 30–40 Typical head gasket markings.

position any head gasket with markings (up, top, front, and so forth). See Figure 30–40. The gasket and head are placed on the block deck. All the head bolts are loosely installed. Very often, the head bolts have different lengths. Make sure that a bolt of the correct length is put into each location.

NOTE: The word "front" means toward the timing belt or chain end of the engine. This can be confusing for a technician working on an engine in a front-wheel-drive vehicle.

Put sealer on the threads of the assembly bolts that go into the cooling system. Put antiseize compound on bolts that hold the exhaust manifold. Lightly oil the threads of bolts that go into blind holes. See the Tech Tip, "Watch Out for Wet and Dry Holes."

NOTE: Most manufacturers recommend putting oil on the threads of bolts (not in the block holes!) during reassembly. Lubricated threads will give as much as 50% more clamping force at the same bolt torque than threads that are tightened dry.

Often, the assembly bolts have different lengths. Make sure that the correct length of bolt is put into each hole.

TECH TIP ✔ **Watch Out for Wet and Dry Holes**

Many engines, such as the small-block Chevrolet V-8, use head bolts that extend through the top deck of the block and end in a coolant passage. These bolt holes are called **wet holes**. When installing head bolts that end up in the coolant passage, use sealer on the threads of the head bolt. Some engines have head bolts that are "wet," whereas others are "dry" because they end in solid cast-iron material. Dry hole bolts do not require sealant, but they still require some oil on the threads of the bolts for lubrication. Do not put oil into a dry hole because the bolt may bottom out in the oil. The liquid oil cannot compress, so the force of the bolt being tightened is transferred to the block by hydraulic force, which can crack the block.

HINT: Apply oil to a shop cloth and rotate the bolt in the cloth to lubricate the threads. This procedure lubricates the threads without applying too much oil.

HEAD BOLT TORQUE SEQUENCE

The torque put on the bolts is used to control the clamping force. The clamping force is correct only when the threads are clean and properly lubricated. In general, the head bolts are tightened in a

specified torque sequence in three steps. By tightening the head bolts in three steps, the head gasket has time to compress and conform to the block deck and cylinder head gasket surfaces. Follow that sequence and tighten the bolts to *one-third* the specified torque. Tighten them a second time following the torque sequence to *two-thirds* the specified torque. Follow the sequence with a final tightening to the specified torque. See Figures 30–41 and 30–42.

TORQUE-TO-YIELD BOLTS

Many engines use a tightening procedure called the **torque-to-yield,** or **torque-angle,** method. The purpose of the torque-to-yield procedure is to have a more constant clamping load from bolt to bolt. This aids in head gasket sealing performance and eliminates the need for retorquing. The torque-to-yield head bolts are made with a narrow section between the head and threads. As the bolts are tightened past their elastic limit, they yield and begin to stretch in this narrow section.

Torque-to-yield head bolts will not become any tighter once they reach this elastic limit, as you can see on the graph in Figure 30–43. The torque-angle method also decreases the differences in clamping force that can occur depending on the condition or lubrication of the threads. See Figure 30–44.

As a result, many engine manufacturers specify *new* head bolts each time the head is installed. If these bolts are reused, they are likely to break during assembly or fail prematurely as the engine runs. If there is any doubt about the head bolts, replace them.

Torque-to-yield bolts are tightened to a specific initial torque, from 18 to 50 pound-feet (25 to 68 Newton-meters). The bolts are then tightened a specified number of degrees, following the tightening sequence. In some cases they are turned a specified number of degrees two or three times. Some specifications limit the maximum torque that can be applied to the bolt while the degree turn is being made. Torque tables in a service manual will show how much initial torque should be applied to the bolt and how many degrees the bolt should be rotated after torquing.

NOTE: The torque-turn method does not necessarily mean torque-to-yield. Some engine specifications call for a beginning torque and then a specified angle, but the fastener is not designed to yield. These head bolts can often be reused. Always follow the manufacturer's recommended procedures.

Head bolts are tightened following a sequence specified in the service manual or torque tables. In general, the tightening sequence starts at the center of the head and moves outward, alternating front to rear and side to side. The bolts are usually tightened to approximately one-half the specified torque, following the tightening sequence. They are then retorqued to the specified torque following the same tightening sequence. See Figures 30–45 and 30–46.

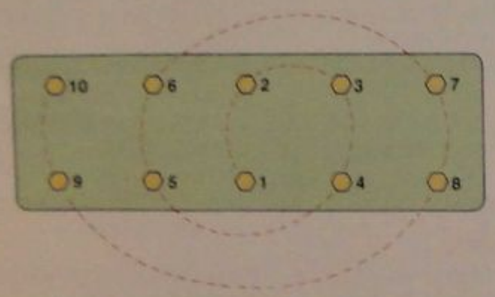


Figure 30–41 Typical cylinder head tightening sequence.

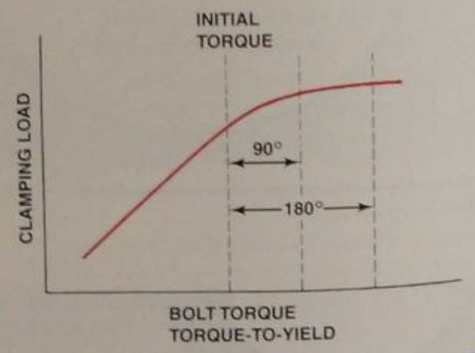


Figure 30–43 Due to variations in clamping force with turning force (torque) of head bolts some engines are specifying the torque-to-yield procedure. The first step is to torque the bolts by an even amount called the initial torque. Final clamping load is achieved by turning the bolt a specified number of degrees. Bolt stretch provides the proper clamping force.

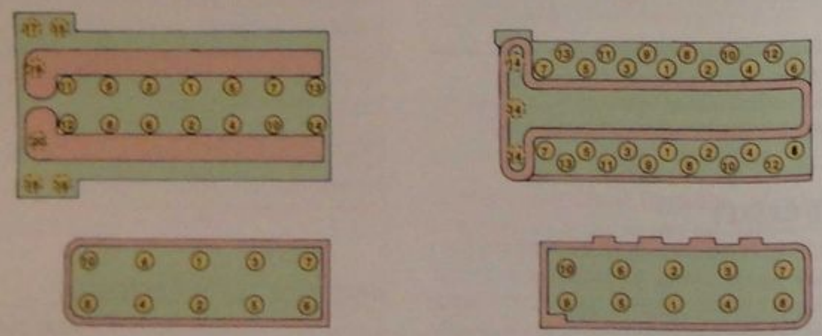


Figure 30–42 Examples of cylinder head bolt torquing sequences.

TIMING DRIVES FOR OVERHEAD CAM ENGINES

After the head bolts have been torqued, the cam drive can be installed on overhead cam engines. This is done by aligning the timing marks of the crankshaft and camshaft drive sprockets with their respective timing marks. The location of these marks differs between engines, but the marks can be identified by



Figure 30–44 To ensure consistent clamp force (load), many manufacturers are recommending the torque-angle or torque-to-yield method of tightening head bolts. The torque-angle method specifies tightening fasteners to a low torque setting and then giving an additional angle of rotation. Notice that the difference in clamping force is much smaller than it would be if just a torque wrench with dirty threads were used.

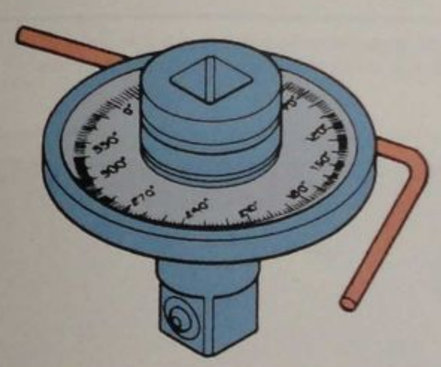


Figure 30–45 Torque angle can be measured using a special adaptor.

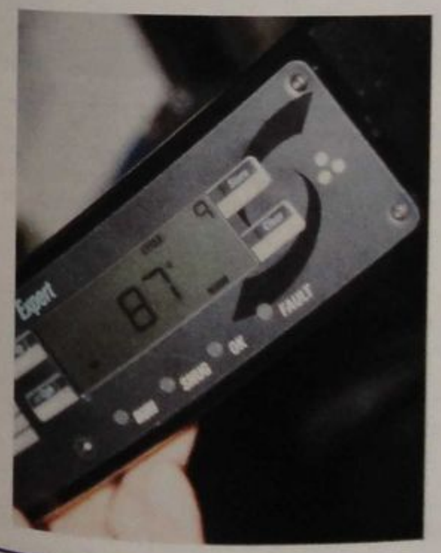


Figure 30–46 An electronic torque wrench showing the number of degrees of rotation. These very accurate and expensive torque wrenches can be programmed to display torque or number of degrees of rotation.

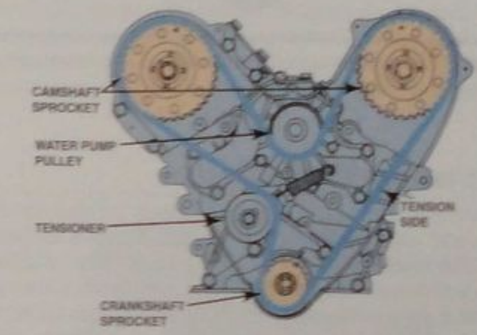


Figure 30–47 Both crankshafts have to be timed on this engine, and the timing belt also drives the water pump.

looking carefully at the sprockets. See Figures 30–47 and 30–48. The tightening idler may be on either or both sides of the timing belt or chain. After the camshaft drive is engaged, rotate the crankshaft through two full revolutions. On the first full revolution, you should see the exhaust valve almost close and the intake valve just starting to open when the *crankshaft* timing mark aligns. At the end of the second revolution, both valves should be closed, and all the timing marks should align on most engines. This is the position the crankshaft should have when cylinder #1 is to fire.

NOTE: Always check the manufacturer's recommended timing chain installation procedure. Engines that use primary and secondary timing chains often require an exact detailed procedure for proper installation.

TECH TIP ✓ **Soak the Timing Chain**

Many experts recommend that a new timing chain be soaked in engine oil prior to engine assembly to help ensure full lubrication at engine start-up. The timing chain is one of the last places in the engine to get lubrication when the engine first starts. This procedure may even extend the life of the chain.

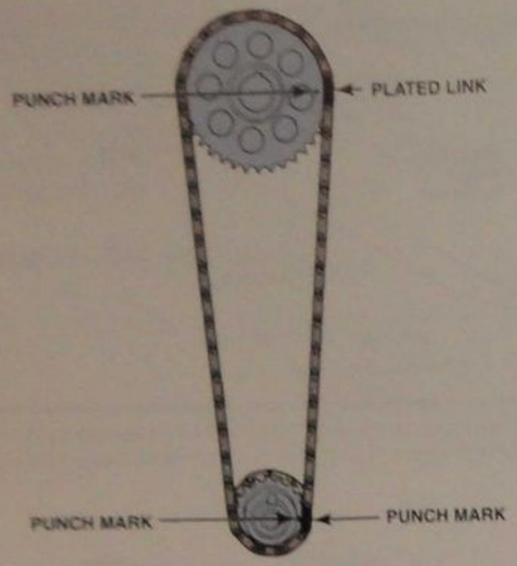


Figure 30–48 Some timing chains have plated links that are used to correctly position the chain on the sprockets.

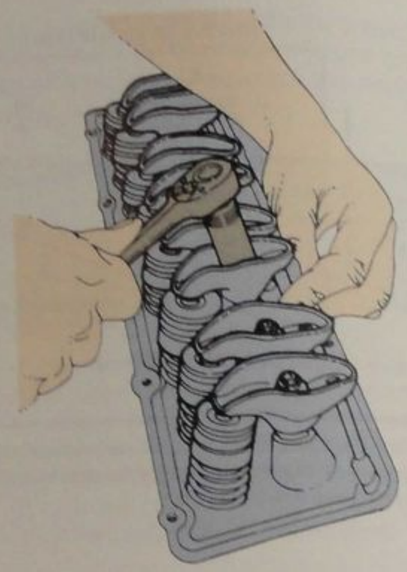


Figure 30–49 With the lifter resting on the base circle of the cam, zero lash is achieved by tightening the rocker arm lock nut until the pushrod no longer rotates freely.

LIFTER AND PUSHROD INSTALLATION

The outside of the lifters and the lifter bores in the block should be cleaned and coated with assembly lubricant. The lifters are installed in the lifter bores and the pushrods put in place. There are different-length pushrods on some engines. Make sure that the pushrods are installed in the proper location. The rocker arms are then put in place, aligning with the valves and pushrods. Rocker arm shafts should have their retaining bolts tightened a little at a time, alternating between the retaining bolts. This keeps the shaft from bending as the rocker arm pushes some of the valves open.

HYDRAULIC LIFTERS

The retaining nut on some rocker arms mounted on studs can be tightened to a specified torque. The rocker arm will be adjusted correctly at this torque when the valve tip has the correct height. Other types of rocker arms require tightening the nut to a position that will center the hydraulic lifter. The general procedure for adjusting the hydraulic lifter types is to tighten the retaining nut to the point that all the free lash is gone. See Figure 30–49. The lifter plunger starts to move down after the lash is gone. From this point, the retaining nut is tightened by a specified amount, such as three-fourths of a turn or one and one-half turns.

HINT: This method usually results in about three threads showing above the adjusting nut on a stock small-block Chevrolet V-8 equipped with flat-bottom hydraulic lifters.

SOLID LIFTERS

The valve clearance or **lash** must be set on a solid lifter engine, so that the valves can positively seat. Some service manuals give an adjustment sequence to follow to set the lash. If this is not available, then the following procedure can be used on all engines requiring valve lash adjustment. The valve lash is adjusted with the valves completely closed. See Figure 30–50.



Figure 30–50 Most adjustable valves use a nut to keep the adjustment from changing. To adjust the valves the nut has to be loosened and the screw rotated until the proper valve clearance is achieved. Then the screw should be held while tightening the lock nut to keep the adjustment from changing. Double-check the valve clearance after tightening the nut.

After the valve lash on cylinder #1 is set, the crankshaft is rotated in its normal direction of rotation to the next cylinder in the firing order. This is done by turning the crankshaft 90 degrees on eight-cylinder engines, 120 degrees on even-firing six-cylinder engines, and 180 degrees on four-cylinder engines. The valves on this next cylinder are adjusted in the same manner, as were those on cylinder #1. This procedure is repeated on each cylinder *following the engine firing order* until all the valves have been adjusted.

The same valve lash adjustment sequence is used on overhead cam engines. Those engines with rocker arms or with adjustable finger follower pivots are adjusted in the same way, as are pushrod engines with rocker arms.

ASSEMBLY SEALANTS

RTV Silicone RTV silicone is used by most technicians in sealing engines. **RTV,** or **room-temperature vulcanization,** means that the silicone rubber material will cure at room temperature. It is not really the temperature that causes RTV silicone to cure, but the moisture in the air. RTV silicone cures to a tack-free state in about 45 minutes. It takes 24 hours to fully cure.

CAUTION: Some RTV silicone sealers use **acetic acid,** and the fumes from this type can be drawn through the engine through the PCV system and cause damage to oxygen sensors. Always use an **amine-type** RTV silicone or one that states on the package that it is safe for oxygen sensors.

RTV silicone is available in several different colors. The color identifies the special blend within a manufacturer's product line. Equal grades of silicone made by different manufacturers may have different colors. RTV silicone can be used in two ways in engine sealing:

1. It can be used as a gasket substitute between a stamped cover and a cast surface.
2. It is used to fill gaps or potential gaps. A joint between gaskets or between a gasket and a seal is a potential gap.

NOTE: RTV silicone should *never* be used around fuel because the fuel will cut through it. Silicone should not be used as a sealer on gaskets. It will squeeze out to leave a bead inside and a bead outside the flange. The inside bead might fall into the engine, plugging passages and causing engine damage. The thin film still remaining on the gasket stays uncured, just as it would be in the original tube. The uncured silicone is likely to let the gasket or seal slip out of place. See Figure 30–51.

Anaerobic Sealers Anaerobic sealers are sealers that cure in the absence of air. They are used as thread lockers (such as Loctite), and they are used to seal rigid machined joints between cast parts. Anaerobic sealers lose their sealing ability at temperatures above 300°F (149°C). On production lines, the curing process is speeded up by using ultraviolet light.

When the anaerobic sealer is used on threads, air does not get to it so it hardens to form a seal to prevent the fastener from loosening. Teflon is added to some anaerobic sealers to seal fluids better. Anaerobic sealers can be used to seal machined surfaces without a gasket. The surfaces *must* be thoroughly clean to get a good seal. Special primers are recommended for use on the sealing surface to get a better bond with anaerobic sealers.



Figure 30–51 Improperly sealed valve cover gasket. Note the use of RTV silicone sealant on a cork-rubber gasket. The cover bolts were also overtightened, which deformed the metal cover around the bolt holes.

INSTALLING MANIFOLDS

The intake manifold gasket for a V-type engine may be a one-piece gasket or it may have several pieces. V-type engines with open-type manifolds have a cover over the lifter valley. The cover may be a separate part or it may be part of a one-piece intake manifold gasket. Closed-type intake manifolds on V-type engines require gasket pieces (end seals) at the front and rear of the intake manifold. See Figure 30–52. Inline engines usually have a one-piece intake manifold gasket.

The intake manifold is put in place over the gaskets. Use a contact adhesive to hold the gasket and end seal if there is a chance they might slip out of place. Just before the manifold is installed, put a spot of RTV silicone on each of the four joints between the intake manifold gasket and end seals. Install the bolts and tighten to the specified torque following the correct tightening sequence.

Only some exhaust manifolds use gaskets. The exhaust manifold operates at very high temperatures, so there is usually some expansion and contraction movement in the manifold-to-head joint. It is very important to use attachment bolts, cap screws, and clamps of the correct type and length. See Figure 30–53. They must be properly torqued to avoid both leakage and cracks.

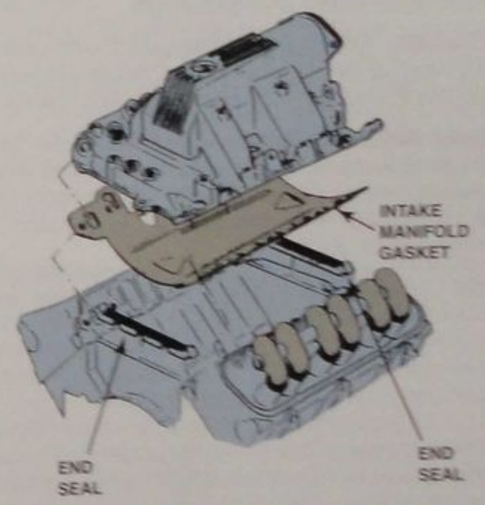


Figure 30–52 This intake manifold gasket includes end seals and a full shield cover for the valley to keep hot engine oil from heating the intake manifold.

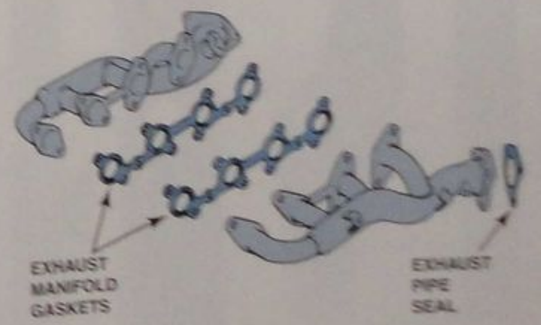


Figure 30–53 An exhaust manifold gasket is used on some engines and seals the exhaust manifold to the cylinder head.

NOTE: When the exhaust manifold gasket has facing on one side, put the facing toward the head and let the manifold rest against the metal side of the gasket.

COVER GASKET MATERIALS

The gasket must be *impermeable* to the fluids it is designed to seal in or out. The gasket must *conform* to the shape of the surface, and it must be *resilient*, or elastic, to maintain the sealing force as it is compressed. Gaskets work best when they are compressed about 30%.

Cork Gaskets Cork is the bark from a Mediterranean cork oak tree. It is made of very small, flexible, 14-sided, air-filled fiber cells, about 0.001 inch (0.025 millimeter) in size. The air-filled cells act like a pneumatic system. This gives resiliency to the cork gasket until the air leaks out. Because cork is mostly wood, it expands when it gets wet and shrinks when it dries. This causes cork gaskets to change in size when they are in storage and while installed in the engine. Oil gradually wicks through the organic binder of the cork, so a cork gasket often looks like it is leaking. Problems with cork gaskets led the gasket industry to develop cork cover gaskets using synthetic rubber as a binder for the cork. This type of gasket is called a **cork-rubber gasket.** These cork-rubber gaskets are easy to use, and they outlast the old cork gaskets. See Figure 30–54.

Fiber Gaskets Some oil pans use fiber gaskets. Covers with higher clamping forces use gaskets with fibers that have greater density. For example, timing covers may have either fiber or paper gaskets.

Synthetic Rubber Gaskets Molded, oil-resistant synthetic rubber is being used in more applications to seal covers. When it is compounded correctly, it forms a superior cover gasket. It operates at high temperatures for a longer period of time than does a cork-rubber cover gasket. See Figure 30–55.

Sealers Sealers are nonhardening materials. Examples of sealer trade names include Form-A-Gasket 2, Pli-A-Seal, Tight Seal 2, Aviation Form-A-Gasket, Brush Tack, Copper Coat, Spray Tack, and High Tack. Sealers are always used to seal the threads of bolts that break into coolant passages. Sealers for sealing threads may include Teflon. Sealer is often recommended for use on shim-type head gaskets and intake manifold gaskets. These gaskets have a metal surface that does not conform to any small amounts of surface roughness on the sealing



Figure 30–54 *Left to right:* Cork-rubber, paper, composite, and synthetic rubber (elastomer) gaskets.

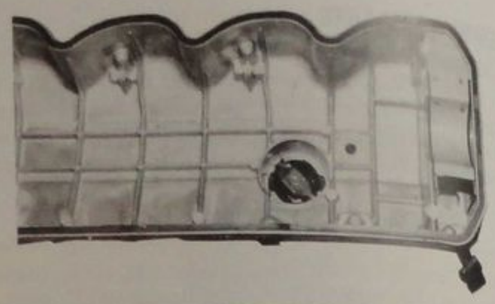


Figure 30–55 Typical cast-aluminum cam (valve) cover. Note the rubber gasket in the cast groove of the cover.

surface. The sealer fills the surface variations between the gasket and the sealing surface.

Sealer may be used as a sealing aid on paper and fiber gaskets if the gasket needs help with sealing on a scratched, corroded, or rough surface finish. The sealer may be used on one side or on both sides of the gasket.

CAUTION: Sealer should *never* be used on rubber or cork-rubber gaskets. Instead of holding the rubber gasket or seal, it will help the rubber to slip out of place because the sealer will never harden.

Antiseize Compounds Antiseize compounds are used on fasteners in the engine that are subjected to high temperatures to prevent seizing caused by galvanic action between dissimilar metals. These compounds minimize corrosion from moisture. Exhaust manifold bolts and nuts, oxygen sensors, and spark plugs, especially those that go into aluminum heads, are kept from seizing. The antiseize compound minimizes the chance of threads being pulled or breaking as the oxygen sensor or spark plug is removed.

TECH TIP ✔ **Hints for Gasket Usage**

Never reuse an old gasket. A used gasket or seal has already been compressed, has lost some of its resilience, and has taken a set. If a used gasket does reseal, it will not seal as well as a new gasket or seal.

A gasket should be checked to make sure it is the correct gasket. Also check the list on the outside of the gasket set to make sure that the set has all the gaskets that may be needed *before* the package is opened.

An instruction sheet is included with most gaskets. It includes a review of the things the technician should do to prepare and install the gaskets to give the best chance of a good seal. The instruction sheet also includes special tips on how to seal spots that are difficult to seal or that require special care to seal on a particular engine.

INSTALLING TIMING COVERS

Most timing covers are installed with a gasket, but some use RTV sealer in place of the gasket. Cast covers use anaerobic compounds as a gasket substitute. A bead of RTV silicone 1/8 to 3/16 inch in diameter is put on the clean sealing surface. See Figure 30–56. Encircle the bolt holes with the sealant. Install the cover before the silicone begins to cure so that the uncured silicone bonds to both surfaces. While installing the cover, do not touch the silicone bead; otherwise, the bead might be displaced, causing a leak.

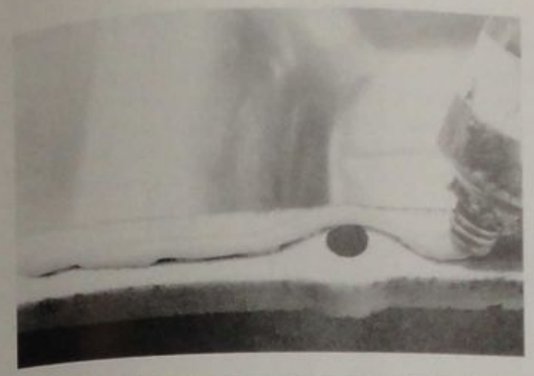


Figure 30–56 1/8- to 3/16-inch (3- to 5-millimeter) bead of RTV silicone on a parting surface with silicone going around the bolt hole.

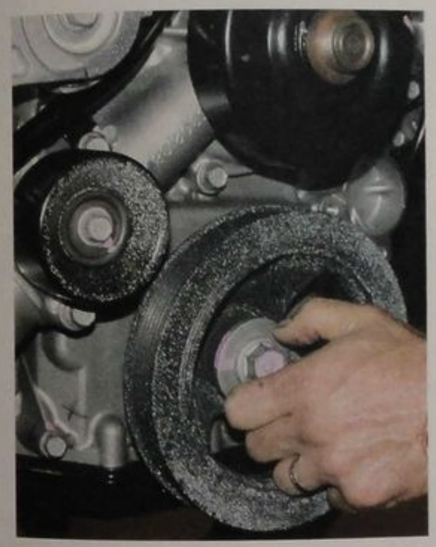


Figure 30–57 Installing the harmonic balancer. Always follow the manufacturer's recommended procedure and torque specifications.

Carefully press the cover into place. Do not slide the cover after it is in place. Install the assembly bolts finger-tight, and let the silicone cure for about 30 minutes; then torque the cover bolts.

INSTALLING THE VIBRATION DAMPER

Vibration dampers are seated in place by one of three methods.

- The damper hub of some engines is pulled into place using the hub-attaching bolt. See Figure 30–57.
- The second method uses a special installing tool that screws into the attaching bolt hole to pull the hub into place. The tool is removed and the attaching bolt is installed and torqued.
- The last method is used on engines that have no attaching bolt. These hubs depend on a press-fit to hold the hub on the crankshaft. The hub is seated using a hammer and a special tube-type driver.

INSTALLING THE OIL PUMP

When an engine is rebuilt, the oil pump should be replaced with a new pump. This ensures positive lubrication and long pump life.

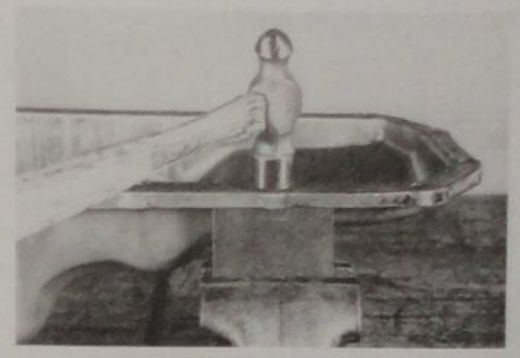


Figure 30–58 Using a hammer to straighten the gasket rail surface before installing a new gasket. When the retaining bolts are tightened, some distortion of sheet-metal covers occurs. If the area around the bolt holes is not straightened, leaks can occur with the new gasket.

Oil pump gears should be coated with assembly lubricant before the cover is put on the pump. This provides initial lubrication, and it primes the pump so that it will draw the oil from the pan when the lubrication system is first operated.

THE OIL PAN

The oil pan should be checked and straightened as necessary. See Figure 30–58. With the oil pump in place, the oil pan gaskets are properly positioned. A spot of RTV silicone is placed at each gasket joint just before the pan is installed. The oil pan is carefully placed over the gaskets. All oil pan bolts should be started into their holes before any are tightened. The bolts should be alternately snugged up; then they should be properly torqued.

REAL WORLD FIX **The New Oil Pump That Failed**

A technician replaced the oil pump and screen on a V-8 with low oil pressure. After the repair, the oil pressure returned to normal for two weeks, but then the oil pressure light came on and the valve train started making noise. The vehicle owner returned to the service garage where the oil pump had been replaced. The technician removed the oil pan and pump. The screen was almost completely clogged with the RTV sealant that the technician had used to "seal" the oil pan gasket. The technician had failed to read the instructions that came with the oil pan gasket. Failure to follow directions and using too much of the wrong sealer cost the repair shop an expensive comeback repair.

TECH TIP ✔ **Oil Pump Precautions**

The oil pump is the heart of any engine, and any failure of the oil circulation system often results in severe and major engine damage. To help prevent possible serious oil pump-related failures, many engine builders recommend the following precautions:

1. Always be sure that the oil pump pickup tube (screen) is securely attached to the oil pump to prevent the pickup tube from vibrating out of the pump.
2. Use modeling clay to check pickup screen-to-oil pan clearance. For proper operation, there should be about 1/4 inch (6 millimeters) between the oil pump pickup screen and the bottom of the oil pan.

INSTALLING THE WATER PUMP

A reconditioned, rebuilt, or new water pump should be used. Once gaskets are fitted in place, the pump is secured with assembly bolts tightened to the correct torque.

A new thermostat is usually installed at this time. It is put in place, with care being taken to place the correct side of the thermostat toward the engine. The thermostat gasket is put in place. Sealers are used on the gasket where they are required. The thermostat housing is installed, and the retaining bolts are tightened to the proper torque.

ENGINE PAINTING

Painting an engine helps prevent rust and corrosion and makes the engine look new. Standard engine paints with original colors are usually available at automotive parts stores. Engine paints should be used rather than other types of paints. Engine paints are compounded to stay on the metal as the engine temperatures change. Normal engine fluids will not remove them. These paints are usually purchased in pressure cans so that they can be sprayed from the can directly onto the engine.

All parts that should not be painted must be covered before spray painting. This can be done with old parts, such as old spark plugs and old gaskets. This can also be done by taping paper over the areas to be covered. If the intake manifold of an inline engine is to be painted, it can be painted separately. Engine assembly can continue after the paint has dried.

CHECKING FOR PROPER OIL PRESSURE

With oil in the engine and the distributor out of the engine, oil pressure should be established before the engine is started. This can be done on most engines by rotating the oil pump by hand. This ensures that oil is delivered to all parts of the engine before the engine is started. A socket speed handle makes an ideal crank for turning the oil pump. A flat-blade adapter that fits the speed handle will operate on General Motors engines. The V-type Chrysler engine requires the use of the same flat-blade adapter, but it also requires an oil pump drive. One can be made by removing the gear from an old oil pump hex driveshaft. A 1/4-inch drive socket can be used on Ford engines. Examples of these are pictured in Figure 30–59. Engines that do not drive the oil pump with the distributor will have to be cranked with the



Figure 30–59 Drivers used to rotate oil pumps to prelubricate all parts of the engine before installing the distributor and starting the engine.



Figure 30–60 The engine can be pressurized with engine oil from an aerosol can as shown or from a pressurized oil container designed for preoiling the engine.

spark plugs removed to establish oil pressure. The load on the starter and battery is reduced with the spark plugs out so that the engine will have a higher cranking speed. A pressurized oil container or an engine oil aerosol could also be used, as shown in Figure 30–60.

REAL WORLD FIX — **"Oops"**

After overhauling a big-block Ford V-8 engine, the technician used an electric drill to rotate the oil pump with a pressure gauge connected to the oil pressure sending unit hole. When the electric drill was turned on, oil pressure would start to increase (to about 10 PSI), then drop to zero. In addition, the oil was very aerated (full of air). Replacing the oil pump did not solve the problem. After hours of troubleshooting and disassembly, it was discovered that an oil gallery plug had been left out underneath the intake manifold. The oil pump was working correctly and pumped oil throughout the engine and out of the end of the unplugged oil gallery. It did not take long for the oil pan to empty; therefore, the oil pump began drawing in air that aerated the oil and the oil pressure dropped. Installing the gallery plug solved the problem. It was smart of the technician to check the oil pressure before starting the engine. This oversight of leaving out one gallery plug could have resulted in a ruined engine shortly after the engine was started.

NOTE: Many overhead camshaft engines use an oil passage check valve in the block near the deck. The purpose of this valve is to hold oil in the cylinder head around the camshaft and lifters when the engine is stopped. Failure to reinstall this check valve can cause the valve train to be noisy after engine start-up.

SETTING INITIAL IGNITION TIMING

After oil pressure is established, the distributor, if equipped, can be installed. Rotate the crankshaft in its normal direction of rotation until there is compression on cylinder #1. This can be done with the starter or by using a wrench on the damper bolt. The compression

stroke can be determined by covering the opening of spark plug #1 with a finger as the crankshaft is rotated. Continue to rotate the crankshaft slowly as compression is felt, until the timing marks on the damper align with the timing indicator on the timing cover.

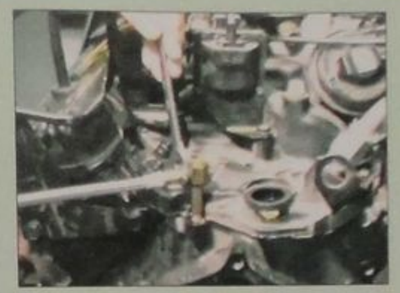
The angle of the distributor gear drive will cause the distributor rotor to turn a few degrees when installed. Before the distributor is installed, the shaft must be positioned to compensate for the gear angle. After installation, the rotor should be pointing to the #1 tower of the distributor cap.

The distributor position should be close enough to the basic timing position to start the engine. If the distributor hold-down clamp is slightly loose, the distributor housing can be adjusted to make the engine run smoothly after the engine has been started.

PHOTO SEQUENCE Preoiling an Engine Step-by-Step



P30–1 Fill the crankcase with the specified amount of oil.



P30–2 Attach an oil pressure gauge to the engine. On this small-block Chevrolet V-8, the oil pressure tap is located near the distributor at the top of the block.



P30–3 To rotate the oil pump an old distributor was cut down and the shaft installed in the chuck of an electric drill.



P30–4 Rotating the oil pump using an electric drill results in the oil pressure increasing to over 50 PSI.



P30–5 The drill should continue being used to prime the engine with oil until oil is observed coming from the rocker arms, indicating that oil has reached the highest part of the engine.



P30–6 After the engine has been primed, the distributor can be installed and the engine can be installed into the vehicle.

Valve Adjustment Step-by-Step



P30–1 Before starting the process of adjusting the valves, look up the specifications and exact procedures. The technician is checking this information from a computer CD-ROM-based information system.



P30–2 The tools necessary to adjust the valves on an engine with adjustable rocker arms include basic hand tools, feeler gauge, and a torque wrench.



P30–3 An overall view of the four-cylinder engine that is due for a scheduled valve adjustment according to the vehicle manufacturer's recommendations.

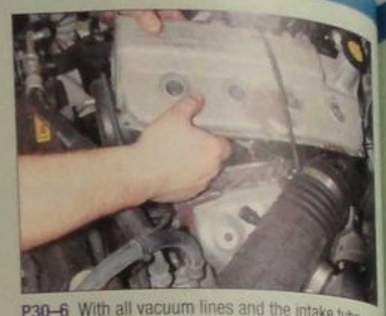
(continued)



P30–4 Start the valve adjustment procedure by first disconnecting and labeling, if necessary, all vacuum lines that need to be removed to gain access to the valve cover.



P30–5 The air intake tube is being removed from the throttle body.



P30–6 With all vacuum lines and the intake tube removed, the valve cover can be removed after removing all retaining bolts.



P30–7 Notice how clean the engine appears. This is a testament of proper maintenance and regular oil changes by the owner.



P30–8 To help locate how far the engine is being rotated, the technician is removing the distributor cap to be able to observe the position of the rotor.



P30–9 The engine is rotated until the timing marks on the front of the crankshaft line up with zero degrees—top dead center (TDC)—with both valves closed on #1 cylinder.



P30–10 With the rocker arms contacting the base circle of the cam, insert a feeler gauge of the specified thickness between the camshaft and the rocker arm. There should be a slight drag on the feeler gauge.



P30–11 If the valve clearance (lash) is not correct, loosen the retaining nut and turn the valve adjusting screw with a screwdriver to achieve the proper clearance.



P30–12 After adjusting the valves that are closed, rotate the engine one full rotation until the engine timing marks again align.



P30–13 The engine is rotated until the timing marks again align indicating that the companion cylinder will now be in position for valve clearance measurement.



P30–14 On some engines, it is necessary to watch the direction the rotor is pointing to help determine how far to rotate the engine. Always follow the vehicle manufacturer's recommended procedure.



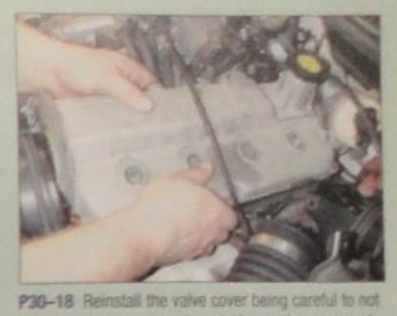
P30–15 The technician is using a feeler gauge that is one-thousandth of an inch thinner and another one-thousandth of an inch thicker than the specified clearance as a double-check that the clearance is correct.



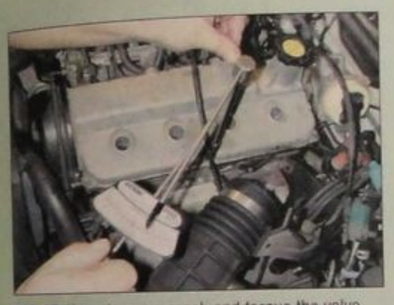
P30–16 Adjusting a valve takes both hands—one to hold the wrench to loosen and tighten the lock nut and one to turn the adjusting screw. Always double-check the clearance after an adjustment is made.



P30–17 After all valves have been properly measured and adjusted as necessary, start the reassembly process by replacing all gaskets and seals as specified by the vehicle manufacturer.



P30–18 Reinstall the valve cover being careful to not pinch a wire or vacuum hose between the cover and the cylinder head.



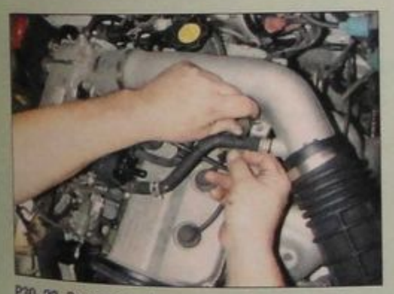
P30–19 Use a torque wrench and torque the valve cover retaining bolts to factory specifications.



P30–20 Reinstall the distributor cap.



P30–21 Reinstall the spark plug wires and all brackets that were removed to gain access to the valve cover.



P30–22 Reconnect all vacuum and air hoses and tubes. Replace with new any vacuum hoses that are brittle or swollen.



P30–23 Be sure that the clips are properly installed. Start the engine and check for proper operation.



P30–24 Double-check for any oil or vacuum leaks after starting the engine.

SUMMARY

1. All oil galleries must be thoroughly cleaned before engine assembly can begin.
2. All expansion cups and plugs should be installed with a sealer to prevent leaks. Avoid the use of Teflon tape on threaded plugs.
3. The cam bearings should be installed using a cam bearing installation tool.
4. Main bearings and rod bearings should be checked for proper oil clearance by precision measuring the crankshaft journals and inside diameter of bearings or by using plastic gauging material.
5. The piston and rod assembly should be installed in the cylinder after being carefully fitted for each bore.
6. Connecting rod side clearance should be checked with a feeler (thickness) gauge.
7. Double-check the flatness of the block deck and cylinder head before installing the cylinder head.
8. Torque the cylinder head bolts according to the proper sequence and procedures.
9. Many cylinder heads use the torque-to-yield method, wherein the head bolts are tightened to a specified torque and then rotated a specified number of degrees.
10. The oil pressure should be tested before installation of the engine in the vehicle.

REVIEW QUESTIONS

1. Describe the procedure for fitting pistons to a cylinder.
2. Explain how main bearings should be checked and fitted to the crankshaft.
3. How is plastic gauging material used to determine oil clearance?
4. What is the procedure for checking thrust bearing clearance?
5. How should the connecting rod side clearance be measured and corrected?
6. How is the piston and connecting rod assembly installed in the engine?
7. What procedures should be followed for installing and torquing the cylinder head?
8. Describe the torque-to-yield head bolt tightening procedure.

CHAPTER QUIZ

1. Typical piston-to-cylinder clearance is _____.
   a. 0.001 to 0.003 inch
   b. 0.010 to 0.023 inch
   c. 0.100 to 0.150 inch
   d. 0.180 to 0.230 inch
2. If the gauging plastic strip is wide after the bearings are tightened, this indicates _____.
   a. A large oil clearance
   b. An old, dried strip of plastic gauging material
   c. A small oil clearance
   d. A small side (thrust) clearance
3. The most common cause of premature bearing failure is _____.
   a. Misassembly
   b. Dirt
   c. Lack of lubrication
   d. Overloading
4. Typical thrust bearing clearance is _____.
   a. 0.001 to 0.003 inch
   b. 0.002 to 0.012 inch
   c. 0.025 to 0.035 inch
   d. 0.050 to 0.100 inch
5. Piston ring end gap can be *increased* by _____.
   a. Filing the ring to make the gap larger
   b. Installing oversize rings
   c. Sleeving the cylinder
   d. Knurling the piston
6. The cylinder head bolts should be tightened (torqued) in what general sequence?
   a. The four outside bolts first, then from the center out
   b. From the outside bolts to the inside bolts
   c. From the inside bolts to the outside bolts
   d. Starting at the front of the engine and torquing bolts from front to rear
7. The torque-angle method involves _____.
   a. Turning all bolts the same number of turns
   b. Torquing to specifications and loosening by a specified number of degrees
   c. Torquing to one-half specifications, then to three-quarter torque, then to full torque
   d. Turning bolts a specified number of degrees after initial torque
8. Turning the oil pump before starting the engine should be done.
   a. To lubricate engine bearings
   b. To lubricate valve train components
   c. To supply oil to the camshaft
   d. All of the above
9. Most bolt torque specifications are for _____.
   a. Clean threads only
   b. Clean and lubricated threads
   c. Dirty threads
   d. Dirty threads, but 50% can be added for clean threads
10. Cam bearings should be installed _____.
    a. Dry
    b. Oiled
    c. With at least 0.010 inch of crush
    d. Both b and c

SECTION VII Electrical and Electronic Systems

31 Electrical Fundamentals
32 Electrical Circuits and Ohm's Law
33 Series, Parallel, and Series-Parallel Circuits
34 Digital Meters and Scope Usage
35 Automotive Wiring and Wire Repair
36 Wiring Schematics and Troubleshooting
37 Capacitance and Magnetism
38 Electronic Fundamentals
39 Batteries and Battery Testing
40 Cranking System Operation and Diagnosis
41 Charging System Operation and Diagnosis
42 Lighting and Signaling Circuits
43 Driver Information and Navigation Systems
44 Horn, Wiper, and Blower Motor Circuits
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47 Audio System Operation and Diagnosis



CHAPTER 31 Electrical Fundamentals

OBJECTIVES: **After studying Chapter 31, the reader will be able to:** Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic System Diagnosis). • Define electricity. • Explain the units of electrical measurement. • Discuss the relationship among volts, amperes, and ohms. • Explain how magnetism is used in automotive applications.

KEY TERMS: ammeter • amperes • atom • bound electrons • concentric rings • conductors • conventional theory • coulomb • current • electrical potential • electricity • electrochemistry • electromotive force (EMF) • electrons • electron theory • elements • free electrons • insulators • ion • neutral charge • neutrons • nucleus • ohmmeter • ohms • peltier effect • photoelectricity • piezoelectricity • positive temperature coefficient (PTC) • potentiometer • protons • resistance • resistors • rheostat • semiconductors • shells • static electricity • thermocouple • thermoelectricity • valence shell • volt • voltmeter • watt

The electrical system is one of the most important systems in a vehicle today. Every year, more and more components and systems use electricity. Those technicians who really know and understand automotive electrical and electronic systems will be in great demand.

ELECTRICITY

Our universe is composed of matter, which is *anything* that has mass and occupies space. All matter is made from slightly over 100 individual components called **elements.** The smallest particle that an element can be broken into and still retain the properties of that element is known as an **atom.** See Figure 31–1. Electricity is the movement of electrons from one atom to another. The dense center of each atom is called the **nucleus.** The nucleus contains **protons,** which have a positive charge, and **neutrons,** which are electrically neutral (have no charge). **Electrons** surround the nucleus in orbits. Each atom contains an equal number of electrons and protons. Because the number of negative-charged electrons is balanced with the same number of positive-charged protons, an atom has a **neutral charge** (no charge).

NOTE: As an example of the relative sizes of the parts of an atom, consider that if an atom were magnified so that the nucleus were the size of the period at the end of this sentence, the whole atom would be bigger than a house.

Positive and Negative Charges The parts of the atom have different charges. The orbiting electrons are negatively charged, while the protons are positively charged. Positive charges are indicated by the "plus" sign (+), and negative charges by the "minus" sign (−), as shown in Figure 31–2. These same + and − signs are used to identify parts of an electrical circuit. Neutrons have no charge at all. They are neutral. In a normal, or balanced, atom, the number of negative particles equals the number of positive particles. That is, there are as many electrons as there are protons. See Figure 31–3. The number of neutrons varies according to the type of atom.

An ordinary magnet has two ends, or poles. One end is called the south pole, and the other is called the north pole. If two magnets are brought close to each other with like poles together (south to south or north to north), the magnets will push each other apart. This is because like poles repel each other. If the opposite poles of the magnets are brought close to each other, south to north, the magnets will snap together because unlike poles attract each other.

The positive and negative charges within an atom are like the north and south poles of a magnet. Charges that are alike will repel each other, similar to the poles of a magnet. See Figure 31–4. That is why the negative electrons continue to orbit around the positive protons. They are attracted and held by the opposite charge of the protons. The electrons keep moving in orbit because they repel each other.

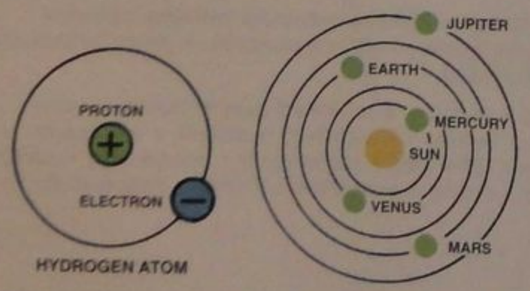


Figure 31–1 In an atom (left), electrons orbit protons in the nucleus just as planets orbit the sun in our solar system (right).

When an atom loses any electrons, it becomes unbalanced. It will have more protons than electrons and therefore will have a positive charge. If it gains more electrons than protons, the atom will be negatively charged. When an atom is not balanced, it becomes a charged particle called an **ion.** Ions try to regain their balance of equal protons and electrons by exchanging electrons with neighboring atoms. See Figure 31–5. This is the flow of electric current or **electricity.**

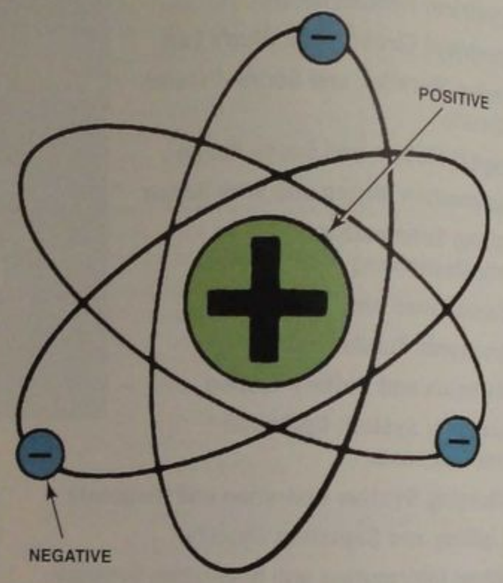


Figure 31–2 The nucleus of an atom has a positive (+) charge and the surrounding electrons have a negative (−) charge.

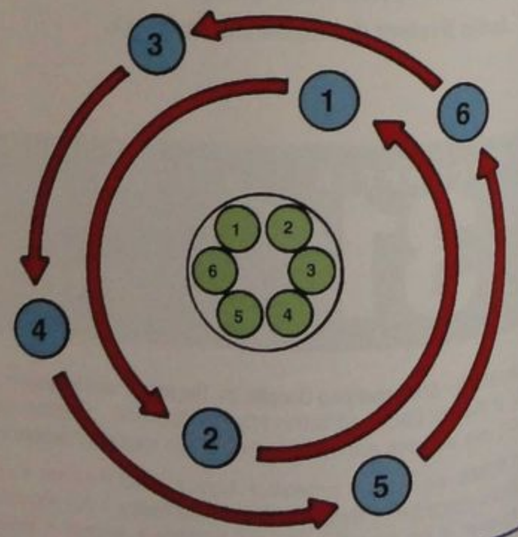


Figure 31–3 This figure shows a balanced atom.

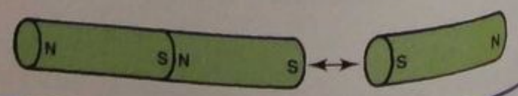


Figure 31–4 Unlike charges attract and like charges repel.

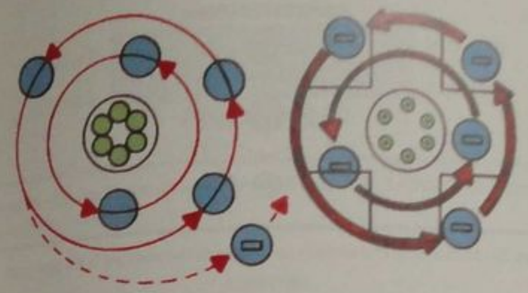


Figure 31–5 An unbalanced, positively charged atom (ion) will attract electrons from neighboring atoms.

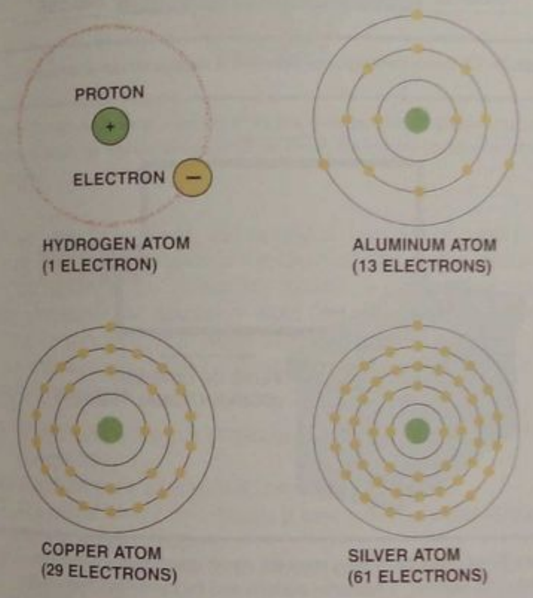


Figure 31–6 The hydrogen atom is the simplest atom, with only one proton, one neutron, and one electron. More complex elements contain higher numbers of protons, neutrons, and electrons.

Electron Shells Electrons orbit around the nucleus in definite paths. These paths form **shells,** like **concentric rings,** around the nucleus. Only a specific number of electrons can orbit within each shell. If there are too many electrons for the first and closest shell to the nucleus, the others will orbit in additional shells until all electrons have an orbit within a shell. There can be as many as seven shells around a single nucleus. See Figure 31–6.

Free and Bound Electrons The outermost electron shell or ring, called the **valence shell,** is the most important to our study of electricity. The number of electrons in this shell determines the valence of the atom and indicates its capacity to combine with other atoms.

If the valence ring of an atom has three or fewer electrons in it, the ring has room for more. The electrons there are held very loosely, and it is easy for a drifting electron to join the valence ring and push another electron away. These loosely held electrons are called **free electrons.** When the valence ring has five or more electrons in it, it is fairly full. The electrons are held tightly, and it is hard for a drifting electron to push its way into the valence ring.

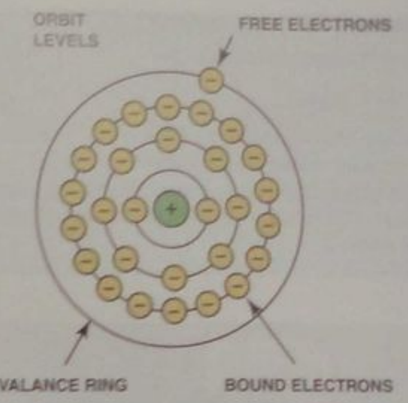


Figure 31–7 As the number of electrons increases, they occupy increasing energy levels that are further from the center of the atom.

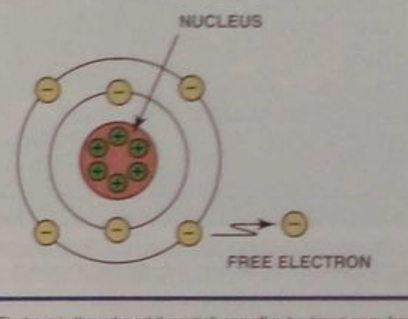


Figure 31–8 Electrons in the outer orbit, or shell, can often be driven away from the atom and become free electrons.

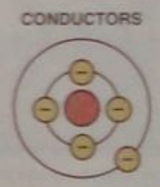


Figure 31–9 A conductor is any element that has one to three electrons in its outer orbit.

These tightly held electrons are called **bound electrons.** See Figures 31–7 and 31–8.

The movement of these drifting electrons is called **current.** Current can be small, with only a few electrons moving, or it can be large, with a tremendous number of electrons moving. Electric current is the controlled, directed movement of electrons from atom to atom within a conductor.

Conductors **Conductors** are materials with fewer than four electrons in their atom's outer orbit. See Figure 31–9. Copper is an excellent conductor because it has only one electron in its outer orbit. This orbit is far enough away from the nucleus of the copper atom that the pull or force holding the outermost electron in orbit is relatively weak. See Figure 31–10. Copper is the conductor most used in vehicles because the price of copper is reasonable compared to the relative cost of other conductors with similar properties.

FREQUENTLY ASKED QUESTION ???

Is Water a Conductor?

Pure water is an insulator; however, if anything is in the water, such as salt or dirt, then the water becomes conductive. Because it is difficult to keep water from becoming contaminated, water is usually thought of as being capable of conducting electricity, especially high voltage such as from household 110-volt or 220-volt outlets.

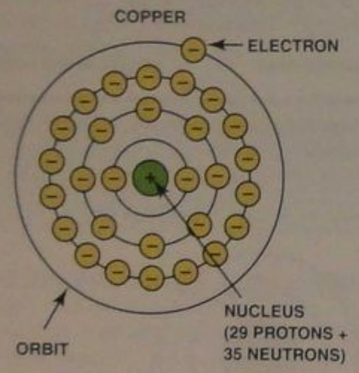


Figure 31–10 Copper is an excellent conductor of electricity because it has just one electron in its outer orbit, making it easy to be knocked out of its orbit and flow to other nearby atoms. This causes electron flow, which is the definition of electricity.

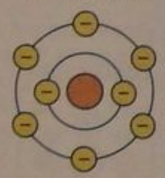


Figure 31–11 Insulators are elements with five to eight electrons in the outer orbit.

Insulators The protons and neutrons in the nucleus are held together very tightly. Normally the nucleus does not change. But some of the outer electrons are held very loosely, and they can move from one atom to another. An atom that loses electrons has more positive charges (protons) than negative charges (electrons); it is positively charged. An atom that gains electrons has more negative than positive particles; it is negatively charged.

Some materials hold their electrons very tightly; therefore, electrons do not move through them very well. These materials are called insulators. **Insulators** are materials with more than four electrons in their atom's outer orbit. Because they have more than four electrons in their outer orbit, it becomes easier for these materials to acquire (gain) electrons than to release electrons. See Figure 31–11. Examples of insulators include plastics, wood, glass, rubber, ceramics (spark plugs), and varnish for covering (insulating) copper wires in alternators and starters.

Semiconductors Materials with exactly four electrons in their outer orbit are neither conductors nor insulators and are called **semiconductor** materials. See Figure 31–12.

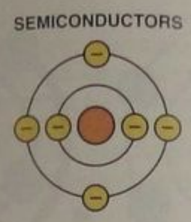


Figure 31–12 Semiconductor elements contain exactly four electrons in the outer orbit.

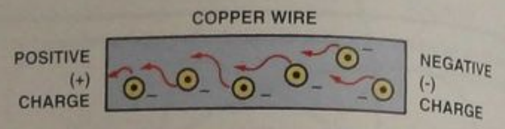


Figure 31–13 Current electricity is the movement of electrons through a conductor.

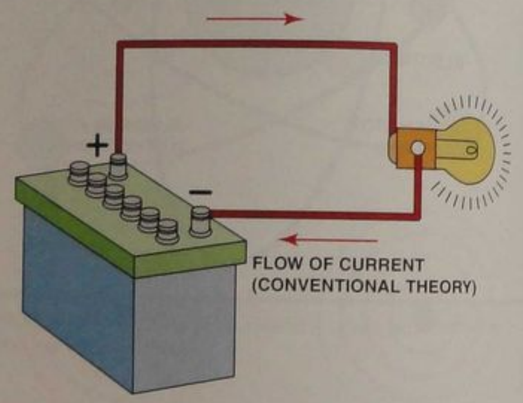


Figure 31–14 Conventional theory states that current flows through a circuit from positive (+) to negative (–). Automotive electricity uses the conventional theory in all electrical diagrams and schematics.

How Electrons Move Through a Conductor If an outside source of power, such as a battery, is connected to the ends of a conductor, a positive charge (lack of electrons) is placed on one end of the conductor and a negative charge is placed on the opposite end of the conductor. The negative charge will repel the free electrons from the atoms of the conductor, whereas the positive charge on the opposite end of the conductor will attract electrons. As a result of this attraction of opposite charges and repulsion of like charges, electrons will flow through the conductor. See Figure 31–13.

Conventional Theory versus Electron Theory It was once thought that electricity had only one charge and moved from positive to negative. This theory of the flow of electricity through a conductor is called the **conventional theory** of current flow. See Figure 31–14. The discovery of the electron and its negative charge led to the **electron theory,** which states that there is electron flow from negative to positive. Most automotive applications use the conventional theory. This book will use the conventional theory unless stated otherwise.

Amperes The **ampere** is the unit used throughout the world to measure current flow. When 6.28 billion billion electrons (the name for this large number of electrons is a **coulomb**) move past a

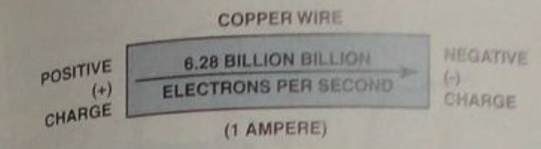


Figure 31–15 One ampere is the movement of 1 coulomb (6.28 billion billion electrons) past a point in 1 second.

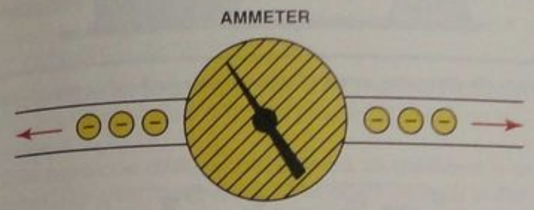


Figure 31–16 An ammeter is installed in the path of the electrons similar to a water meter used to measure the flow of water in gallons per minute. The ammeter displays current flow in amperes.

certain point in 1 second, this represents 1 ampere of current. See Figure 31–15. The ampere is the electrical unit for the amount of electron flow just as "gallons per minute" is the unit that can be used to measure the quantity of water flow. The ampere was named for the French electrician André Marie Ampère (1775–1836). The conventional abbreviations and measurement for amperes are summarized as follows:

1. The ampere is the unit of measurement for the amount of current flow.
2. *A* and *amps* are acceptable abbreviations for *amperes.*
3. The capital letter *I,* for *intensity,* is used in mathematical calculations to represent amperes.
4. Amperes are measured by an **ammeter** (not ampmeter). See Figure 31–16.

Volts The **volt** is the unit of measurement for electrical pressure. It is named for Alessandro Volta (1745–1827), an Italian physicist. The comparable unit using water as an example would be pounds per square inch (PSI). It is possible to have very high pressures (volts) and low water flow (amperes). It is also possible to have high water flow (amperes) and low pressure (volts). Voltage is also called **electrical potential,** because if there is voltage present in a conductor, there is a potential (possibility) for current flow. Voltage does *not* flow through conductors, but voltage does cause current (in amperes) to flow through conductors. See Figure 31–17. The conventional abbreviations and measurement for voltage are as follows:

1. The volt is the unit of measurement for the amount of electrical pressure.
2. **Electromotive force,** abbreviated **EMF,** is another term for voltage.
3. *V* is the generally accepted abbreviation for *volts.*
4. The symbol used in calculations is *E,* for *electromotive force.*
5. Volts are measured with a **voltmeter.** See Figure 31–18.

Ohms **Resistance** to the flow of current through a conductor is measured in units called **ohms,** named after the German physicist Georg Simon Ohm (1787–1854). The resistance to the flow of free electrons through a conductor results from the countless collisions the electrons cause within the atoms of the conductor. See



Figure 31–17 Voltage is the electrical pressure that causes the electrons to flow through a conductor.

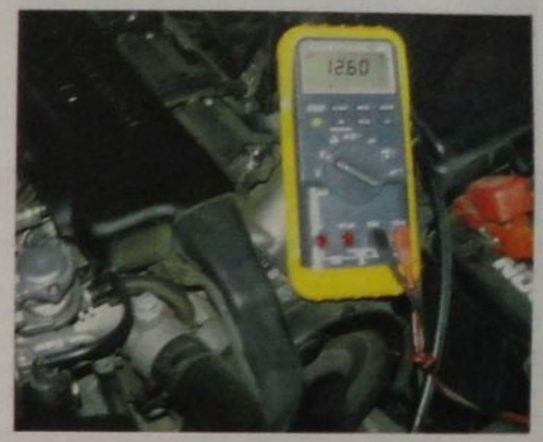


Figure 31–18 This digital multimeter set to read DC volts is being used to test the voltage of a vehicle battery. Most multimeters can also measure resistance (ohms) and current flow (amperes).

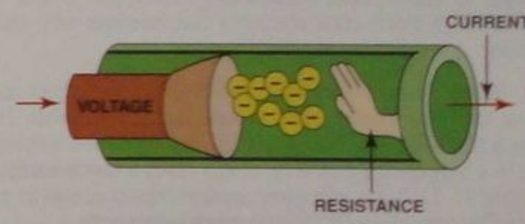


Figure 31–19 Resistance to the flow of electrons through a conductor is measured in ohms.

Figure 31–19. The conventional abbreviations and measurement for resistance are as follows:

1. The ohm is the unit of measurement for electrical resistance.
2. The symbol for ohms is Ω (Greek capital letter omega), the last letter of the Greek alphabet.
3. The symbol used in calculations is *R,* for *resistance.*
4. Ohms are measured with an **ohmmeter.**

Watts A **watt** is the electrical unit for *power,* the capacity to do work. It is named after a Scottish inventor, James Watt (1736–1819). The symbol for power is *P.* Electrical power is calculated as amperes times volts:

$$P\text{(power)} = I\text{(amperes)} \times E\text{(volts)}$$

See Figure 31–20.



Figure 31–20 A display at the Henry Ford Museum in Dearborn, Michigan, that includes a hand-cranked generator and a series of light bulbs. This figure shows a young man attempting to light as many bulbs as possible. The crank gets harder to turn as more bulbs light because it requires more power to produce the necessary watts of electricity.

SOURCES OF ELECTRICITY

There are several sources of electrical energy, but only a few of them are used in automotive electrical systems.

Friction When certain different materials are rubbed together, the friction causes electrons to be transferred from one to the other. Both materials become electrically charged. These charges are not in motion but stay on the surface where they were deposited. Because the charges are stationary, or static, this type of voltage is called **static electricity.** Vehicle tires rolling on pavement often create static electricity that interferes with radio reception.

Heat When pieces of two metals are joined together at both ends and one junction is heated, current passes through the metals. The current is very small, only millionths of an ampere, but this is enough to use in a temperature-measuring device called a **thermocouple.** See Figure 31–21. Some engine temperature sensors operate in this manner. This form of voltage is called **thermoelectricity.**

Thermoelectricity was discovered over a century ago. In 1823, the German physicist Thomas Johann Seebeck discovered that a voltage was developed in a loop containing two dissimilar metals, provided the two junctions were maintained at different temperatures. A decade later, French scientist Jean Charles Peltier found that electrons moving through a solid can carry heat from one side of the material to the other side. This effect is called the **Peltier effect.** A Peltier effect device is often used in portable coolers to keep food items cool if the current flows in one direction and to keep items warm if the current flows in reverse.

Light In 1839, Edmond Becquerel noticed that by shining a beam of sunlight over two different liquids, an electric current was developed. When certain metals are exposed to light, some of the light energy is transferred to the free electrons of the metal. This excess energy breaks the electrons loose from the surface of the metal. They can then be collected and made to flow in a conductor. See Figure 31–22. This **photoelectricity** is widely used in light-measuring devices such as photographic exposure meters and automatic headlamp dimmers.

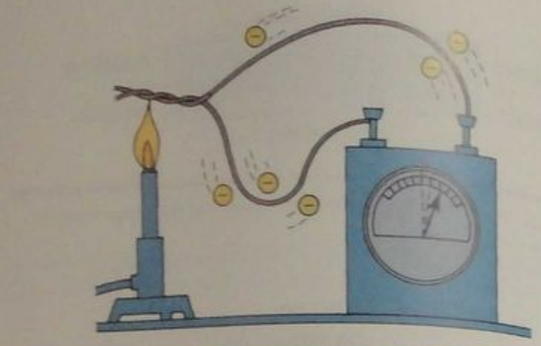


Figure 31–21 Electron flow is produced by heating the connection of two different metals.

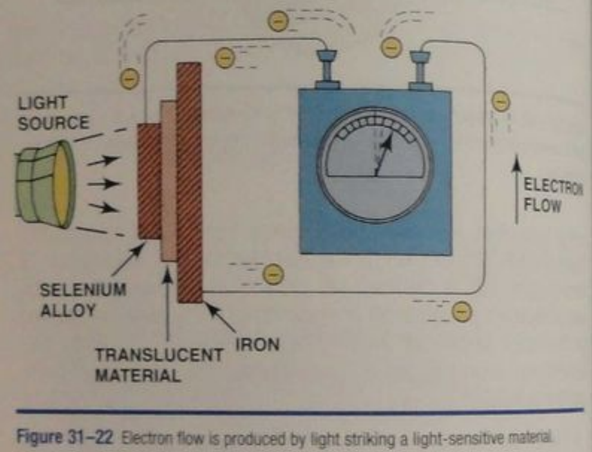


Figure 31–22 Electron flow is produced by light striking a light-sensitive material.

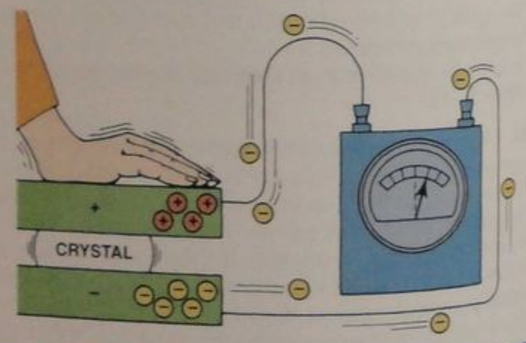


Figure 31–23 Electron flow is produced by pressure on certain crystals.

Pressure The first experimental demonstration of a connection between macroscopic piezoelectric phenomena and crystallographic structure was published in 1880 by Pierre and Jacques Curie. Their experiment consisted of a conclusive measurement of surface charges appearing on specially prepared crystals (tourmaline, quartz, topaz, cane sugar, and Rochelle salt among them), which were subjected to mechanical stress.

When subjected to pressure, certain crystals, such as quartz, develop a potential difference, or voltage, on the crystal faces. See Figure 31–23. This current is used in phonograph pickups, crystal microphones, underwater hydrophones, and certain stethoscopes. The voltage created is called **piezoelectricity.** Some automobile engine control sensors, such as the knock sensor (KS), use piezoelectricity to create voltage or to vary resistance and control a computer input signal.

Chemistry Two different materials (usually metals) placed in a conducting and reactive chemical solution create a difference in potential, or voltage, between them. This principle is called **electrochemistry** and is the basis of the automotive battery.

Conductors and Resistance All conductors have some resistance to current flow. Several principles of conductors and their resistance include the following.

- **If the conductor length is doubled, its resistance doubles.** This is the reason battery cables are designed to be as short as possible.
- **If the conductor diameter is increased, its resistance is reduced.** This is the reason starter motor cables are larger in diameter than other wiring in the vehicle. See Chapter 7 for further details on wiring sizes.
- **As the temperature increases, the resistance of the conductor also increases.** This is the reason for installing heat shields on some starter motors. The heat shield helps to protect the conductors (copper wiring inside the starter) from excessive engine heat and so reduces the resistance of starter circuits. Because a conductor increases in resistance with increased temperature, the conductor is called a **positive temperature coefficient** (PTC) resistor.
- **Materials used in the conductor have an impact on its resistance.** Silver has the lowest resistance of any conductor, but is expensive. Copper is the next lowest in resistance and it is reasonably priced. See the following chart for a comparison of materials.

Conduction Rating (Starting with the Best)
1. Silver
2. Copper
3. Gold
4. Aluminum
5. Tungsten
6. Zinc
7. Brass (copper and zinc)
8. Platinum
9. Iron
10. Nickel
11. Tin
12. Steel
13. Lead

Resistors Resistance is the opposition to current flow. **Resistors** represent an electrical load, or resistance, to current flow. Most electrical and electronic devices use resistors of specific values to limit and control the flow of current. Resistors can be made from carbon or from other materials that restrict the flow of electricity and are available in various sizes and resistance values. Most resistors have a series of painted color bands around them. These color bands are coded to indicate the degree of resistance. See Figures 31–24 and 31–25.

Variable Resistors Two basic types of mechanically operated variable resistors are used in automotive applications. A **potentiometer** is a three-terminal variable resistor where the majority of the current flow travels through the resistance of the unit and a wiper contact provides a variable voltage output. See Figure 31–26.

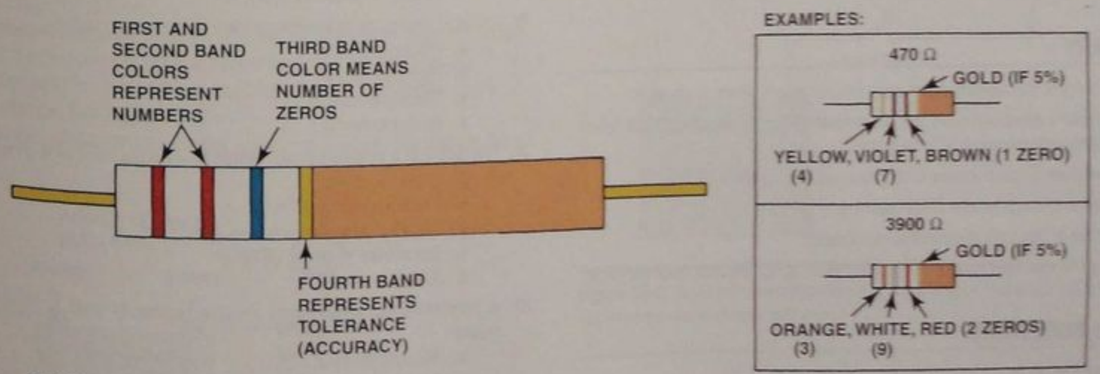


Figure 31–24 This figure shows a resistor color code interpretation.

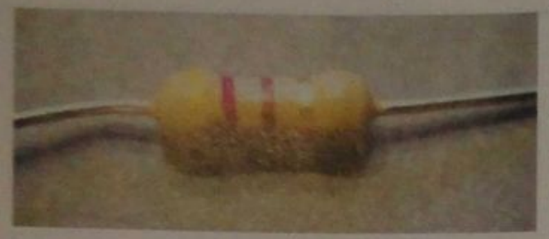


Figure 31–25 This figure shows a typical carbon resistor.

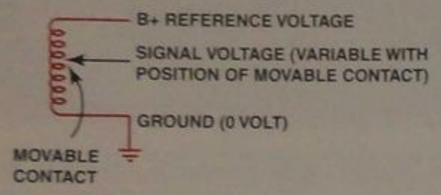


Figure 31–26 A three-wire variable resistor is called a potentiometer.

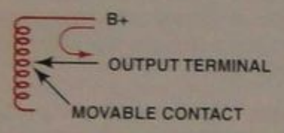


Figure 31–27 A two-wire variable resistor is called a rheostat.

Potentiometers are most commonly used as throttle position (TP) sensors on computer-equipped engines.

Another type of mechanically operated variable resistor is the **rheostat.** A rheostat is a two-terminal unit in which all of the current flows through the movable arm. See Figure 31–27. A rheostat is commonly used for a dash light dimmer control.

SUMMARY

1. Electricity is the movement of electrons from one atom to another.
2. Automotive electricity uses the conventional theory of current flow (electricity flows from positive to negative).
3. The ampere is the measure of the amount of current flow.
4. Voltage is the unit of electrical pressure.
5. The ohm is the unit of electrical resistance.
6. Sources of electricity include: friction, heat, light, pressure, and chemical.

REVIEW QUESTIONS

1. Define electricity.
2. Define ampere, volt, and ohm.
3. List three materials that are conductors and three materials that are insulators.
4. List four sources of electricity.

CHAPTER QUIZ

1. An electrical conductor is an element with _____ electrons in its outer orbit.
   a. Less than 2
   b. Less than 4
   c. Exactly 4
   d. More than 4
2. Like charges _____.
   a. Attract
   b. Repel
   c. Neutralize each other
   d. Add
3. Which of the following is the best conductor of electricity?
   a. Silver
   b. Copper
   c. Gold
   d. Zinc
4. Which unit of electricity does the work in a circuit?
   a. A volt
   b. An ampere
   c. An ohm
   d. A coulomb
5. As temperature increases _____.
   a. The resistance of a conductor decreases
   b. The resistance of a conductor increases
   c. The resistance of a conductor remains the same
   d. The voltage of the conductor decreases
6. The _____ is a unit of electrical pressure.
   a. Coulomb
   b. Volt
   c. Ampere
   d. Ohm
7. Technician A says that a two-wire variable resistor is called a rheostat. Technician B says that a three-wire variable resistor is called a potentiometer. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Creating electricity by exerting a force on a crystal is called _____
   a. Electrochemistry
   b. Piezoelectricity
   c. Thermoelectricity
   d. Photoelectricity
9. The fact that a voltage can be created by exerting force on a crystal is put in which type of sensor?
   a. Throttle position (TP)
   b. Manifold absolute pressure (MAP)
   c. Barometric pressure (BARO)
   d. Knock sensor (KS)
10. A potentiometer, a three-wire variable resistor, is used in which type of sensor?
    a. Throttle position (TP)
    b. Manifold absolute pressure (MAP)
    c. Barometric pressure (BARO)
    d. Knock sensor (KS)

CHAPTER 32

Electrical Circuits and Ohm's Law

OBJECTIVES: After studying Chapter 32, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • State Ohm's law. • Identify the parts of a complete circuit. • State Watt's law. • Describe the characteristics of an open circuit, a short-to-ground, and a short-to-voltage.

KEY TERMS: circuit • complete circuit • continuity • electrical load • ground (return) path • grounded • insulated path • kilowatt • Ohm's law • open circuit • power source • protection • shorted • short-to-ground • short-to-voltage • Watt's law

CIRCUITS

A **circuit** is a path that electrons travel from a power source (such as a battery) through a load (such as a light bulb) and back to the power source. It is called a *circuit* because the current must start and finish at the same place (power source). See Figure 32–1.

For *any* electrical circuit to work at all, it must be continuous from the battery (power) through all the wires and components and back to the battery (ground). A circuit that is continuous throughout is said to have **continuity.**

Parts of a Complete Circuit Every **complete circuit** contains the following parts:

1. A **power source,** such as a vehicle's battery.
2. **Protection** from harmful overloads (excessive current flow). Fuses, circuit breakers, and fusible links are examples of electrical circuit protection devices.
3. An **insulated path** for the current to flow through from the power source to the resistance. This path from a power source to the load (a light bulb in this example) is usually an insulated copper wire.
4. The **electrical load** or resistance converts electrical energy into heat, light, or motion.
5. A **ground (return) path** for the electrical current from the load back to the power source so that there is a *complete* circuit. This ground path is usually the metal body, frame, and engine block of the vehicle. See Figure 32–2.
6. Switches and controls turn the circuit on and off. See Figure 32–3.

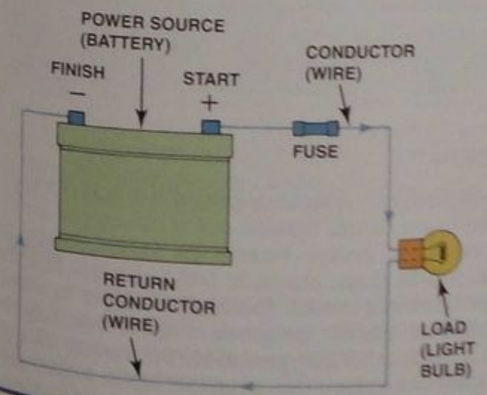


Figure 32–1 All complete circuits must have a power source, a power path, protection (fuse), an electrical load (light bulb in this case), and a return path back to the power source.

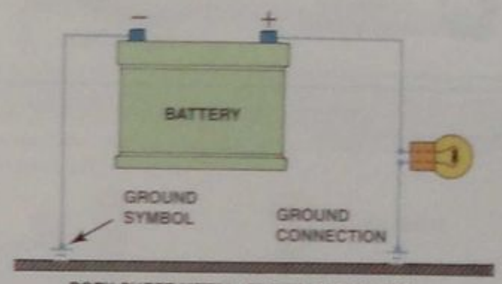


Figure 32–2 The return path back to the battery can be any electrical conductor, such as the metal frame or body of the vehicle.

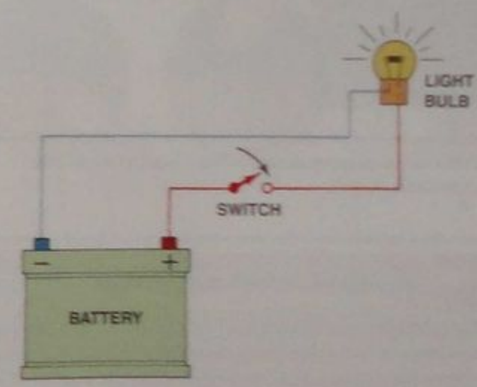


Figure 32–3 An electrical switch opens the circuit and no current flows. The switch could also be on the return (ground) path wire.

Open Circuits An **open circuit** is any circuit that is *not* complete, or that lacks continuity. See Figure 32–4.

No current at all will flow through an incomplete circuit. An open circuit may be created by a break in the circuit or by a switch that opens (turns off) the circuit and prevents the flow of current. In any circuit containing a power load and ground, an opening anywhere in the circuit will cause the circuit to stop working. A light switch in a home and the headlight switch in a vehicle are examples of devices that open a circuit to control its operation.

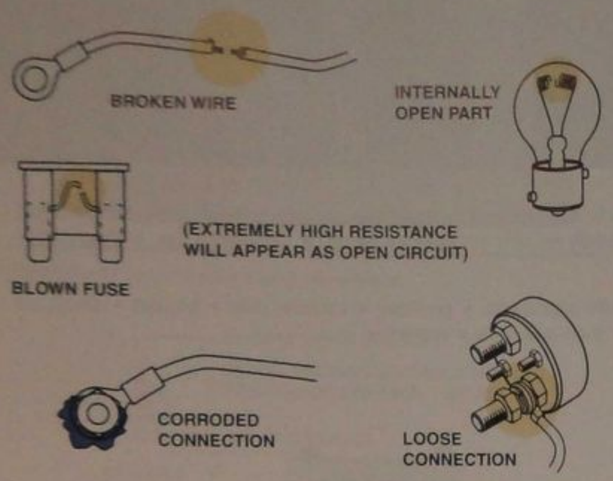


Figure 32–4 This figure shows examples of common causes of open circuits. Some of these causes are often difficult to find.

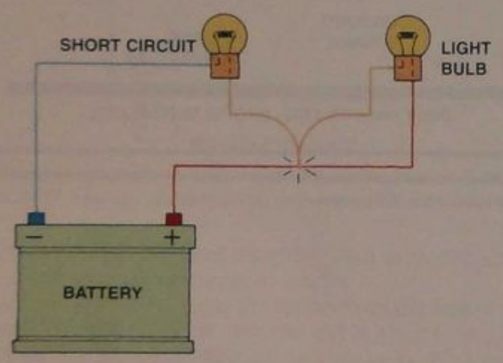


Figure 32–5 A short circuit permits electrical current to bypass some or all of the resistance in the circuit.

TECH TIP **Use a Schematic as a Road Map**

The wiring schematic is the "road map" of a circuit and shows all electrical paths. If an open occurs in a circuit, the current stops flowing and the electrical load device does not work. Trace the circuit by following the path from the battery through the power side component, load, and on the ground. Check for voltage at various points in the circuit to locate where the open is in the circuit.

Short-to-Voltage If a wire (conductor) or component is shorted to voltage, it is commonly called **shorted.** See Figure 32–5. A short circuit:

1. Is a complete circuit in which the current bypasses *some* or *all* of the resistance in the circuit.
2. Involves the power side of the circuit.
3. Involves a copper-to-copper connection.
4. Is also called a **short-to-voltage.**
5. Usually affects more than one circuit.
6. *May or may not* blow a fuse. See Figure 32–6.

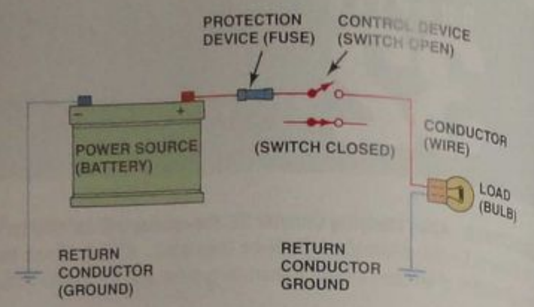


Figure 32–6 A fuse or circuit breaker opens the circuit to prevent possible overheating damage in the event of a short circuit.

REAL WORLD FIX **The Short-to-Voltage Story**

A technician was working on a Chevrolet pickup truck with unusual electrical problems including the following:

1. Whenever the brake pedal was depressed, the dash light and the side marker lights would light.
2. The turn signals caused all lights to blink and the fuel gauge needle to bounce up and down.
3. When the brake lights were on, the front parking lights also came on.

The technician tested all fuses using a conventional test light (not a low-current test light) and found them to be okay. All body-to-engine block ground wires were clean and tight. All bulbs were of the correct trade number as specified in the owner's manual.

NOTE: Using a single-filament bulb (such as a #1156) in the place of a dual-filament bulb (such as a #1157) could also cause many of these same problems.

Because most of the trouble occurred when the brake pedal was depressed, the technician decided to trace all the wires in the brake light circuit. The problem was found near the exhaust system. A small hole in the tailpipe (after the muffler) directed hot exhaust gases to the wiring harness containing all of the wires for circuits at the rear of the truck. The heat had melted the insulation and caused most of the wires to touch. Whenever one circuit was activated (such as when the brake pedal was applied), the current had a complete path to several other circuits. A fuse did not blow because there was enough resistance in the circuits being energized so that the current (in amperes) was too low to blow any fuses.

Short-to-Ground A **short-to-ground** is a type of circuit failure wherein the current bypasses part of the normal circuit and flows directly to ground. Because the ground return circuit is metal (vehicle frame, engine, or body), this type of circuit is identified as having current flowing from copper to steel. See Figure 32–7. A defective component or circuit that is shorted to ground is commonly called **grounded.** For example, if a penny was accidentally inserted into a cigarette lighter socket, the current would flow through the penny to ground. Because the penny has little resistance, an excessive amount of current flow causes the fuse to blow.

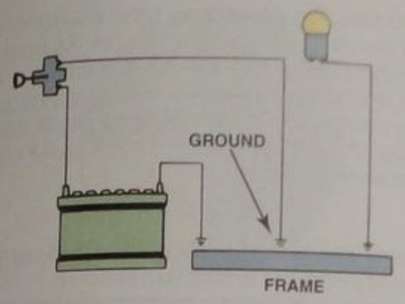


Figure 32–7 A short-to-ground affects the power side of the circuit. Current flows directly to the ground return, bypassing some or all of the electrical loads in the circuit. There is no current in the circuit past the short.

High Resistance Another circuit fault that can commonly occur is excessive resistance in the circuit. This extra resistance can be caused by several circuit faults including:

- Corrosion of wires on the terminals
- Poor electrical connections at connectors
- Loose ground connection

Any of the above will cause the current in amperes to decrease in the circuit. As a result of the reduced current flow, the electrical load device may operate, but with reduced speed or brightness. High-resistance faults can also be intermittent and cause problems just when conditions or temperatures cause a problem in the circuit.

TECH TIP **Think of a Waterwheel**

A beginner technician cleaned the positive terminal of the battery to correct the problem of slow cranking. When questioned by the shop foreman as to why only the positive post had been cleaned, the technician responded that the negative terminal was "only a ground." The foreman reminded the technician that the current, in amperes, is constant throughout a series circuit (such as the cranking motor circuit). If 200 amperes leaves the positive post of the battery, then 200 amperes must return to the battery through the negative post.

The technician just could not understand how electricity can do work (crank an engine), yet return the same amount of current, in amperes, as left the battery. The shop foreman explained that even though the current is constant throughout the circuit, the voltage (electrical pressure or potential) is dropped to zero in the circuit. To explain further, the shop foreman drew a waterwheel. See Figure 32–8.

As water drops from a higher level to a lower level, high potential energy (or voltage) is used to turn the waterwheel and results in low potential energy (or lower voltage). The same amount of water (or amperes) reaches the pond under the waterwheel as started the fall above the waterwheel. As current (amperes) flows through a conductor, it performs work in the circuit (turns the waterwheel) while its voltage (potential) is dropped.

OHM'S LAW

The German physicist, Georg Simon Ohm, established that electric pressure (EMF) in volts, electrical resistance in ohms, and the amount of current in amperes flowing through any circuit are all related. **Ohm's law** states: *It requires 1 volt to push 1 ampere through 1 ohm of resistance.* This means that if the voltage is doubled, then the number of amperes of current flowing through a circuit will also double if the resistance of the circuit remains the same.

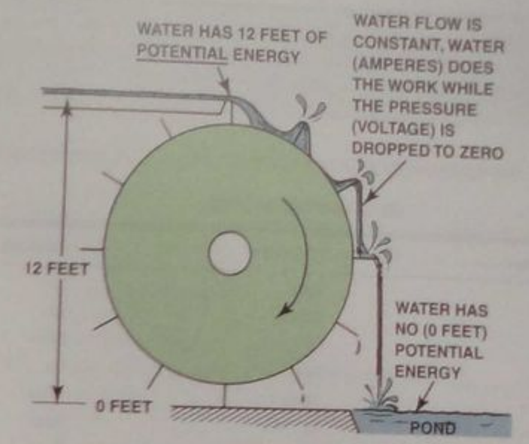


Figure 32–8 Electrical flow through a circuit is similar to water flowing over a waterwheel. The more the water (amperes in electricity), the greater the amount of work (waterwheel). The amount of water remains constant, yet the pressure (voltage in electricity) drops as the current flows through the circuit.

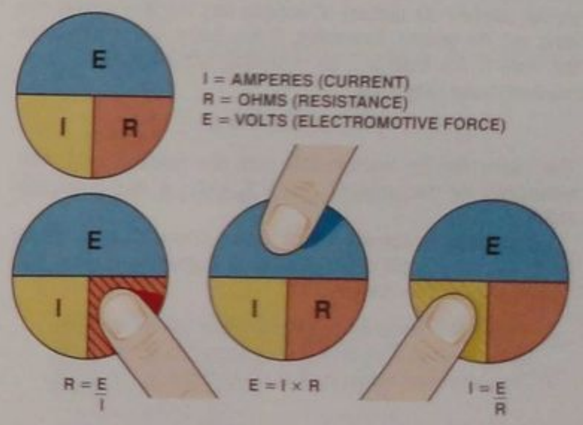


Figure 32–9 To calculate one unit of electricity when the other two are known, simply use your finger and cover the unit you do not know. For example, if both voltage (E) and resistance (R) are known, cover the letter I (amperes). Notice that the letter E is above the letter R so divide the resistor's value into the voltage to determine the current in the circuit.

Ohm's law can also be stated as a simple formula used to calculate one value of an electrical circuit if the other two are known. See Figure 32–9.

$$I = E/R$$

where

I = Current in amperes (A)
E = Electromotive force (EMF) in volts (V)
R = Resistance in ohms (Ω)

1. Ohm's law can determine the *resistance* if the volts and amperes are known: $R = E/I$.
2. Ohm's law can determine the *voltage* if the resistance (ohms) and amperes are known: $E = I \times R$.
3. Ohm's law can determine the *amperes* if the resistance and voltage are known: $I = E/R$.

NOTE: Before applying Ohm's law, be sure that each unit of electricity is converted into base units. For example, 10 kΩ should be converted to 10,000 ohms and 10 mA should be converted into 0.010 A.

See the following table for a summary of Ohm's law relationships.

Ohm's Law Relationships

Voltage	Resistance	Amperage
Up	Down	Up
Up	Same	Up
Up	Up	Same
Same	Down	Up
Same	Same	Same
Same	Up	Down
Down	Up	Down
Down	Same	Down

Ohm's Law Applied to Simple Circuits If a battery with 12 volts is connected to a resistor of 4 ohms, as shown in Figure 32–10, how many amperes will flow through the circuit? Using Ohm's law, we can calculate the number of amperes that will flow through the wires and the resistor. Remember, if two factors are known (volts and ohms in this example), the remaining factor (amperes) can be calculated using Ohm's law.

$$I = E/R = 12\ V/4\ \Omega$$

The values for the voltage (12) and the resistance (4) were substituted for the variables E and R, and I is thus 3 amperes ($12/4 = 3$).

If we want to connect a resistor to a 12-volt battery, we now know that this simple circuit requires 3 amperes to operate. This may help us for two reasons.

1. We can now determine the wire diameter that we will need based on the number of amperes flowing through the circuit.
2. The correct fuse rating can be selected to protect the circuit.

WATT'S LAW

James Watt (1736–1819), a Scottish inventor, first determined the power of a typical horse while measuring the amount of coal being lifted out of a mine. The power of one horse was determined to be 33,000 foot-pounds per minute. Electricity can also be expressed in a unit of power called a *watt* and the relationship is known as **Watt's law,** which states: *A watt is a unit of electrical power represented by a current of 1 ampere through a circuit with a potential difference of 1 volt.* The symbol for a watt is the capital letter *W*. The formula for watts is:

$$W = I \times E$$

Another way to express this formula is to use the letter P to represent the unit of power. The formula then becomes:

$$P = I \times E$$

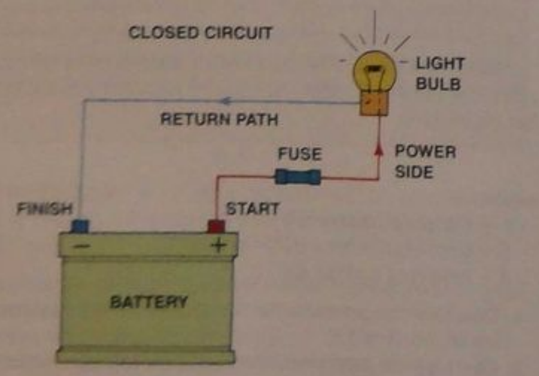


Figure 32–10 This closed circuit includes a power source, power-side wire, circuit protection (fuse), resistance (bulb), and return path wire.

HINT: An easy way to remember this equation is that it spells "pie."

FREQUENTLY ASKED QUESTION ???

Why Are Vehicle Engines for Europe Rated in Kilowatts?

Engine power is commonly rated in watts or **kilowatts** (1,000 watts equal 1 kilowatt) because 1 horsepower is equal to 746 watts. For example, a 200-horsepower engine can be rated as having the power equal to 149,200 watts or 149.2 kilowatts (kW).

To calculate watts, both the current in amperes and the voltage in the circuit must be known. If any two of these factors are known, then the other remaining factor can be determined by the following equation:

$P = I \times E$ (watts equal amperes times voltage)

$I = P/E$ (amperes equal watts divided by voltage)

$E = P/I$ (voltage equals watts divided by amperes)

A Watt's circle can be drawn and used like the Ohm's law circle diagram. See Figure 32–11.

Magic Circle The formulas for calculating any combination of electrical units are shown in Figure 32–12.

TECH TIP **Wattage Increases by the Square of the Voltage**

The brightness of a light bulb, such as an automotive headlight or courtesy light, depends on the number of watts available. The watt is the unit by which electrical power is measured. If the battery voltage drops, even slightly, the light becomes noticeably dimmer. The formula for calculating power (P) in watts is $P = I \times E$. This can also be expressed as Watts = Amps × Volts.

According to Ohm's law, $I = E/R$. Therefore, E/R can be substituted for I in the previous formula resulting in $P = E/R \times E$ or $P = E^2/R$.

E^2 means E multiplied by itself. A small change in the voltage (E) has a big effect on the total brightness of the bulb. (Remember, household light bulbs are sold according to their wattage.) Therefore, if the voltage to an automotive bulb is reduced, such as by a poor electrical connection, the brightness of the bulb is greatly affected. A poor electrical ground causes a voltage drop. The voltage at the bulb is reduced and the bulb's brightness is reduced.

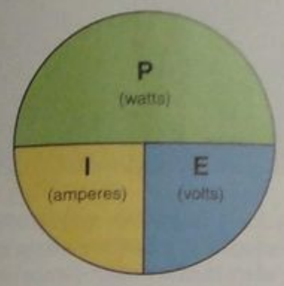


Figure 32–11 To calculate one unit when the other two are known, simply cover the unknown unit to see what unit needs to be divided or multiplied to arrive at the solution.

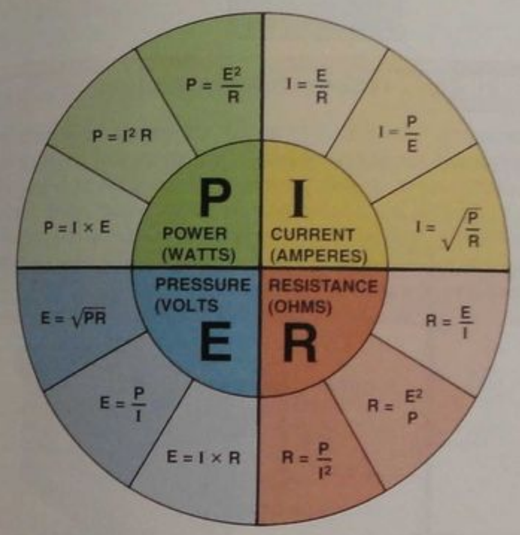


Figure 32–12 "Magic circle" of most of the formulas for problems involving Ohm's law. Each quarter of the "pie" has formulas used to solve for a particular unknown value: current (amperes), in the upper right segment; resistance (ohms), in the lower right; voltage (E), in the lower left; and power (watts), in the upper left.

SUMMARY

1. All complete electrical circuits have a power source (such as a battery), a circuit protection device (such as a fuse), a power-side wire or path, an electrical load, a ground return path, and a switch or a control device.
2. A short-to-voltage involves a copper-to-copper connection and often affects more than one circuit.
3. A short-to-ground involves a copper-to-steel connection and usually causes the fuse to blow.
4. An open is a break in the circuit resulting in absolutely no current flow through the circuit.

REVIEW QUESTIONS

1. List the parts of a complete electrical circuit.
2. Describe the difference between a short-to-voltage and a short-to-ground.
3. Describe the difference between an open and a short.
4. State Ohm's law.
5. Explain what occurs to current flow (amperes) and wattage if the resistance of a circuit is increased because of a corroded connection.

CHAPTER QUIZ

1. If an insulated wire rubbed through a part of the insulation and the wire conductor touched the steel body of a vehicle, the type of failure would be called _____.
   a. A short-to-voltage
   b. A short-to-ground
   c. An open
   d. A chassis ground
2. If two insulated wires were to melt together where the copper conductors touched each other, the type of failure would be called _____.
   a. A short-to-voltage
   b. A short-to-ground
   c. An open
   d. A floating ground
3. If 12 volts are being applied to a resistance of 3 ohms, _____ amperes will flow.
   a. 12
   b. 3
   c. 4
   d. 36
4. How many watts are consumed by a light bulb if 1.2 amperes are measured when 12 volts are applied?
   a. 14.4 watts
   b. 144 watts
   c. 10 watts
   d. 0.10 watt
5. How many watts are consumed by a starter motor if it draws 150 amperes at 10 volts?
   a. 15
   b. 150
   c. 1500
   d. 15,000
6. If a conductor breaks, the type of fault is called a(an) _____.
   a. Open
   b. Short
   c. High resistance
   d. Bridge
7. An electrical connector becomes corroded. Technician A says that the current flow (amperes) will increase in the circuit. Technician B says that the resistance in the circuit will be less than the resistance of the original. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. If 200 amperes flow from the positive terminal of a battery and operate the starter motor, how many amperes will flow back to the negative terminal of the battery?
   a. Cannot be determined
   b. Zero
   c. About one-half (about 100 amperes)
   d. 200 amperes
9. What is the symbol for voltage used in calculations?
   a. V
   b. E
   c. EMF
   d. I
10. Which circuit failure is most likely to cause the fuse to blow?
    a. Open
    b. Short-to-ground
    c. Short-to-voltage
    d. High resistance

CHAPTER

33 Series, Parallel, and Series-Parallel Circuits

OBJECTIVES: After studying Chapter 33, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic System Diagnosis). • Identify a series circuit. • State Kirchhoff's voltage law. • Calculate voltage drops in a series circuit. • Explain series and parallel circuit laws. • State Kirchhoff's current law. • Identify where faults in a series-parallel circuit can be detected or determined.

KEY TERMS: branches • combination circuit • compound circuit • Kirchhoff's current law • Kirchhoff's voltage law • leg • parallel circuit • series circuit • series-parallel circuits • shunt • total circuit resistance • voltage drop

SERIES CIRCUITS

A **series circuit** is a complete circuit that has more than one electrical load where all of the current has only one path to flow through all of the loads. Electrical components such as fuses and switches are generally not considered to be included in the determination of a series circuit. The circuit must be continuous or have continuity in order for current to flow through the circuit.

NOTE: Because an electrical load needs both a power and a ground to operate, a break (open) anywhere in a series circuit will cause the current in the circuit to stop.

TECH TIP ✔ **Farsighted Quality of Electricity**

Electricity almost seems to act as if it "knows" what resistances are ahead on the long trip through a circuit. If the trip through the circuit has many high-resistance components, very few electrons (amperes) will choose to attempt to make the trip. If a circuit has little or no resistance (for example, a short circuit), then as many electrons (amperes) as possible attempt to flow through the complete circuit. If the flow exceeds the capacity of the fuse or the circuit breaker, then the circuit is opened and all current flow stops.

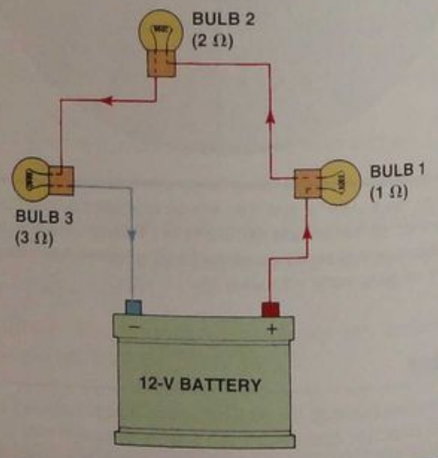


Figure 33–1 A series circuit with three bulbs. All current flows through all resistances (bulbs). The total resistance of the circuit is the sum of the total resistance of the bulbs, and the bulbs will light dimly because of the increased resistance and the reduction of current flow (amperes) through the circuit.

KIRCHHOFF'S VOLTAGE LAW

The voltage that is applied through a series circuit drops with each resistor in a manner similar to that in which the strength of an athlete drops each time a strenuous physical feat is performed. The greater the resistance, the greater the drop in voltage.

A German physicist, Gustav Robert Kirchhoff (1824–1887), developed laws about electrical circuits. His second law, **Kirchhoff's voltage law,** concerns voltage drops. It states: *The voltage around any closed circuit is equal to the sum (total) of the voltage drops across the resistances.*

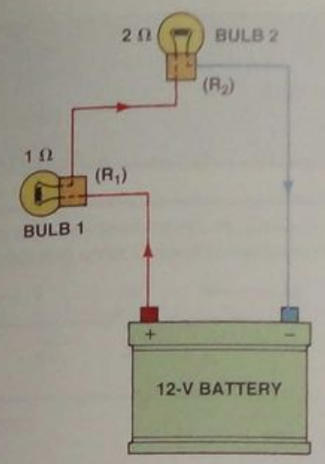


Figure 33–2 A series circuit with two bulbs.

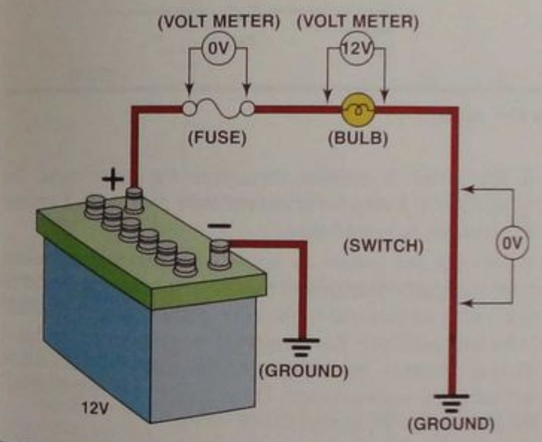


Figure 33–3 As current flows through a circuit, the voltage drops in proportion to the amount of resistance in the circuit. Most, if not all, of the resistance should occur across the load such as the bulb in this circuit. All of the other components and wiring should produce little, if any, voltage drop. If a wire or connection did cause a voltage drop, less voltage would be available to light the bulb and the bulb would be dimmer than normal.

Applying Kirchhoff's Voltage Law Kirchhoff states in his second law that the voltage will drop in proportion to the resistance and that the total of all voltage drops will equal the applied voltage. See Figure 33–3. Using Figure 33–4, the total resistance of the circuit can be determined by adding the individual resistances (2Ω + 4Ω + 6Ω = 12Ω). The current through the circuit is determined by using Ohm's law, $I = E/R = 12V/12\Omega = 1A$. Therefore, in the circuit shown, the following values are known:

Resistance = 12Ω
Voltage = 12V
Current = 1A

Everything is known *except* the voltage drop caused by each resistance. The **voltage drop** can be determined by using Ohm's law and calculating for voltage (E) using the value of each resistance individually:

$$E = I \times R$$

where

E = Voltage
I = Current in the circuit (remember, the current is constant in a series circuit; only the voltage varies)
R = Resistance of only one of the resistances

The voltage drops are as follows:

Voltage drop for bulb 1: $E = I \times R = 1A \times 2\Omega = 2V$

Voltage drop for bulb 2: $E = I \times R = 1A \times 4\Omega = 4V$

Voltage drop for bulb 3: $E = I \times R = 1A \times 6\Omega = 6V$

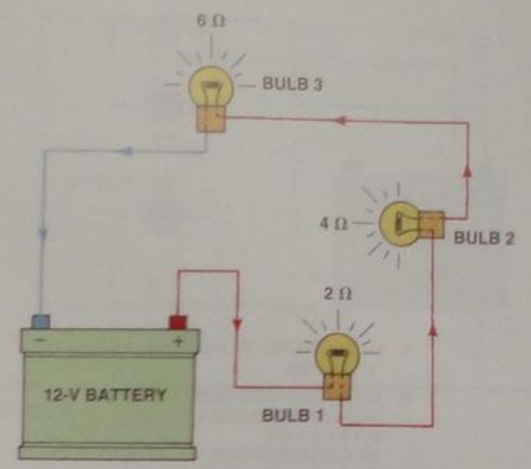


Figure 33–4 In a series circuit the voltage is dropped or lowered by each resistance in the circuit. The higher the resistance, the greater the drop in voltage.

NOTE: Notice that the voltage drop is proportional to the resistance. In other words, the higher the resistance, the greater the voltage drop. A 6-ohm resistance dropped the voltage three times as much as the voltage drop created by the 2-ohm resistance.

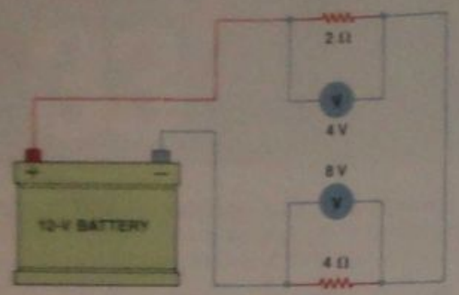
According to Kirchhoff, the sum (addition) of the voltage drops should equal the applied voltage (battery voltage):

Total of voltage drops = 2V + 4V + 6V = 12V = Battery voltage

This illustrates Kirchhoff's second (voltage) law. Another example is illustrated in Figure 33–5.

Use of Voltage Drops Voltage drops, due to built-in resistance, are used in automotive electrical systems to drop the voltage in the following examples.

1. **Dash lights.** Most vehicles are equipped with a method of dimming the brightness of the dash lights by turning a variable resistor. This type of resistor can be changed and therefore varies the voltage to the dash light bulbs. A high voltage to the bulbs causes them to be bright, and a low voltage results in a dim light.
2. **Blower motor** (heater or air-conditioning fan). Speeds are usually controlled by a fan switch sending current through high-,



A. I = E/R (TOTAL "R" = 6 Ω)
= 12/6 = 2A

B. E = I/R (VOLTAGE DROP)
AT 2 Ω RESISTANCE =
E = 2 x 2 = 4 V
AT 4 Ω RESISTANCE =
E = 2 x 4 = 8 V

C. 4 + 8 = 12 V
SUM OF VOLTAGE DROP
EQUALS APPLIED VOLTAGE

Figure 33–5 A voltmeter reads the differences of voltage between the test leads. The voltage read across a resistance is the voltage drop that occurs when current flows through a resistance. A voltage drop is also called an "IR" drop because it is calculated by multiplying the current (I) through the resistance (electrical load) by the value of the resistance (R).

medium-, or low-resistance wire resistors. The highest resistance will drop the voltage the most, causing the motor to run at the lowest speed. The highest speed of the motor will occur when *no* resistance is in the circuit and full battery voltage is switched to the blower motor.

FREQUENTLY ASKED QUESTION ???

Why Check the Voltage Drop Instead of Measuring the Resistance?

Imagine a wire with all strands cut except for one. An ohmmeter can be used to check the resistance of this wire and the resistance would be low, indicating that the wire was okay. But this one small strand cannot properly carry the current (amperes) in the circuit. A voltage drop test is therefore a better test to determine the resistance in components for two reasons:

- An ohmmeter can only test a wire or component that has been disconnected from the circuit and is not carrying current. The resistance can, and does, change when current flows.
- A voltage drop test is a dynamic test because as the current flows through a component, the conductor increases in temperature, which in turn increases resistance. This means that a voltage drop test is testing the circuit during normal operation and is therefore the most accurate way of determining circuit conditions.

A voltage drop test is also easier to perform because the resistance does not have to be known, only that the unwanted loss of voltage in a circuit should be less than 3% or less than about 0.14 volts for any 12-volt circuit.

SERIES CIRCUIT LAWS

Law 1 The total resistance in a series circuit is the sum total of the individual resistances. The resistance values of each electrical load are simply added together.

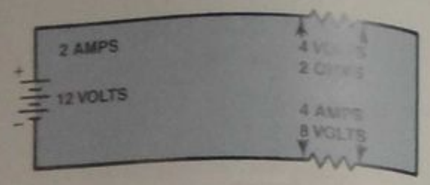


Figure 33–6 In this series circuit with a 2-ohm resistor and a 4-ohm resistor, current (2 amperes) is the same throughout even though the voltage drops across each resistor

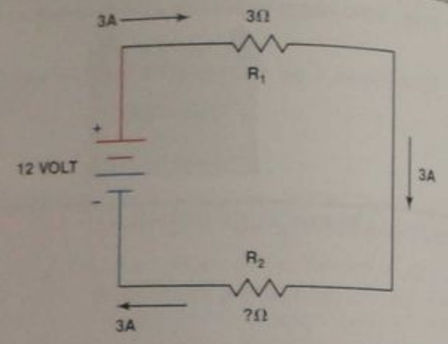


Figure 33–7 Example 1.

Law 2 The current is constant throughout the entire circuit. See Figure 33–6. If 2 amperes of current leave the battery, 2 amperes of current return to the battery.

Law 3 Although the current (in amperes) is constant, the voltage drops across each resistance in the circuit. The voltage drop across each load is proportional to the value of the resistance compared to the total resistance. For example, if the resistance is one-half of the total resistance, the voltage drop across that resistance will be one-half of the applied voltage. The sum total of all individual voltage drops equals the applied source voltage.

SERIES CIRCUIT EXAMPLES

Each of the four examples includes solving for the following:

- Total resistance in the circuit
- Current flow (amperes) through the circuit
- Voltage drop across each resistance

Example 1:

(See Figure 33–7.)

The unknown in this problem is the value of R_2. The total resistance, however, can be calculated using Ohm's law.

$$R_{total} = E/I = 12 \text{ volts}/3 \text{ A} = 4\Omega$$

Because R_1 is 3 ohms and the total resistance is 4 ohms, the value of R_2 is 1 ohm.

Example 2:

(See Figure 33–8.)

The unknown in this problem is the value of R_3. The total resistance, however, can be calculated using Ohm's law.

$$R_{total} = E/I = 12 \text{ volts}/2 \text{ A} = 6\Omega$$

The total resistance of R_1 (3 ohms) and R_2 (1 ohm) equals 4 ohms so that the value of R_3 is the difference between the total resistance (6 ohms) and the value of the known resistance (4 ohms).

$$6 - 4 = 2 \text{ ohms} = R_3$$

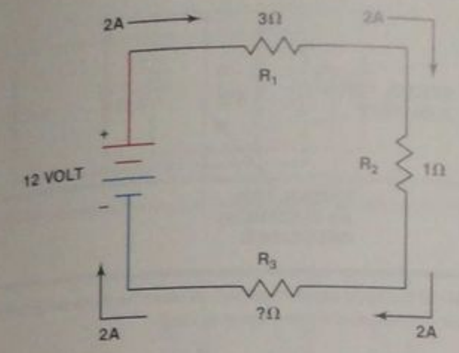


Figure 33–8 Example 2.

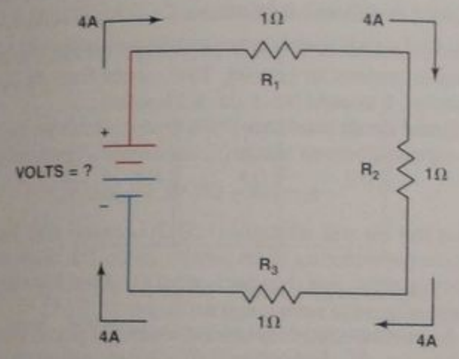


Figure 33–9 Example 3.

Example 3:

(See Figure 33–9.)

The unknown value in this problem is the voltage of the battery. To solve for voltage, use Ohm's law ($E = I \times R$). The "R" in this problem refers to the total resistance (R_T). The total resistance of a series circuit is determined by adding the values of the individual resistors.

$$R_T = 1\Omega + 1\Omega + 1\Omega$$
$$R_T = 3\Omega$$

Placing the value for the total resistance (3Ω) into the equation results in a battery voltage of 12 volts.

$$E = 4\text{A} \times 3\Omega$$
$$E = 12 \text{ volts}$$

Example 4:

(See Figure 33–10.)

The unknown in this example is the current (amperes) in the circuit. To solve for current, use Ohm's law.

$$I = E/R = 12 \text{ volts}/6 \text{ ohms} = 2\text{A}$$

Notice that the total resistance in the circuit (6 ohms) was used in this example, which is the total of the three individual resistors ($2\Omega + 2\Omega + 2\Omega = 6\Omega$). The current through the circuit is two amperes.

PARALLEL CIRCUITS

A **parallel circuit** is a complete circuit that has more than one path for the current. The separate paths which split and meet at junction points are called **branches, legs,** or **shunts.** The current flow through each branch or leg varies depending on the resistance

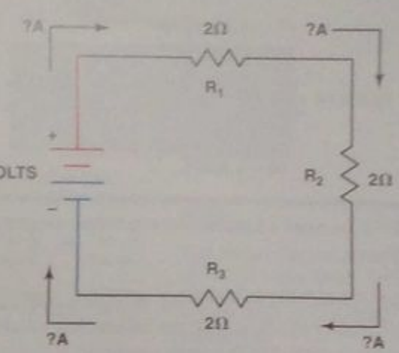


Figure 33–10 Example 4.

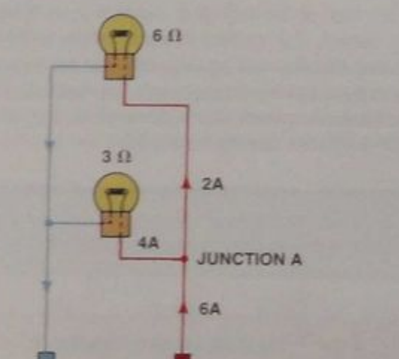


Figure 33–11 The amount of current flowing into junction point A equals the total amount of current flowing out of the junction.

in that branch. A break or open in one leg or section of a parallel circuit does not stop the current flow through the remaining legs of the parallel circuit.

KIRCHHOFF'S CURRENT LAW

Kirchhoff's current law (his first law) states: *The current flowing into any junction of an electrical circuit is equal to the current flowing out of that junction.* This first law can be illustrated using Ohm's law, as seen in Figure 33–11. Kirchhoff's law states that the amount of current flowing into junction A will equal the current flowing out of junction A.

Because the 6-ohm leg requires 2 amperes and the 3-ohm resistance leg requires 4 amperes, it is necessary that the wire from the battery to junction A be capable of handling 6 amperes. Also notice that the sum of the current flowing *out* of a junction (2 + 4 = 6 A) is equal to the current flowing *into* the junction (6 A), proving Kirchhoff's current law.

PARALLEL CIRCUIT LAWS

Law 1 The total resistance of a parallel circuit is always less than that of the smallest-resistance leg. This occurs because not all of the

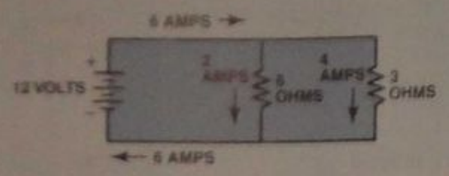


Figure 33–12 The current in a parallel circuit splits (divides) according to the resistance in each branch.

current flows through each leg or branch. With many branches, more current can flow from the battery just as more vehicles can travel on a road with five lanes compared to a road with only one or two lanes.

Law 2 The voltage is the same for each leg of a parallel circuit.

Law 3 The sum of the individual currents in each leg will equal the total current. The amount of current flow through a parallel circuit may vary for each leg depending on the resistance of that leg. The current flowing through each leg results in the same voltage drop (from the power side to the ground side) as for every other leg of the circuit. See Figure 33–12.

NOTE: A parallel circuit drops the voltage from source voltage to zero (ground) across the resistance in each leg of the circuit.

TECH TIP ✔ **The Path of Least Resistance**

There is an old saying that electricity will always take the path of least resistance. This is true, especially if there is a fault such as in the secondary (high-voltage) section of the ignition system. If there is a path to ground that is lower than the path to the spark plug, the high-voltage spark will take the path of least resistance. In a parallel circuit where there is more than one path for the current to flow, most of the current will flow through the branch with the lower resistance. This does not mean that all of the current will flow through the lowest resistance, because the other path does provide a path to ground, and the amount of current flow through the other branches is determined by the resistance and the applied voltage according to Ohm's law.

Therefore, the only place where electricity takes the path of least resistance is in a series circuit where there are not other paths for the current to flow.

DETERMINING TOTAL RESISTANCE IN A PARALLEL CIRCUIT

There are five methods commonly used to determine total resistance in a parallel circuit.

NOTE: Determining the total resistance of a parallel circuit is very important to automotive service. Electronic fuel-injector and diesel engine glow plug circuits are two of the most commonly tested circuits where parallel circuit knowledge is required. Also, when installing extra lighting, the technician must determine the proper gauge wire and protection device.

Method 1 The total *current* (in amperes) can be calculated first by treating each leg of the parallel circuit as a simple circuit. See Figure 33–13. Each leg has its own power and ground (−), and therefore, the current through each leg is independent of the current through any other leg.

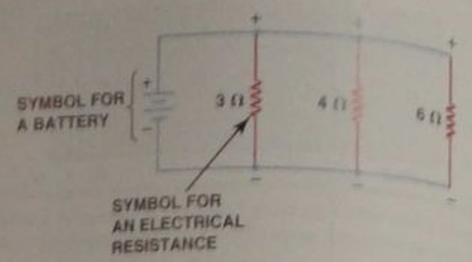


Figure 33–13 In a typical parallel circuit, each resistance has power and ground and each leg operates independently of the other legs of the circuit.

Current through the 3-Ω resistance = $I = E/R = 12V/3\Omega = 4A$
Current through the 4-Ω resistance = $I = E/R = 12V/4\Omega = 3A$
Current through the 6-Ω resistance = $I = E/R = 12V/6\Omega = 2A$

The total current flowing from the battery is the sum total of the individual currents for each leg. Total current from the battery is, therefore, 9 amperes (4A + 3A + 2A = 9A).

If **total circuit resistance** (R_T) is needed, Ohm's law can be used to calculate it because voltage (E) and current (I) are now known.

$$R_T = E/I = 12V/9A = 1.33\Omega$$

Note that the total resistance (1.33 Ω) is smaller than that of the smallest-resistance leg of the parallel circuit. This characteristic of a parallel circuit holds true because not all current flows through all resistances as in a series circuit.

Because the current has alternative paths to ground through the various legs of a parallel circuit, as additional resistances (legs) are added to a parallel circuit, the total current from the battery (power source) *increases*.

Additional current can flow when resistances are added in parallel, because each leg of a parallel circuit has its own power and ground and the current flowing through each leg is strictly dependent on the resistance of *that* leg.

Method 2 If only two resistors are connected in parallel, the total resistance (R_T) can be found using the formula $R_T = (R_1 \times R_2)/(R_1 + R_2)$. For example, using the circuit in Figure 33–14 and substituting 3 ohms for R_1 and 4 amperes for R_2, $R_T = (3 \times 4)/(3 + 4) = 12/7 = 1.7\Omega$. Note that the total resistance (1.7 Ω) is smaller than that of the smallest-resistance leg of the circuit.

NOTE: Which resistor is R_1 and which is R_2 is not important. The position in the formula makes no difference in the multiplication and addition of the resistor values.

This formula can be used for more than two resistances in parallel, but only two resistances can be calculated at a time. After solving for R_T for two resistors, use the value of R_T as R_1 and the additional resistance in parallel as R_2. Then solve for another R_T. Continue the process for all resistance legs of the parallel circuit. However, note that it might be easier to solve for R_T when there are more than two resistances in parallel by using Method 3 or 4.

Method 3 A formula that can be used to find the total resistance for any number of resistances in parallel is $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \ldots$

To solve for R_T for the three resistance legs in Figure 33–15, substitute the values of the resistances for R_1, R_2, and

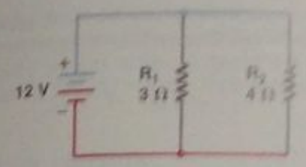


Figure 33–14 A schematic showing two resistors in parallel connected to a 12-volt battery.

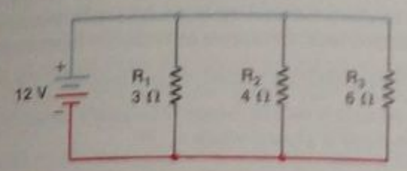
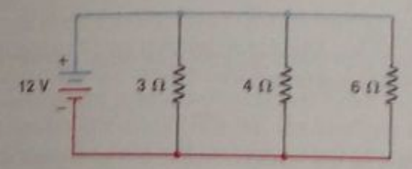


Figure 33–15 A parallel circuit with three resistors connected to a 12-volt battery.



1 ÷ 3 M+ TO SOLVE THIS PARALLEL CIRCUIT PROBLEM FOR R_T (TOTAL RESISTANCE), PUSH THE EXACT BUTTONS ON AN ELECTRONIC CALCULATOR

1 ÷ 4 M+

1 ÷ 6 M+

NOTE: BE CERTAIN TO PUSH THE = BUTTON. FAILURE TO DO SO WILL RESULT IN INCORRECT ANSWERS WHEN USING MOST CALCULATORS.

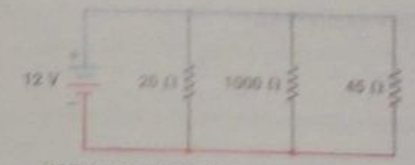
÷ M_{RC} =

(ANSWER = 1.3333)

Figure 33–16 Using an electronic calculator to determine the total resistance of a parallel circuit.

R_3: $1/R_T = 1/3 + 1/4 + 1/6$. The fractions cannot be added together unless they all have the same denominator. The lowest common denominator in this example is 12. Therefore, 1/3 becomes 4/12, 1/4 becomes 3/12, and 1/6 becomes 2/12. $1/R_T = 4/12 + 3/12 + 2/12$ or 9/12. Cross multiplying $R_T = 12/9 = 1.33\Omega$. Note that the result (1.33Ω) is the same regardless of the method used (see Method 1). The most difficult part of using this method (besides using fractions) is determining the lowest common denominator, especially for circuits containing a wide range of ohmic values for the various legs. For an easier method using a calculator, see Method 4.

Method 4 This method uses an electronic calculator, commonly available at very low cost. Instead of determining the lowest common denominator as in Method 3, one can use the electronic calculator to convert the fractions to decimal equivalents. The memory buttons on most calculators can be used to keep a running total of the fractional values. Use Figure 33–16 and calculate the total resistance (R_T) by pushing the indicated buttons on the calculator. Also see Figure 33–17.



USE AN ELECTRONIC CALCULATOR TO SOLVE:

R_T = 1 ÷ 20 M+

1 ÷ 1000 M+

1 ÷ 45 M+

1 ÷ M_{RC} =

NOTE:

THE TOTAL RESISTANCE (R_T) MUST BE LESS THAN THE SMALLEST RESISTANCE (LESS THAN 20 Ω IN THIS EXAMPLE).

Figure 33–17 Another example of how to use an electronic calculator to determine the total resistance of a parallel circuit. The answer is 13.45 ohms. Notice that the effective resistance of this circuit is less than the resistance of the lowest branch (20 ohms).

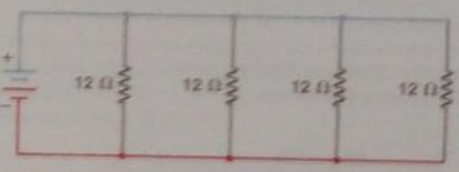


Figure 33–18 A parallel circuit containing four 12-ohm resistors. When a circuit has more than one resistor of equal value, the total resistance can be determined by simply dividing the value of the resistance (12 ohms in this example) by the number of equal-value resistors (4 in this example) to get 3 ohms.

NOTE: This method can be used to find the total resistance of *any number* of resistances in parallel.

The memory recall (MRC) and equals (=) buttons invert the answer to give the correct value for total resistance (1.33 Ω). The inverse (1/X or X^{-1}) button can be used with the sum (SUM) button on scientific calculators without using the memory button.

Method 5 This method can be easily used whenever two or more resistances connected in parallel are of the same value. See Figure 33–18. To calculate the total resistance (R_T) of equal-value resistors, divide the number of equal resistors into the value of the resistance. R_T = Value of equal resistance/Number of equal resistances = 12Ω/4 = 3Ω.

NOTE: Since most automotive and light-truck electrical circuits involve multiple use of the same resistance, this method is the most useful. For example, if six additional 12-ohm lights were added to a vehicle, the additional lights would represent just 2 ohms of resistance (12 Ω/6 lights = 2). Therefore, 6 amperes of additional current would be drawn by the additional lights ($I = E/R = 12V/2\Omega = 6$ A).

PARALLEL CIRCUIT EXAMPLES

Each of the four examples includes solving for the following:

- Total resistance
- Current flow (amperes) through each branch as well as total current flow
- Voltage drop across each resistance

Example 1:

(See Figure 33–19.)

In this example, the voltage of the battery is unknown and the equation to be used is $E = I \times R$ where R represents the total resistance of the circuit. Using the equation for two resistors in parallel, the total resistance is 6 ohms.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{12 \times 12}{12 + 12} = \frac{144}{24} = 6\Omega$$

Placing the value of the total resistors into the equation results in a value for the battery voltage of 12 volts.

$$E = I \times R$$
$$E = 2\text{A} \times 6\Omega$$
$$E = 12 \text{ volts}$$

Example 2:

(See Figure 33–20.)

In this example, the value of R_2 is unknown. Because the voltage (12 volts) and the current (12 A) are known, it is easier to solve for the unknown resistance by treating each branch or leg as a separate circuit. Using Kirchhoff's law, the total current equals the total current flow through each branch. The current flow through R_1 is 3 A ($I = E/R = 12\text{ V}/4\,\Omega = 3\text{ A}$) and the current flow through R_2 is 6A ($I = E/R = 12\text{V}/2\Omega = 6\text{A}$).

Therefore, the total current through the two known branches equals 9 A (3A + 6A = 9A). Because there are 12A leaving and returning to the battery, the current flow through R_3 must be 3A (12A − 9A = 3A). The resistance must therefore be 4Ω ($I = E/R = 12\text{V}/4\Omega = 3\text{A}$).

Example 3:

(See Figure 33–21.)

In this example, the voltage of the battery is unknown. The equation to solve for voltage according to Ohm's law is:

$$E = I \times R$$

The R in this equation refers to the total resistance. Because there are four resistors of equal value, the total can be determined by the equation:

R_{Total} = Value of Resistors/Number of Equal Resistors = 12Ω/4 = 3Ω

Inserting the value of the total resistors of the parallel circuit (3Ω) into Ohm's law results in a battery voltage of 12V.

$$E = 4\text{A} \times 3\Omega$$
$$E = 12\text{ V}$$

Example 4:

(See Figure 33–22.)

The unknown is the amount of current in the circuit. The Ohm's law equation for determining current is:

$$I = E/R$$

The R represents the total resistance. Because there are two equal resistances (8Ω), these two can be replaced by one resistance of 4Ω (R_{Total} = Value/Number = 8Ω/2 = 4Ω).

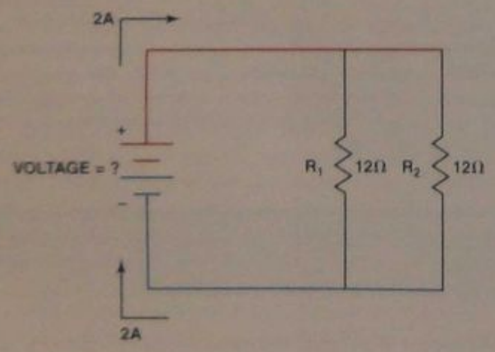


Figure 33–19 Example 1.

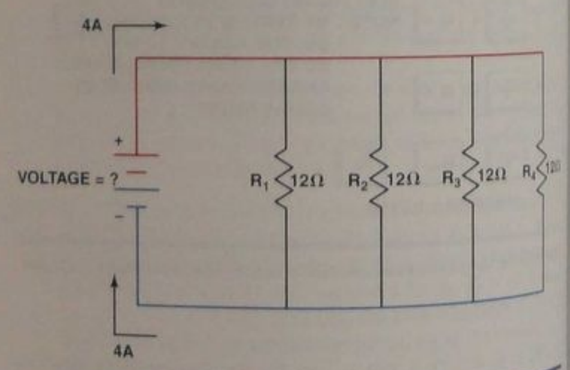


Figure 33–21 Example 3.

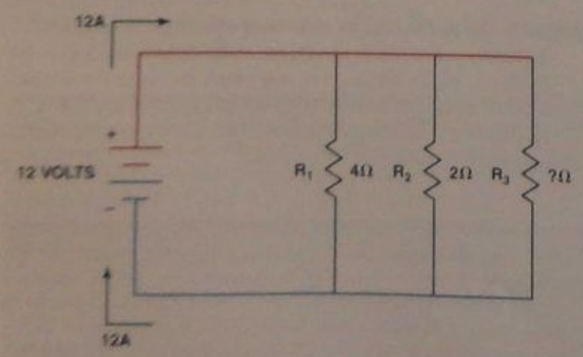


Figure 33–20 Example 2.

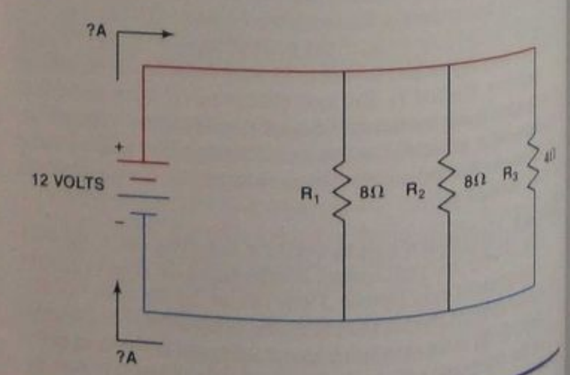


Figure 33–22 Example 4.

The total resistance of this parallel circuit containing two 8-ohm resistors and one 4-ohm resistor is 2 ohms. The current flow from the battery is then calculated to be 6A.

$$I = E/R = 12\text{V}/2\Omega = 6\text{A}$$

SERIES-PARALLEL CIRCUITS

Series-parallel circuits are a combination of series and parallel segments in one complex circuit. A series-parallel circuit is also called a **compound** or a **combination circuit.** Many automotive circuits include sections that are in parallel and in series.

A series-parallel circuit includes both parallel loads or resistances, plus additional loads or resistances that are electrically connected in series. There are two basic types of series-parallel circuits.

- A circuit where the load is in series with other loads is parallel. See Figure 33–23. An example of this type of series-parallel circuit is a dash light dimming circuit. The variable resistor is used to limit current flow to the dash light bulbs, which are wired in parallel.
- A circuit where a parallel circuit contains resistors or loads is in series in one or more branches. A headlight and starter circuit is an example of this type of series-parallel circuit. A headlight switch is usually connected in series with a dimmer switch and in parallel with the dash light dimmer resistors. The headlights are also connected in parallel along with the taillights and side marker lights. See Figure 33–24.

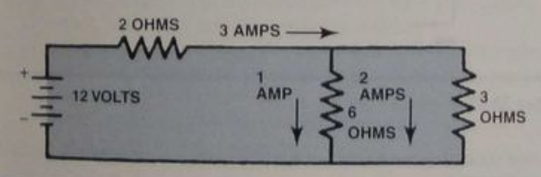


Figure 33–23 A series-parallel circuit.

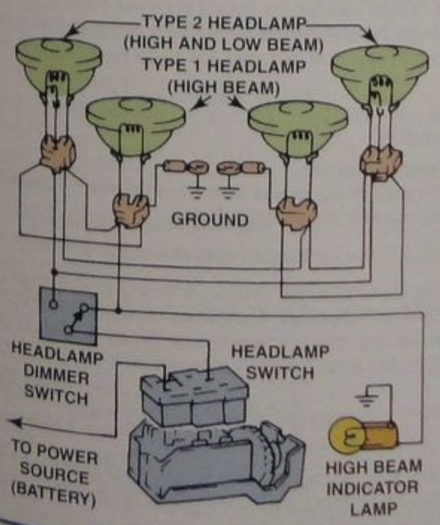


Figure 33–24 This complete headlight circuit with all bulbs and switches is a series-parallel circuit.

Series-Parallel Circuit Faults If a conventional parallel circuit, such as a taillight circuit, had an electrical fault that increased the resistance in one branch of the circuit, then the amount of current flow through that one branch will be reduced. The added resistance, due to corrosion or other similar cause, would create a voltage drop. As a result of this drop in voltage, a lower voltage would be applied and the bulb in the taillight would be dimmer than normal. Because the brightness of the bulb depends on the voltage and current applied, the lower voltage and current would cause the bulb to be dimmer than normal. If, however, the added resistance occurred in a part of the circuit that fed both taillights, then both taillights would be dimmer than normal. In this case, the added resistance created a series-parallel circuit that was originally just a simple parallel circuit.

SOLVING SERIES-PARALLEL CIRCUIT PROBLEMS

The key to solving series-parallel circuit problems is to combine or simplify as much as possible. For example, if there are two loads or resistances in series within a parallel branch or leg, then the circuit can be made simpler if the two are first added together before attempting to solve the parallel section. See Figure 33–25.

SERIES-PARALLEL CIRCUIT EXAMPLES

Each of the four examples includes solving for the following.

- Total resistance
- Current flow (amperes) through each branch, as well as total current flow
- Voltage drop across each resistance

Example 1:

(See Figure 33–26.)

The unknown resistor is in series with the other two resistances, which are connected in parallel. The Ohm's law equation to determine resistance is:

$$R = E/I = 12\text{V}/3\text{A} = 4\Omega$$

The total resistance of the circuit is therefore 4 ohms, and the value of the unknown can be determined by subtracting the value of the two resistors that are connected in parallel. The parallel branch resistance is 2 Ω.

$$R_T = \frac{4 \times 4}{4 + 4} = \frac{16}{8} = 2\Omega$$

The value of the unknown resistance is therefore 2 Ω.

$$\text{Total } R = 4\Omega - 2\Omega = 2\Omega$$

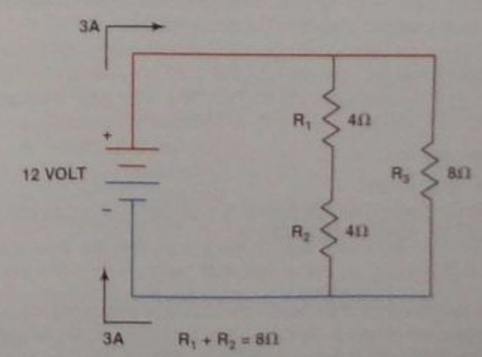


Figure 33–25 Solving a series-parallel circuit problem.

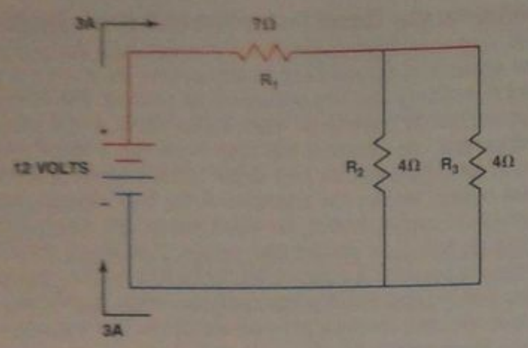


Figure 33–26 Example 1.

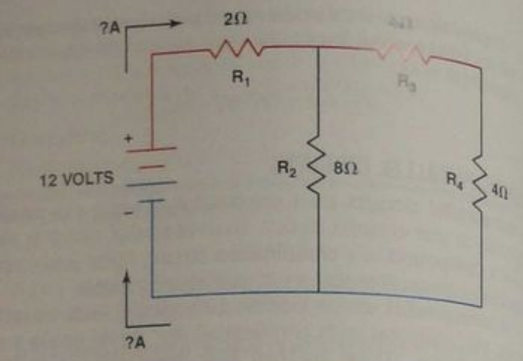


Figure 33–28 Example 3.

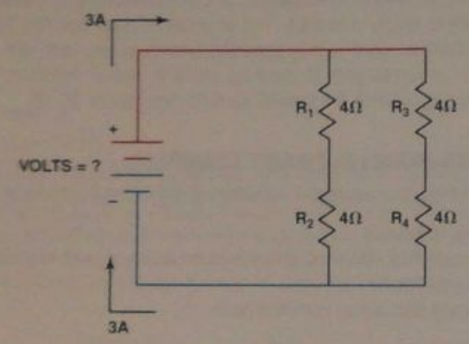


Figure 33–27 Example 2.

Example 2:

(See Figure 33–27.)

The unknown unit in this circuit is the voltage of the battery. The Ohm's law equation is:

$$E = I \times R$$

Before solving the problem, the total resistance must be determined. Because each branch contains two 4-ohm resistors in series, the value in each branch can be added to help simplify the circuit. By adding the resistors in each branch together, the parallel circuit now consists of two 8-ohm resistors.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{8 \times 8}{8 + 8} = \frac{64}{16} = 4\Omega$$

Inserting the value for the total resistance into the Ohm's law equation results in a value of 12 volts for the battery voltage.

$$E = I \times R$$
$$E = 3\text{A} \times 4\Omega$$
$$E = 12 \text{ volts}$$

Example 3:

(See Figure 33–28.)

In this example, the total current through the circuit is unknown. The Ohm's law equation to solve for it is:

$$I = E/R$$

The total resistance of the parallel circuit must be determined before the equation can be used to solve for current (amperes). To solve for total resistance, the circuit can first be simplified by adding R_3 and R_4 together because these two resistors are in series in the same branch of the parallel circuit. To simplify even more, the resulting parallel section of the circuit,

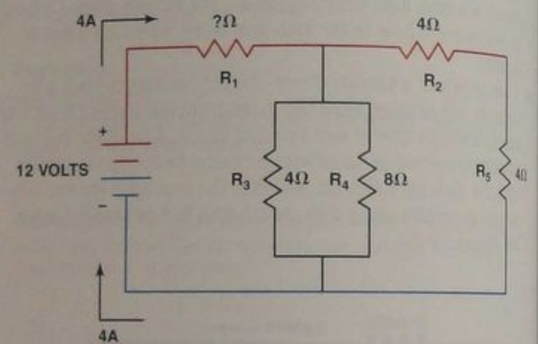


Figure 33–29 Example 4.

now containing two 8-ohm resistors in parallel, can be replaced with one 4-ohm resistor.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{8 \times 8}{8 + 8} = \frac{64}{16} = 4\Omega$$

With the parallel branches now reduced to just one 4-ohm resistor, this can be added to the 2-ohm (R_1) resistor because it is in series, creating a total circuit resistance of 6 ohms. Now the current flow can be determined from Ohm's law.

$$I = E/R = 12\text{V}/6\Omega = 2\text{A}$$

Example 4:

(See Figure 33–29.)

In this example, the value of resistor R_1 is unknown. Using Ohm's law, the total resistance of the circuit is 3 ohms.

$$R = E/I = 12\text{V}/4\text{A} = 3\Omega$$

However, knowing the total resistance is not enough to determine the value of R_1. To simplify the circuit, R_2 and R_5 can combine to create a parallel branch resistance value of 8 ohms because they are in series. To simplify even further, the two 8-ohm branches can be reduced to one branch of 4 ohms.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{8 \times 8}{8 + 8} = \frac{64}{16} = 4\Omega$$

Now the circuit has been simplified to one resistor in series (R_1) with two branches with 4 ohms in each branch. These two branches can be reduced to the equal of one 2-ohm resistor.

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{4 \times 4}{4 + 4} = \frac{16}{8} = 2\Omega$$

Now the circuit includes just one 2-ohm resistor plus the unknown R_1. Because the total resistance is 3 ohms, the value of R_1 must be 1 ohm.

$$3\Omega - 2\Omega = 1\Omega$$

SUMMARY

1. Series circuits:
   a. In a simple series circuit, the current remains constant throughout, but the voltage drops as current flows through the resistances of the circuit.
   b. The voltage drop across each resistance or load is directly proportional to the value of the resistance compared to the total resistance in the circuit.
   c. The sum (total) of the voltage drops equals the applied voltage (Kirchhoff's voltage law).
   d. An open or a break anywhere in a series circuit stops all current from flowing.
2. Parallel circuits:
   a. A parallel circuit, such as is used for all automotive lighting, has the same voltage available to each resistance (bulb).
   b. The total resistance of a parallel circuit is always lower than the smallest resistance.
   c. The separate paths that split and meet at junction points are called branches, legs, or shunts.
   d. Kirchhoff's current law states: "The current flowing into a junction of an electrical circuit is equal to current flowing out of that junction."
3. Series-parallel circuits:
   a. A series-parallel circuit is also called a compound circuit or a combination circuit.
   b. A series-parallel circuit is a combination of a series and a parallel circuit, which does not include fuses or switches.
   c. A fault in a series portion of the circuit would affect the operation if the series part was in the power or the ground side of the parallel portion of the circuit.
   d. A fault in one leg of a series-parallel circuit will affect just the component(s) in that one leg.

REVIEW QUESTIONS

1. What is Kirchhoff's voltage law?
2. What would current (amperes) do if the voltage were doubled in a circuit?
3. What would current (amperes) do if the resistance in the circuit were doubled?
4. What is the formula for voltage drop?
5. Why is the total resistance of a parallel circuit less than the smallest resistance?
6. Why are parallel circuits (instead of series circuits) used in most automotive applications?
7. What does Kirchhoff's current law state?
8. What would be the effect of an open circuit in one leg of a parallel portion of a series-parallel circuit?
9. What would be the effect of an open circuit in a series portion of a series-parallel circuit?

CHAPTER QUIZ

1. The amperage in a series circuit is _____.
   a. The same anywhere in the circuit
   b. Varies in the circuit due to the different resistances
   c. High at the beginning of the circuit and decreases as the current flows through the resistance
   d. Always less returning to the battery than leaving the battery
2. The sum of the voltage drops in a series circuit equals the _____.
   a. Amperage
   b. Resistance
   c. Source voltage
   d. Wattage
3. If the resistance and the voltage are known, what is the formula for finding the current (amperes)?
   a. $E = I \times R$
   b. $I = E \times R$
   c. $R = E \times I$
   d. $I = E/R$
4. A series circuit has three resistors of 6 ohms each. The voltage drop across each resistor is 4 volts. Technician A says that the source voltage is 12 volts. Technician B says that the total resistance is 18 ohms. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. If a 12-volt battery is connected to a series circuit with three resistors of 2 ohms, 4 ohms, and 6 ohms, how much current will flow through the circuit?
   a. 1 amp
   b. 2 amp
   c. 3 amp
   d. 4 amp
6. A series circuit has two 10-ohm bulbs. A third bulb is added in series. Technician A says that the three bulbs will be dimmer than when only two bulbs were in the circuit. Technician B says that the current in the circuit will increase. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Technician A says that the sum of the voltage drops in a series circuit should equal the source voltage. Technician B says that the current (amperes) varies depending on the value of the resistance in a series circuit. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Two bulbs are connected in parallel to a 12-volt battery. One bulb has a resistance of 6 ohms and the other bulb has a resistance of 2 ohms. Technician A says that only the 2-ohm bulb will light because all of the current will flow through the path with the least resistance and no current will flow through the 6-ohm bulb. Technician B says that the 6-ohm bulb will be dimmer than the 2-ohm bulb. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Calculate the total resistance and current in a parallel circuit with three resistors of 4 Ω, 8 Ω, and 16 Ω, using any one of the five methods (calculator suggested). What is the total resistance and current?
   a. 27 ohms (0.4 ampere)
   b. 14 ohms (0.8 ampere)
   c. 4 ohms (3.0 amperes)
   d. 2.3 ohms (5.3 amperes)
10. A vehicle has four parking lights all connected in parallel and one of the bulbs burns out. Technician A says that this could cause the parking light circuit fuse to blow (open). Technician B says that it would decrease the current in the circuit. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 34

Digital Meters and Scope Usage

OBJECTIVES: After studying Chapter 34, the reader will be able to: Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Explain how to set a digital meter to read volts, amperes, and ohms. • List the precautions necessary when working with test equipment. • Explain how a digital storage scope differs from an analog scope. • Describe how to safely connect test equipment or a meter to a circuit or component without doing any harm.

KEY TERMS: 8 × 10 display • AC coupling • AC/DC clamp-on DMM • alternating current (AC) • BNC connector • cathode ray tube (CRT) • CAT ratings • continuity light • counts • current analog • DC coupling • digits • digital meter • digital multimeter (DMM) • digital storage oscilloscope (DSO) • digital volt-ohm-milliammeter (DVOM) • direct current (DC) • duty cycle • external trigger • frequency • graphing multimeter (GMM) • graticule • high-impedance meter • inductive ammeter • International Electrotechnical Commission (IEC) • kilo • LED test light • logic probe • mega • micro • milli • oscilloscope • over limit (OL) • pulse trains • pulse width • pulse width modulation (PWM) • resolution • root-mean-square (RMS) • scope • self-powered test light • test light • time base • trigger level • trigger slope • volts per division

Test equipment must be used by the service technician because electrical signals cannot be seen or felt and therefore must be measured. This chapter reviews the basics of electrical measurement and provides the background for measuring the components and circuits in the remaining chapters.

TEST LIGHTS

A **test light** is simply a light bulb with two wires attached. See Figure 34–1. It is used to test for low-voltage level (6 to 12 volts). Battery voltage cannot be seen or felt and can be detected only with test equipment. See Figure 34–2.

A test light can be purchased or homemade. A purchased test light could be labeled as a 6- to 12-volt test light. Do not purchase a test light designed for household current (110 or 220 volts). It will not light with 12 volts.

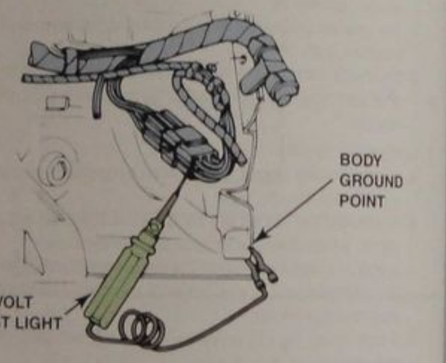


Figure 34–1 A 12-volt test light is attached to a good ground while probing for power.

TECH TIP ✔ **Always Test Your Test Equipment**

More than one technician has misdiagnosed a problem because the test equipment did not work correctly. Examples include the following:

- *Test light bulb burned out.* A test light bulb can be easily checked by regularly testing the test light bulb across a battery. A burned out test light bulb will not be able to detect voltage.
- *Meter fuse blown.* If an ammeter fuse is blown (open), the meter will simply read 0.0 amperes (A) and not conduct current in the circuit. If an inline fuse is used in the meter leads, all functions of the meter will not work. Volts will read 0.0 all the time and often will read **OL (over limit)** on all ohmmeter scales.

Self-Powered Test Lights A **self-powered test light,** also called a **continuity light,** is similar to a test light but includes a battery. A self-powered light will light when connected to both ends of a wire that has continuity or that is not broken. See Figure 34–3.

CAUTION: The use of a continuity test light is not recommended on any electronic circuit. Because a continuity light contains a battery and applies voltage, it may harm delicate electronic components.

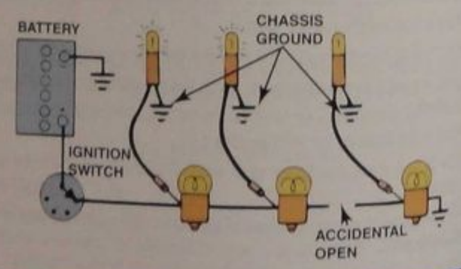


Figure 34–2 A test light can be used to locate an open in a circuit. Note that the test light is grounded at a different location than the circuit itself.

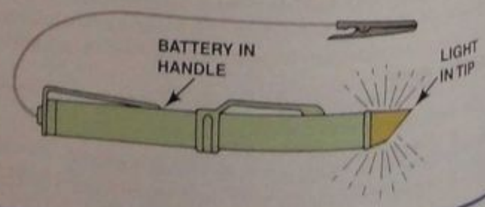


Figure 34–3 A continuity light should not be used on computer circuits because the applied voltage can damage delicate electronic components or circuits.

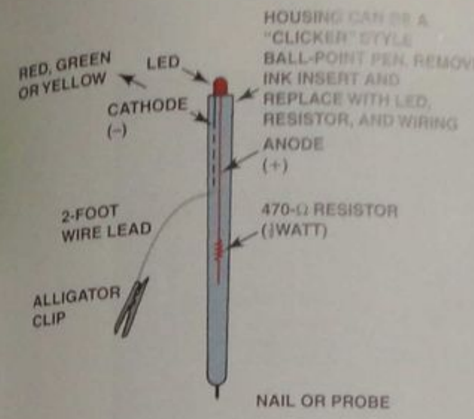


Figure 34–4 High-impedance test light. An LED test light can be easily made using low-cost components and an old ink pen. With the 470-ohm resistor in series with the LED, this tester only draws 0.025 amperes (25 milliamperes) from the circuit being tested. This low current draw helps assure the technician that the circuit or component being tested will not be damaged by excessive current flow.

LED Test Light Another type of test light uses an LED instead of a standard automotive bulb for a visual indication of voltage. An **LED test light** requires only about 25 mA (0.025 A) to light, so it can be used on electronic circuits and on standard circuits. See Figure 34–4 for construction details.

LOGIC PROBE

A **logic probe** is an electronic device that lights up a red (usually) LED if the probe is touched to battery voltage. If the probe is touched to ground, a green (usually) LED lights. See Figure 34–5. A logic probe can "sense" the difference between high- and low-voltage levels, thus the term *logic*. A typical logic probe can also light another light (a "pulse" light) when a change in voltage levels occurs. This feature is helpful when checking for a variable voltage output from a computer or ignition sensor.

A logic probe must be first connected to a power source (vehicle battery). This connection powers the probe and gives it a reference low (ground).

Most logic probes also make a distinctive sound for each high- and low-voltage level, which makes troubleshooting easier when probing connectors or component terminals. A sound (usually a beep) is heard when the probe tip is touched to a voltage source that is changing. The changing voltage also usually lights the pulse light on the logic probe. Therefore, the probe can be used to check components such as pickup coils, Hall-effect sensors, magnetic sensors, and many other circuits.

DIGITAL MULTIMETERS

Digital multimeter (DMM) and **digital volt-ohm-milliammeter (DVOM)** are terms commonly used for electronic **high-impedance test meters,** which have a high internal resistance. Most digital meters have 10 megohms (MΩ) (10 million ohms) or more of internal resistance. *Analog (needle type) meters are almost always lower than 10 megohms and should not be used to measure any computer circuit.* A high-impedance meter can be used to measure any automotive circuit within the ranges of the meter. See Figures 34–6 through 34–8 on page 343.

MEASURING AMPERES

An ammeter measures the flow of current through a complete circuit in units of amperes. The ammeter has to be installed in the circuit (in series) so that it can measure all the current flow in that circuit, just as a water flow meter would measure the amount of water flow (cubic feet per minute, for example).

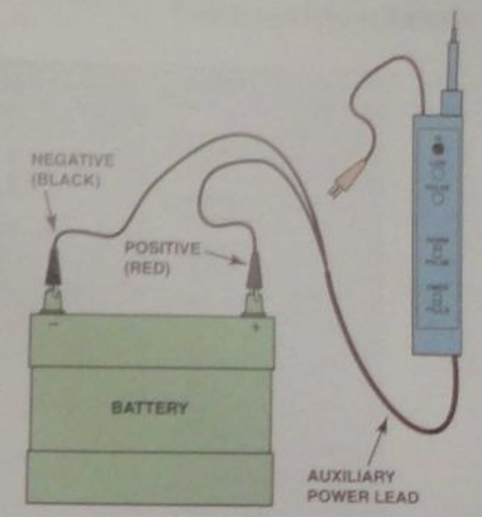


Figure 34–5 A logic probe connected to the vehicle battery and relay used to check for power, ground, or a pulse.

CAUTION: An ammeter must be installed in the circuit to measure the current flow in the circuit. If a meter set to read amperes is connected in parallel, such as across a battery, the meter fuse will blow or the meter itself may be destroyed by the current available across the battery.

Digital meters require that the meter leads be moved to the ammeter terminals. Most digital meters have an ampere scale that can accommodate a maximum of 10 A. See the Tech Tip, "Fuse Your Meter Leads."

Many ammeters are the **inductive** type. See Figure 34–9. Inductive means that the meter probe surrounds the wire(s) carrying the current and measures the strength of the magnetic field that surrounds any conductor carrying a current.

TECH TIP ✔ **Fuse Your Meter Leads**

Most digital meters include an ammeter capability. When reading amperes, the leads of the meter must be moved from volts or ohms (V or Ω) to amperes (A) or milliamperes (mA) or microamperes (μA).

A common problem may then occur the next time voltage is measured. Although the technician may switch the selector to read volts, often the leads are not switched back to the volt or ohm position. Because the ammeter lead position results in 0 ohms of resistance to current flow through the meter, the meter or the fuse inside the meter will be destroyed if the meter is connected to a battery. Many meter fuses are expensive and difficult to find.

To solve this problem, simply solder an inline blade fuse holder into one meter lead. See Figure 34–10 on page 343. Do not think that this fuse is necessary only for beginners. Experienced technicians often get in a hurry and forget to switch the lead. A blade fuse is faster, easier, and less expensive to replace than a meter fuse or the meter itself. Also, if the soldering is done properly, the addition of an inline fuse holder and fuse does not increase the resistance of the meter leads. All meter leads have some resistance. If the meter is measuring very low resistance, simply touch the two leads together and read the resistance (usually only a couple of tenths of an ohm). Simply subtract the resistance of the leads from the resistance of the component being measured.



Figure 34–6 Typical digital multimeter. The black meter lead always is placed in the COM terminal. Except when measuring the current in amperes, the red meter test lead remains in the VΩ terminal.

SYMBOL	MEANING
AC	Alternating current or voltage
DC	Direct current or voltage
V	Volts
mV	Millivolts (1/1000 volts)
A	Ampere (amps). Current
mA	Milliampere (1/1000 amps)
%	Percent (for duty cycle readings only)
Ω	Ohms. Resistance
kΩ	Kilohm (1000 ohms). Resistance
MΩ	Megaohm (1,000,000 ohms). Resistance
Hz	Hertz (1 cycle/sec). Frequency
kHz	Kilohertz (1000 cycles/sec). Frequency
RPM 1	Revolutions/minute. Counting one cycle per spark.
RPM 2	Revolutions/minute. Counting 2 cycle per spark
ms	Milliseconds (1/1000 sec) for Pulse Width measurements

Figure 34–7 Common abbreviations used on the display face of many digital multimeters.

AC/DC CLAMP-ON DIGITAL MULTIMETER

An **AC/DC clamp-on DMM** is a useful meter for automotive diagnostic work. See Figure 34–11.

The major advantage of the clamp-on-type meter is that there is no need to break the circuit to measure current (amperes). Simply clamp the jaws of the meter around the power lead(s) or ground lead(s) of the component being measured and read the display. Most clamp-on meters can also measure AC, which is helpful in the diagnosis of a generator (alternator) problem. Volts, ohms, frequency, and temperature can also be measured with the typical clamp-on DMM.

MEASURING VOLTAGE

A voltmeter measures the *pressure* or potential of electricity in units of volts. A voltmeter is connected to a circuit in parallel. All voltmeters have a large, built-in resistance so that the current flow through the meter will not affect either the circuit being tested or the meter. Most digital meters have an internal resistance of 10 MΩ (10,000,000 ohms) or more on the voltmeter scale only. This is called the *impedance* of the meter and represents the total internal resistance of the meter circuit due to internal coils, capacitors, and resistors. A typical analog voltmeter has only about 12,000 ohms of internal resistance. Although this may sound like a lot of resistance, it is too low for electronic and computer circuit measurement. When a voltmeter is connected to measure voltage, the meter itself becomes a part of the circuit. This is the reason why vehicle manufacturers specify that a high-impedance digital meter be used. The high internal resistance has little effect on the circuit or component being measured. See Figures 34–12 and 34–13.

SYSTEM COMPONENTS	VOLTAGE PRESENCE AND LEVEL	VOLTAGE DROP	CURRENT (AMPS)	RESISTANCE (OHMS)	FREQUENCY (HZ)
CHARGING SYSTEM					
GENERATOR (ALTERNATOR)	●		●		●
CONNECTORS	●	●		●	
DIODES		●			
REGULATORS	●				●
COOLING SYSTEM					
CONNECTORS	●	●		●	
FAN MOTORS	●		●	●	
RELAYS	●	●		●	
TEMP. SWITCHES	●	●		●	
IGNITION SYSTEM					
COILS	●			●	
CONNECTORS	●	●		●	
CONTACT SET	●			●	
MAF SENSOR	●			●	
MAGNETIC PICK-UP	●		●	●	
MAP/BP SENSOR	●			●	●
O_2 SENSOR	●			●	
STARTING SYSTEM					
BATTERIES	●	●	●		
CONNECTORS		●	●		
INTERLOCKS			●		
SOLENOIDS	●	●		●	
STARTERS	●	●	●		

Figure 34–8 A summary chart indicating what measurement type may be used to test which vehicle system.



Figure 34–9 An inductive ammeter uses a clamp that measures the current through the wire by using the strength of the magnetic field surrounding the wire.

NOTE: The input impedance of any meter can be measured by using another meter set to read ohms and measuring the resistance of the test meter set to the voltmeter scale.

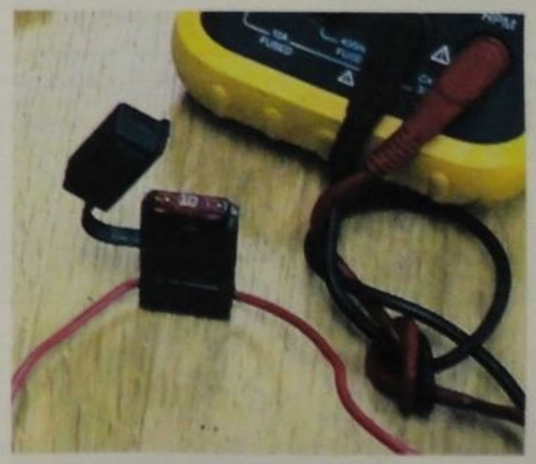


Figure 34–10 Note the blade-type fuse holder soldered in series with one of the meter leads. A 10-amp fuse helps protect the internal meter fuse (if equipped) and the meter itself from damage that might result from excessive current flow if accidentally used incorrectly.

Remember, the resistance of any meter is only effective when the meter is set on the voltmeter scales. This is the major reason why most automobile manufacturers recommend testing voltage at selected points instead of resistance or current.

TECH TIP ✓ **The T-Pin Advantage**

T-pins are commonly found in discount stores and craft shops. See Figure 34–14.

These low-cost pins are extremely helpful in gaining access to signals without doing any harm. These T-pins are commonly found in 1.5-in. and 1.75-in. lengths.

To use a T-pin, carefully push the sharp end alongside the wire and push toward the connector. The sharp end of the T-pin will slide alongside the insulation and contact the metal terminal inside the plastic connector. The T shape of the pin makes it easy to attach scope probes or meter alligator clips to it. After scope or voltage measurements have been completed, the T-pin can be easily pulled out without damaging the environmental seal of the connector.

CAUTION: Do not use T-pins on high-voltage secondary ignition cables or components. These ignition systems represent a serious shock hazard. Only use T-pins on voltages less than 30 volts AC or 60 volts DC.



Figure 34–11 A typical mini clamp-on-type digital multimeter. This meter is capable of measuring alternating current (AC) and direct current (DC) without requiring that the circuit be disconnected to install the meter in series. The jaws are simply placed over the wire and current flow through the circuit is displayed.

MEASURING RESISTANCE

An ohmmeter measures the resistance in ohms of a component or circuit section when no current is flowing through the circuit. An ohmmeter contains a battery (or other power source). When the leads are connected to a component, current flows through the test



Figure 34–13 Typical digital multimeter (DMM) set to read DC volts.



Figure 34–14 A typical T-pin.



BECAUSE THE SIGNAL READING IS BELOW 4 VOLTS, THE METER AUTORANGES TO THE 4-VOLT SCALE. IN THE 4-VOLT SCALE, THIS METER PROVIDES THREE DECIMAL PLACES.



WHEN THE VOLTAGE EXCEEDED 4 VOLTS, THE METER AUTORANGES INTO THE 40-VOLT SCALE. THE DECIMAL POINT MOVES ONE PLACE TO THE RIGHT LEAVING ONLY TWO DECIMAL PLACES.

Figure 34–12 A typical autoranging digital multimeter automatically selects the proper scale to read the voltage being tested. The scale selected is usually displayed on the meter face. (a) Note that the display indicates "4," meaning that this range can read up to 4 volts. (b) The range is now set to the 40-volt scale, meaning that the meter can read up to 40 volts on the scale. Any reading above this level will cause the meter to reset to a higher scale. If not set on autoranging, the meter display would indicate OL if a reading exceeds the limit of the scale selected.

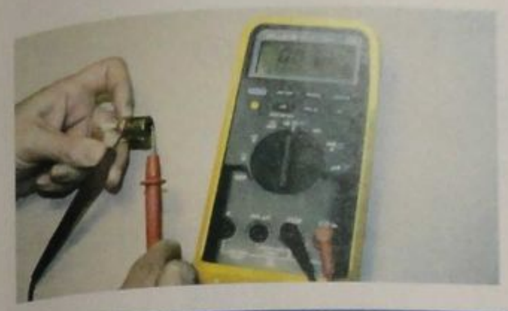


Figure 34–15 Using a digital multimeter set to read ohms (Ω) to test this light bulb. The meter reads the resistance of the filament.

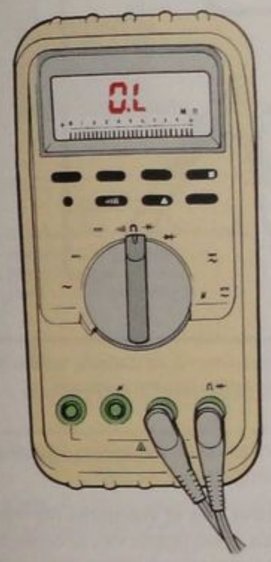


Figure 34–16 Typical digital multimeter showing OL (over limit) on the readout with the ohms (Ω) unit selected. This usually means that the unit being measured is open (infinity resistance) and has no continuity.

leads and actually measures the difference in voltage (voltage drop) between the leads, which the meter registers as resistance on its scale. See Figure 34–15. Zero ohms mean no resistance between the test leads, indicating that there is continuity or a continuous path for the current to flow in a closed circuit. Infinity means no connection, as in an open circuit.

With a closed circuit (low ohms), maximum current from the built-in battery causes a low reading, whereas an open circuit prevents any current from flowing. Different meters have different ways of indicating infinite resistance, or a reading higher than the scale allows. For example, most meters read OL, meaning "over limit," whereas others may show a number 1 or 3 on the left side of the display. See Figure 34–16. To summarize open and zero readings, remember:

0.00 Ω = zero resistance
OL = an open circuit (no current flows)

TECH TIP **"OL" Does Not Mean the Meter Is Reading "Nothing"**

Beginner technicians often confuse the meaning of the display on a digital meter. When asked what the meter is reading when OL is displayed on the meter face, the response often heard is "nothing." Many meters indicate OL on the display to indicate over limit or overload. Over limit means that the reading is over the maximum that can be displayed for the selected range. For example, OL is displayed if 12 volts is being read, but the meter has been set to read a maximum of 4 volts.

Autoranging meters adjust the range to match what is being measured. Here OL means a value higher than the meter can read (unlikely on the voltage scale for automobile usage) or infinity while measuring resistance (ohms). Therefore, OL means infinity while measuring resistance or an open circuit is being indicated. The meter will read 00.0 if the resistance is zero. See Figure 34–17. "Nothing" in this case indicates continuity (zero resistance), whereas OL indicates infinite resistance. Therefore, when talking with another technician about a meter reading, make sure you know exactly what the reading on the face of the meter means. See Figure 34–18 for examples of how the meter should be attached to read voltage, current (amperes), and resistance (ohms).

ELECTRICAL UNIT PREFIXES

Electrical units are measured in numbers such as 12 volts, 150 amperes, and 470 ohms. Large units over a 1,000 may be expressed in kilo units. The prefix **kilo** means "thousand."

1,100 volts = 1.1 kilovolts (kV)
4,700 ohms = 4.7 kilohms (kΩ)

FREQUENTLY ASKED QUESTION ???

How Much Voltage Does an Ohmmeter Apply?

Most digital meters that are set to measure ohms (resistance) apply a voltage of from 0.3 to 1.0 volt to the component being measured. The voltage comes from the meter itself to measure the resistance. Two things are important to remember about an ohmmeter.

1. The component or circuit must be disconnected from any electrical circuit while the resistance is being measured.
2. Because the meter itself applies a voltage (even though it is relatively low), a meter set to measure ohms can damage electronic circuits. Computer or electronic chips can be easily damaged if subjected to only a few milliamperes of current similar to the amount an ohmmeter applies when a resistance measurement is being performed.

If the value is over 1 million (1,000,000), then the prefix **mega** (M) is often used.

1,100,000 volts = 1.1 megavolts (MV)
4,700,000 ohms = 4.7 megohms (MΩ)

See Figure 34–19 on page 348.

Sometimes a circuit conducts so little current that a smaller unit of measure is required. Small units of measure of 1/1,000 are called **milli** (m).

The **micro** is represented by the Greek letter *mu* (μ). One microampere is one-millionth (1/1,000,000) of an ampere. To summarize:

mega (M) = 1,000,000 (decimal point six places to the right = 1000000.)

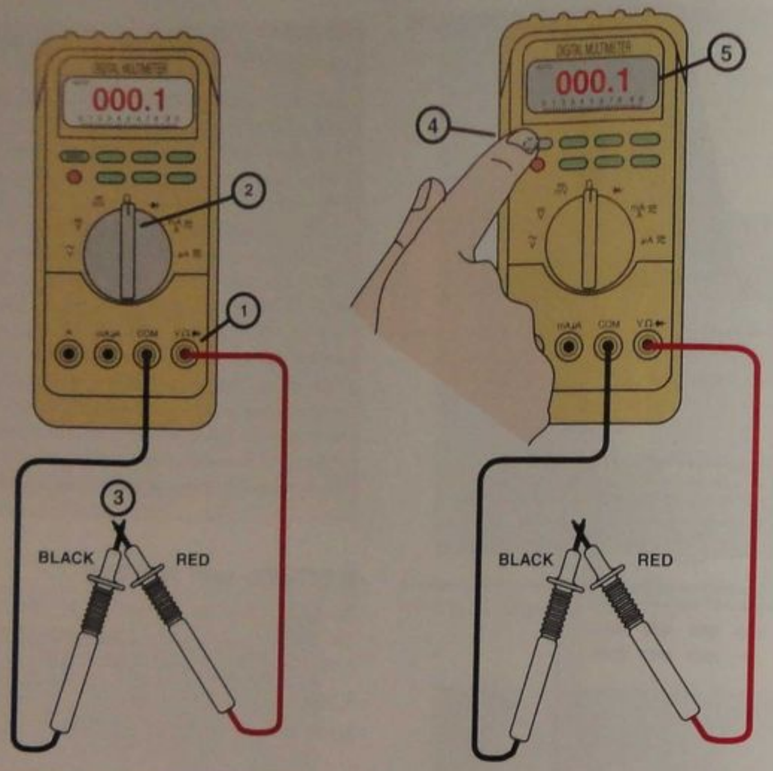


Figure 34–17 Many digital multimeters can have the display indicate zero to compensate for test lead resistance. (1) Connect leads in the V Ω and COM meter terminals. (2) Select the Ω scale. (3) Touch the two meter leads together. (4) Push the "zero" or "relative" button on the meter. (5) The meter display will now indicate zero ohms of resistance.

kilo (k) = 1,000 (decimal point three places to the right = 1000.)
milli (m) = 1/1,000 (decimal point three places to the left = 0.001)
micro (μ) = 1/1,000,000 (decimal point six places to the left = 0.000001)

HINT: Lowercase *m* equals a small unit (milli), whereas a capital *M* represents a large unit (mega).

These prefixes can be confusing because most digital meters can express values in more than one prefix, especially if the meter is autoranging. For example, an ammeter reading may show 36.7 mA on autoranging. When the scale is changed to amperes ("A" in the window of the display), the number displayed will be 0.037 A. Note that the resolution of the value is reduced.

HINT: Always check the face of the meter display for the unit being measured. To best understand what is being displayed on the face of a digital meter, select a manual scale and move the selector until *base units* appear, such as A for amperes instead of mA for milliamperes.

HOW TO READ DIGITAL METERS

Getting to know and use a digital meter takes time and practice. The first step is to read, understand, and follow all safety and operational instructions that come with the meter. Use of the meter usually involves the following steps.

1. **Select the proper unit of electricity for what is being measured:** volts, ohms (resistance), or amperes (amount of current flow). If the meter is not autoranging, select the proper scale for the anticipated reading. For example, if a 12-volt battery is being measured, select a meter reading range that is higher than the voltage but not too high. A 20- or 30-volt range will accurately show the voltage of a 12-volt battery. If a 1,000-volt scale is selected, a 12-volt reading may not be accurate.
2. **Place the meter leads into the proper input terminals.**
   - The black lead usually is inserted into the common (COM) terminal, and stays in this location for all meter functions.
   - The red lead is inserted into the volt, ohm, or diode check terminal usually labeled "V Ω," when voltage, resistance, or diodes are being measured.
   - When current flow in amperes is being measured, most digital meters require that the red test lead be inserted in the ammeter terminal, usually labeled "A" or "mA."

CAUTION: If the meter leads are inserted into ammeter terminals, even though the selector is set to volts, the meter may be damaged or an internal fuse may blow if the test leads touch both terminals of a battery.

3. **Measure the component being tested.** Carefully note the decimal point and the unit on the meter face.
   - **Correct scale.** A 12-volt battery is measured with a low-voltage scale selected. The proper reading of 12.0 is given.
   - **Incorrect scale.** A 12-volt battery is measured with a high-voltage scale selected. Use of the incorrect scale results in a reading of 0.012.

If a 12-volt battery is measured with an autoranging meter, the correct reading of 12.0 is given. "AUTO" and "V" should show on the face of the meter.

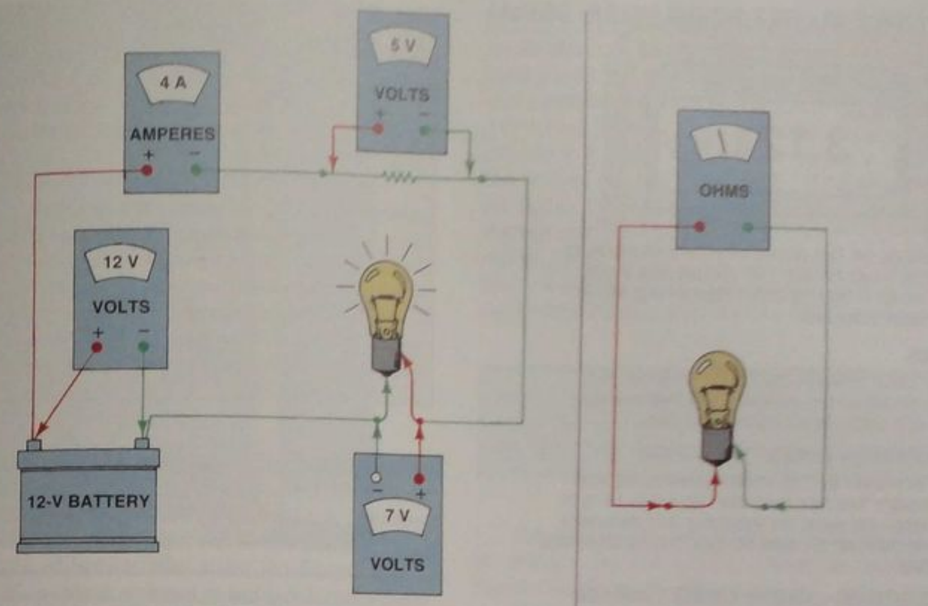
4. **Interpret the reading.** This is especially difficult on autoranging meters, where the meter itself selects the proper scale. The following are two examples of different readings.
   - A voltage drop is being measured. The specifications indicate a maximum voltage drop of 0.2 volt. The meter reads "AUTO" and "43.6 mV." This reading means that the voltage drop is 0.0436 volt, or 43.6 mV, which is far lower than the 0.2 volt (200 mV). Because the number showing on the meter face is much larger than the specifications, many beginner technicians are led to believe that the voltage drop is excessive.

HINT: Pay attention to the units displayed on the meter face and convert to base units.

   - A spark plug wire is being measured. The reading should be less than 10,000 ohms for each foot in length if the wire is usable. The wire being tested is 3 ft long (maximum allowable resistance is 30,000 ohms). The meter reads "AUTO" and "14.85 KΩ." This reading is equivalent to 14,850 ohms.

HINT: When converting from kilohms to ohms, make the decimal point a comma.

Because this reading is well below the specified maximum allowable, the spark plug wire is usable.



AMMETER	VOLTMETER	OHMMETER
1. Connected in series IN a circuit according to polarity. 2. Measures current flow. 3. Used in a closed circuit.	1. Connected in parallel to a circuit or part of a circuit according to polarity. 2. Measures voltage drop: This is the difference between voltage at its two leads. 3. Used in a closed circuit.	1. Has its own supply of power. 2. USED ONLY WHEN UNIT IS DISCONNECTED from its original circuit. 3. Measures resistance directly on meter. 4. Low ohms means continuity. 5. Infinity ready means open circuit.

ALWAYS USE A LARGE ENOUGH AMMETER AND VOLTMETER

Figure 34–18 Summary of test meter hookup.

TECH TIP ✓ **Purchase a Digital Meter That Will Work for Automotive Use**

Purchase a digital meter that is capable of reading the following:

- DC volts
- AC volts
- DC amperes (up to 10 A or more is helpful)
- Ohms up to 40 MΩ (40 million ohms)
- Diode check

Additional features for advanced automotive diagnosis include:

- Frequency (hertz (Hz))
- Temperature probe (°F and/or °C)
- Pulse width (millisecond (ms))
- Duty cycle (%)

If working on older-model vehicles, select a meter that includes:

- RPM (engine speed)
- Dwell (degrees)



THE SYMBOL ON THE RIGHT SIDE OF THE DISPLAY INDICATES WHAT RANGE THE METER HAS BEEN SET TO READ. Ω MEANS OHMS TIMES 1000, MΩ IS OHMS TIMES 1,000,000.

Ω = OHMS

IF THE ONLY SYMBOL ON THE DISPLAY IS THE OHMS SYMBOL, THE READING ON THE DISPLAY IS EXACTLY THE RESISTANCE IN OHMS.

KΩ = KILOHMS = OHMS TIMES 1000

A "K" IN FRONT OF THE OHMS SYMBOL MEANS "KILOHMS"; THE READING ON THE DISPLAY IS IN KILOHMS. YOU HAVE TO MULTIPLY THE READING ON THE DISPLAY BY 1000 TO GET THE RESISTANCE IN OHMS.

MΩ = MEGOHMS = OHMS TIMES 1,000,000

A "M" IN FRONT OF THE OHMS SYMBOL MEANS "MEGOHMS"; THE READING ON THE DISPLAY IS IN MEGOHMS. YOU HAVE TO MULTIPLY THE READING ON THE DISPLAY BY 1,000,000 TO GET THE RESISTANCE IN OHMS.

Figure 34–19 Always look at the meter display when a measurement is being made, especially if using an autoranging meter.

RMS versus Average Alternating current voltage waveforms can be true sinusoidal or nonsinusoidal. A true sine wave pattern measurement will be the same for both **root-mean-square (RMS)** and average reading meters. RMS and averaging are two methods used to measure the true effective rating of a signal that is constantly changing. See Figure 34–20.

TECH TIP ✓ **Think of Money**

Digital meter displays can often be confusing. A battery being measured as 12.5 volts would be displayed as 12.50 V, just as $12.50 is 12 dollars and 50 cents. A 0.5-volt reading on a digital meter will be displayed as 0.50 V, just as $0.50 is half of a dollar.

Low-value displays can be even more confusing. For example, if a voltage reading is 0.063 volt, an autoranging meter will display 63 mV or 63/1,000 of a volt or $63 of $1,000. (It takes 1,000 mV to equal 1 volt.) Millivolts are like one-tenth of a cent with 1 volt being $1.00. Therefore, 630 mV is equal to $0.63 of $1.00 (630 one-tenths of a cent or 63 cents).

To avoid confusion, manually range the meter to read base units (whole volts). If the meter is ranged to base unit volts, 63 mV would be displayed as 0.063 or maybe just 0.06 depending on the display capabilities of the meter.

Resolution, Digits, and Counts Resolution refers to how small or fine a measurement the meter can make. By knowing the resolution of a DMM, you can determine if the meter could measure down to 1 volt or to 1 millivolt (1/1,000 of a volt).

You would not buy a ruler marked in 1-in. segments (or in centimeters) if you had to measure down to .25 in. (or to 1 mm). A thermometer that measures only in whole degrees is of little use when your normal temperature is 98.6°F. You need a thermometer with 0.1° *resolution.*

The terms **digits** and **counts** are used to describe a meter's resolution. DMMs are grouped by the number of counts or digits they display. A 3.5-digit meter can display three full digits ranging from 0 to 9, and one "half" digit which displays only a 1 or is left blank. A 3.5-digit meter will display up to 1,999 counts of resolution. A 4.5-digit meter can display up to 19,000 counts of resolution.

It is more precise to describe a meter by counts of resolution rather than by 3.5 or 4.5 digits. Some 3.5-digit meters have enhanced resolution of up to 3,200 or 4,000 counts.

Meters with more counts offer better resolution for certain measurements. For example, a 1,999-count meter cannot measure down to a tenth of 0.10 volt when measuring 200 volts or more. See Figure 34–21. However, a 3,200-count meter will display 0.10 volt up to 320 volts. Digits displayed to the far right of the display may at times flicker or constantly change. This is called *digit rattle* and represents a changing voltage being measured on the ground (COM terminal of the meter lead). High-quality meters are designed to reject this unwanted voltage.



Figure 34–20 When reading AC voltage signals, a true RMS meter (such as a Fluke 87) provides a different reading than an average responding meter (such as a Fluke 88). The only place the difference is important is when a reading is to be compared with a specification.



Figure 34–21 This meter display shows 052.2 AC volts. Notice that the zero beside the 5 indicates that the meter can read over 100 volts AC with a resolution of 0.1 volt.

Accuracy Accuracy is the largest allowable error that will occur under specific operating conditions. In other words, it is an indication of how close the DMM's displayed measurement is to the actual value of the signal being measured.

Accuracy for a DMM is usually expressed as a percent of reading. An accuracy of ±1% of reading means that for a displayed reading of 100.0 V, the actual value of the voltage could be anywhere between 99.0 to 101.0 volts. Thus, a lower accuracy percentage is better.

- Unacceptable = 1.00%
- Okay = 0.50% (1/2%)
- Good = 0.25% (1/4%)
- Excellent = 0.10% (1/10%)

For example, if a battery had 12.6 volts, a meter could read between the following, based on its accuracy.

± 0.1%	high	12.61
	low	12.59
± 0.25%	high	12.63
	low	12.57
± 0.50%	high	12.66
	low	12.54
± 1.00%	high	12.73
	low	12.47

Before you purchase a meter, check the accuracy. Accuracy is usually indicated on the meter specification sheet.

ANALOG VERSUS DIGITAL STORAGE OSCILLOSCOPE

An **oscilloscope** (usually called a **scope**) is a visual voltmeter with a timer (clock) that shows when a voltage changes. An *analog scope* uses a **cathode ray tube (CRT)** similar to a television screen to display voltage patterns. The scope screen displays the electrical signal constantly. A *digital scope* commonly uses a LCD, but a CRT may also be used on some digital scopes. A digital scope takes samples of the signals that can be stopped or stored; hence the term **digital storage oscilloscope (DSO).** Because an analog scope displays all voltage signals and does not take samples, it cannot miss an occurrence. A digital storage scope can miss glitches that may occur between samples; thus, a DSO with a high "sampling rate" is preferred.

NOTE: Some digital storage scopes, such as the Fluke 190 series, increase the capture rate of 25 million samples per second, which means that the scope can capture a glitch (fault) that lasts just 40 nano seconds (0.00000040 sec).

For example, if a throttle position sensor was to be tested on an analog scope and a DSO, the results would be as shown in Figures 34–22 and 34–23.

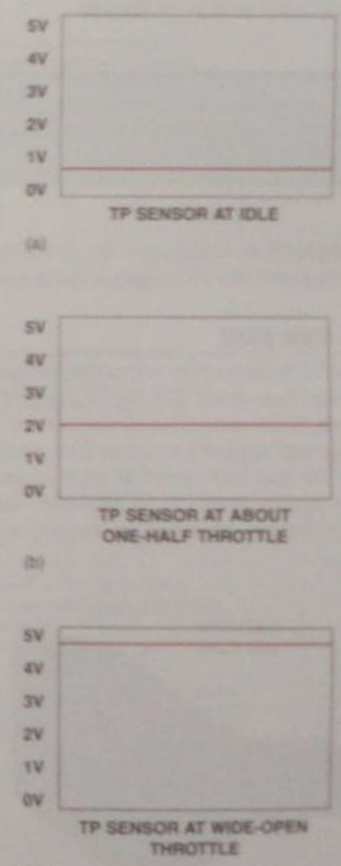


Figure 34–22 (a) On an analog scope, the voltage measured at the throttle position signal wire is displayed on a horizontal line at about 0.5 volts. (b) As the throttle is opened, the horizontal line representing the voltage increases. (c) At wide-open throttle (WOT), the horizontal line indicates about 4.5 volts.

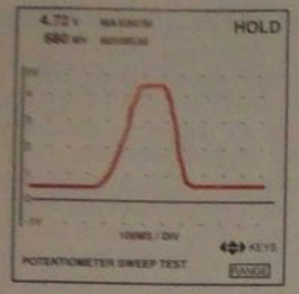


Figure 34–23 The display on a digital storage oscilloscope (DSO) displays the entire waveform from idle to wide-open throttle and then returns to idle. The display also indicates the maximum reading (4.72 V) and the minimum (680 mV or 0.68 V). The display does not show anything until the throttle is opened, because the scope has been set up to only start displaying a waveform after a certain voltage level has been reached. This voltage is called the trigger.

OSCILLOSCOPE DISPLAY GRID

A typical scope face has 8 divisions vertically (up and down) and 10 divisions horizontally. The grid lines on the scope screen are used as a reference scale, which is called a **graticule.** This arrangement is commonly called an **8 × 10 display**.

NOTE: These numbers represent the metric dimensions of the graticule in centimeters. Therefore, the display would be 8 cm (80 mm or 3.14 in.) high and 10 cm (100 mm or 3.90 in.) wide.

Voltage is displayed on a scope as a line vertically fromthe bottom. The scope illustrates time left to right as shown in Figure 34–24.

SETTING THE TIME BASE

Most scopes use 10 divisions from left to right on the display. The **time base** indicates how much time will be displayed in each division. For example, if the scope is set to read 200 ms (0.200 s) per division, then the total displayed would be 2 sec (0.200 × 10 divisions = 2 sec). The time base should be set to an amount of time that allows two to four events to be displayed. Sample time is milliseconds per division (indicated as ms/div) and total time includes:

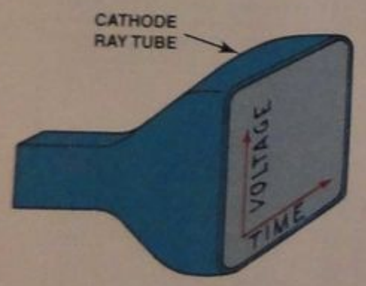


Figure 34–24 An automotive oscilloscope (scope) is of the same construction as a cathode ray tube (CRT) or television screen. An automotive oscilloscope is a visual voltmeter. The higher up a trace (line) on the scope, the higher the voltage. The scope illustrates time from left to right. The longer the horizontal line, the longer the amount of time.

ms/Division	Total Time
1	10 ms (0.010 sec)
10	100 ms (0.100 sec)
50	500 ms (0.500 sec)
100	1 sec (1.000 sec)
500	5 sec (5.0 sec)
1000	10 sec (10.0 sec)

NOTE: Increasing the time base reduces the number of samples per second.

The horizontal scale is divided into 10 divisions. If each division represented 1 sec of time, then the total time period displayed on the screen will be 10 sec. Time per division can vary greatly in automotive use, as follows:

Fuel injector—2 ms per division (20 ms total)
Throttle position (TP) sensor—100 ms per division (1 sec total)
Oxygen sensor—1 sec per division (10 sec total)

The time per division is selected so that several events of the waveform are displayed. This allows comparisons to see if the waveform is consistent or is changing. Multiple waveforms shown on the display at the same time also allow for measurements to be seen more easily.

Commonly used time per division units for various component tests are as follows:

- MAP/MAF—2 ms/div
- Stepper motor—10 ms/div
- Primary ignition—10 ms/div
- Secondary ignition—10 ms/div
- Voltage measurements—5 ms/div
- Display diode test—50 ms/div

SETTING THE VOLTS PER DIVISION

The vertical scale has eight divisions. If each division is set to equal 1 volt, the display will show 0 to 8 volts. This is acceptable in a 0- to 5-volt variable sensor such as a TP sensor. The **volts per division** (V/div) should be set so that the entire anticipated waveform can be viewed. Examples include:

TP sensor	1 V/div (8 V total)
Battery, starting and charging	2 V/div (16 V total)
Oxygen sensor	200 mV/div (1.6 V total)

Notice from the examples that the total voltage to be displayed exceeds the voltage range of the component being tested. This ensures that all the waveform will be displayed. It also allows for some unanticipated voltage readings. For example, an oxygen sensor should read between 0 and 1 V (1,000 mV). By setting the V/div to 200 mV, up to 1.6 V (1,600 mV) will be displayed.

DC COUPLING

DC coupling allows the scope to display both AC and DC voltage signals and is the most used setting for automotive applications.

A flat horizontal line across the display at a level of 12 volts indicates the DC voltage signal. A DC voltage signal is the starting and charging voltage measured at the battery. When the starter motor is energized, a load is applied to the battery and the battery voltage drops to about 10.5 volts. This is displayed again as a horizontal line, but now at a level lower than previously seen. When the engine starts, the generator starts to charge the battery and the voltage increases to about 14.5 volts. Again, the display is a horizontal line, but with a higher level than before that shows the charging voltage. Any generator (alternator) ripple voltage caused by leaking diodes would be displayed as an AC signal on top of the DC waveform.

AC COUPLING

AC coupling allows the scope to read **alternating current (AC)** voltage signals and ignore any **direct current (DC)** voltage present in the circuit. For example, this setting allows the technician to view the ripple voltage of the charging circuit without seeing the 14 volts DC signal. For example, connect the scope probes to display 120 volts AC household voltage at an outlet.

CAUTION: 110 V AC can cause bodily injury. Always touch the rubber or plastic portions of the scope probes when making measurements of any circuit that exceed 30 volts (AC or DC). Also, some scopes, such as the MODIS, cannot handle household or industrial AC voltages.

An AC voltage rises and falls above and below the zero level. To display several repeating continuously variable voltage signals, the proper time per division must be selected. Household electricity is 60 hertz (60 cycles per second) where 1 cycle requires just 18 ms (0.018 sec). One complete cycle displays as 0.2 ms/div (10 divisions × 2 ms/div = 20 ms). Because it is best to view two or three cycles, set the time base to 4 or 6 ms per division.

Setting the volts per division is a little tricky. A 120 V AC signal actually goes over 120 volts positive and down more than 120 volts negative. Therefore, to view the entire waveform, the total voltage range on the display must be greater than 240 volts. Because there are eight vertical grids, a setting of 50 volts per division would allow the scope to display a total of 400 volts (50 V × 8 = 400) with 200 volts positive and 200 volts negative.

PULSE TRAINS

A DC voltage that turns on and off in a series of pulses is called a **pulse train.** See Figure 34–25. Pulse train signals can vary in several ways.

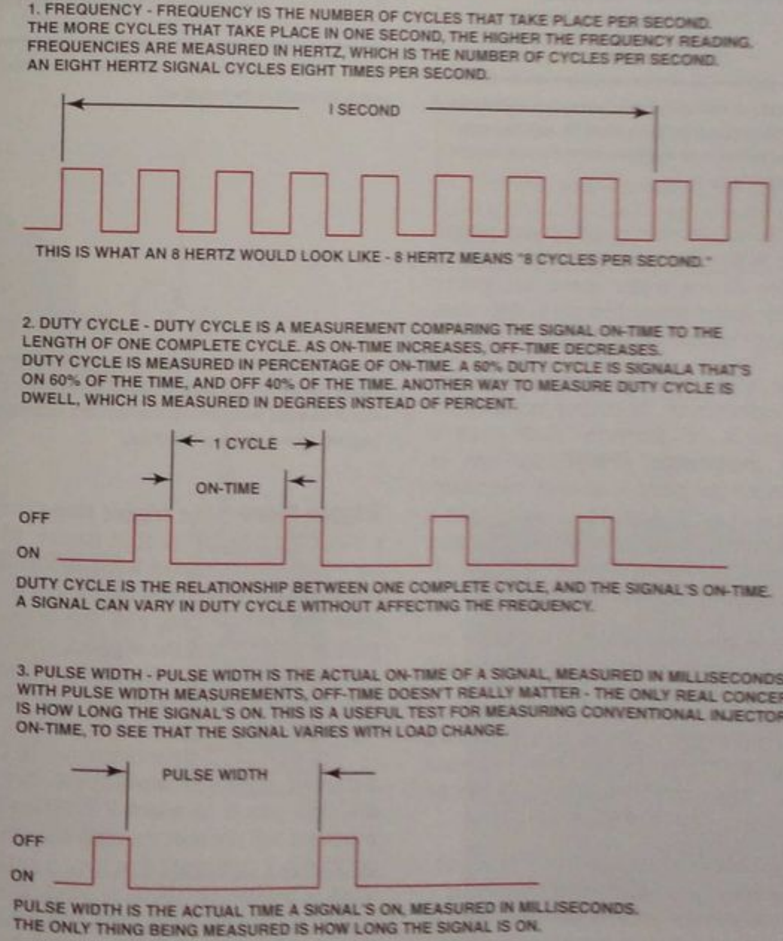
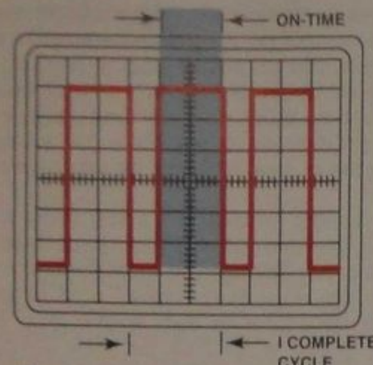


Figure 34–25 A pulse train is any electrical signal that turns on and off, or goes high and low in a series of pulses. Igniter and fuel-injector pulses are examples of a pulse train signal.



(a)



THE % SIGN IN THE UPPER RIGHT CORNER OF THE DISPLAY INDICATES THAT THE METER IS READING A DUTY CYCLE SIGNAL.

(b)

Figure 34–26 (a) A scope representation of a complete cycle showing both on-time and off time. (b) A meter display indicating the on-time duty cycle in percent (%). Note the trigger and negative (–) symbol. This indicates that the meter started to record the percentage of on-time when the voltage dropped (start of on-time).

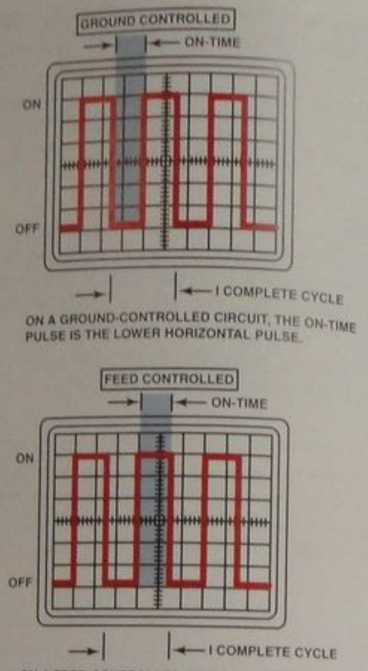
Frequency **Frequency** is the number of cycles per second, measured in hertz. Engine RPM signal is one example that can occur at various frequencies. At low engine speed, the ignition pulses occur fewer times per second (lower frequency) than when the engine is operated at higher engine speeds (RPMs).

Duty Cycle **Duty cycle** refers to the percentage of on-time of the signal during one complete cycle. As on-time increases, the amount of time the signal is off decreases. Duty cycle is also called **pulse width modulation (PWM)** and can be measured in degrees. An electric fuel pump in an electronic returnless fuel system is an example of a PWM pulsed on and off with a variable duty cycle. The solenoid activation is constantly changing at 10 times per second (10 Hz), but the on-time varies. In this example, the duty cycle is measured in degrees. See Figure 34–26.

Pulse Width The **pulse width** is a measure of the actual on-time measured in milliseconds. Fuel injectors are usually controlled by varying the pulse width. See Figure 34–27.

External Trigger An **external trigger** occurs when the trace starts when a signal is received from another (external) source. A common example of an external trigger comes from the probe clamp around cylinder 1 spark plug wire to trigger the start of an ignition pattern.

Trigger Level A scope will not start displaying a voltage signal until it is triggered or told to start. The **trigger level** must be set to start the display. In the example, we want the pattern to start at 1 volt, then the trace will begin displaying on the left side of the screen *after* the trace has reached 1 volt.



ON A GROUND-CONTROLLED CIRCUIT, THE ON-TIME PULSE IS THE LOWER HORIZONTAL PULSE.

ON A FEED-CONTROLLED CIRCUIT, THE ON-TIME PULSE IS THE UPPER HORIZONTAL PULSE.

Figure 34–27 Most automotive computer systems control the device by opening and closing the ground to the component.

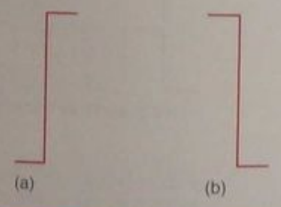


Figure 34–28 (a) A symbol for a positive trigger—a trigger occurs at a rising (positive) edge of the signal (waveform). (b) A symbol for a negative trigger—trigger occurs at a falling (negative) edge of the signal (waveform).

Trigger Slope The **trigger slope** is the voltage direction that a waveform requires to start display. Most often, the trigger to start a waveform display is taken from the signal itself. Besides trigger voltage level, most scopes can be adjusted to trigger only when the voltage rises past the trigger-level voltage, called a *positive slope*. When the trigger is activated by the voltage falling past the trigger level, it is called a *negative slope*. The scope display indicates both a positive and a negative slope symbol. See Figure 34–28.

For example, if a waveform such as a magnetic sensor used for crankshaft position or wheel speed starts moving upward, a positive slope should be selected. If a negative slope is selected, the waveform will not start showing until the voltage reaches the trigger level in a downward direction. A negative slope should be used when a fuel-injector circuit is being analyzed. In this circuit, the computer provides the ground and the voltage level drops when the computer commands the injector on. See the remaining chapters for examples of scope usage.

USING SCOPE LEADS

Most scopes, both analog and digital, normally use the same test leads. These leads usually attach to the scope through a **BNC connector,** a miniature standard coaxial cable connector named after its inventor, Baby Neil Councilman. BNC is an international standard that is used in the electronics industry. Each scope lead has an attached ground lead that should be connected to a good clean, metal engine ground. The probe of the scope lead attaches to the circuit or component being tested.

MEASURING BATTERY VOLTAGE WITH A SCOPE

One of the easiest things to measure and observe on a scope is battery voltage. A lower voltage can be observed on the scope display as the engine is started and a higher voltage should be displayed after the engine starts. See Figure 34–29.

An analog scope displays rapidly and cannot be set to show or freeze a display. Therefore, even though an analog scope shows all voltage signals, it is easy to miss a momentary event (glitch) on an analog scope.

GRAPHING MULTIMETER

A **graphing multimeter,** abbreviated **GMM,** is a cross between a digital meter and a digital storage oscilloscope. A graphing multimeter displays the voltage levels on a display and a digital readout. It is usually not capable of capturing very short duration faults or glitches that would likely be captured with a digital storage oscilloscope. See Figure 34–30.

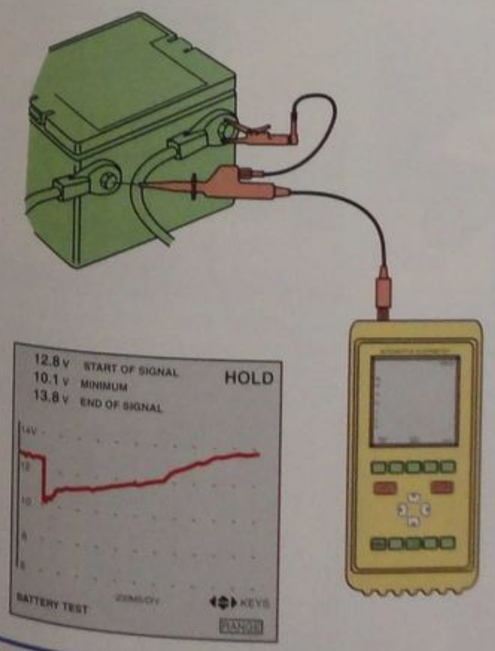


Figure 34–29 Battery voltage is represented by a flat horizontal line. In this example, the engine was started and the battery voltage dropped to about 10 V as shown on the left side of the scope display. When the engine started, the generator (alternator) started to charge the battery and the voltage is shown as climbing.

SAFETY TIP **Meter Usage on Hybrid Vehicles**

Many hybrid (gasoline and electric motor) powered vehicles are equipped with a generator that can exceed 400 volts DC. Be sure to follow all vehicle manufacturer's testing procedures and if a voltage measurement is needed, be sure to use a meter and test leaks that are designed to insulate against high voltages. The **International Electrotechnical Commission (IEC)** has several categories of voltage standards for meter and meter leads. These categories are ratings for overvoltage protection and are rated CAT I, CAT II, CAT III, and CAT IV. The higher the category, the greater the protection against voltage spikes. Under each category there are various voltage ratings.

- **CAT I** Typically a CAT I meter is used for low-voltage measurements such as voltage measurements at wall outlets in the home. Meters with a CAT I rating are usually rated at 300 to 800 volts.
- **CAT II** A higher-rated meter that would be typically used for checking voltages at the fuse panel in the home. Meters with a CAT II rating are usually rated at 300 to 600 volts.
- **CAT III** The minimum-rated meter that should be used for hybrid vehicles. This category is designed for voltage measurements at the service pole transformer. Meters with a CAT III rating are usually rated at 600 to 1,000 volts.
- **CAT IV** CAT IV meters are for clamp-on meters only. If a clamp-on meter also has meter leads for voltage measurements, that part of the meter will be rated as CAT III.

NOTE: Always use the highest **CAT rating** meter, especially when working with hybrid vehicles. A CAT III 600-volt meter is safer than a CAT II 1,000-volt meter because of the way the CAT rating is determined.

For best personal protection, use only meters and meter leads that are CAT III or CAT IV rated when measuring voltage on a hybrid vehicle. See Figures 34–31 and 34–32.



Figure 34–30 This shows a typical graphing multimeter.



Figure 34–31 Be sure to only use a meter that is CAT III-rated when taking electrical voltage measurements on a hybrid vehicle.

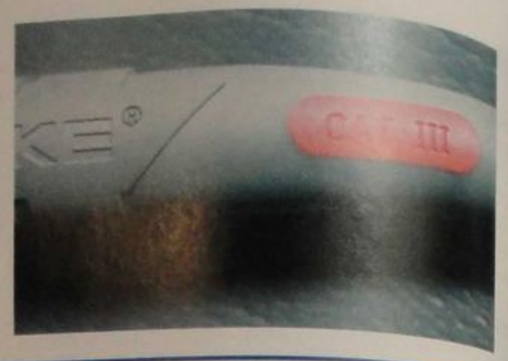


Figure 34–32 Always use meter leads that are CAT III-rated on a meter that is also CAT III-rated to maintain the protection needed when working on hybrid vehicles.

SUMMARY

1. Digital multimeter (DMM) and digital volt-ohm-milliammeter (DVOM) are terms commonly used for electronic high-impedance test meters.
2. Use of a high-impedance digital meter is required on any computer-related circuit or component.
3. Ammeters measure current and must be connected in series in the circuit.
4. Voltmeters measure voltage and are connected in parallel.
5. Ohmmeters measure resistance of a component and must be connected in parallel, with the circuit or component disconnected from power.
6. Logic probes can indicate the presence of both ground and power.

REVIEW QUESTIONS

1. Why are most digital meters called high-impedance meters?
2. How should an ammeter be connected to an electrical circuit?
3. Why must an ohmmeter be connected to a disconnected circuit or component?
4. How should a voltmeter be connected to an electrical circuit?

PHOTO SEQUENCE Digital Meter Usage #1



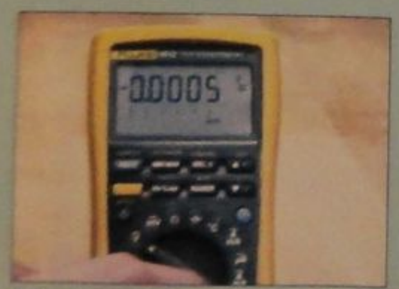
P34–1 Meter leads often become tangled. Start work with a digital meter by straightening the meter leads.



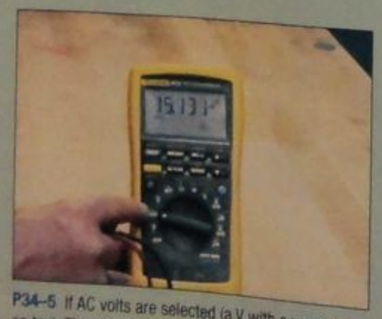
P34–2 To help prevent the leads from becoming tangled tie a loose knot at the meter end of the leads.



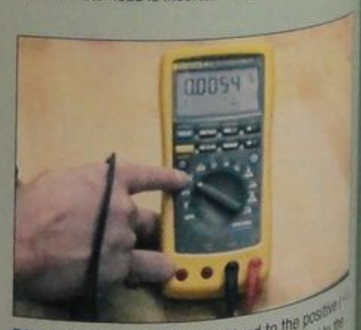
P34–3 For most electrical measurements, the black meter lead is inserted in the terminal labeled COM and the red meter lead is inserted into the terminal labeled



P34–4 To use a digital meter, turn the power switch and select the unit of electricity to be measured. In this case, the rotary switch is turned to select DC volts.



P34–5 If AC volts are selected (a V with a wavy line on top). The AC voltage shown is caused by the flourescent lights.



P34–6 Connect the red meter lead to the positive (+) terminal of a battery and the black meter lead to the negative (−) terminal of a battery. The meter reads the voltage difference between the leads.

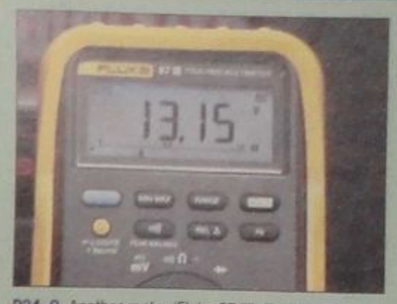
PHOTO SEQUENCE Digital Meter Usage #1—continued



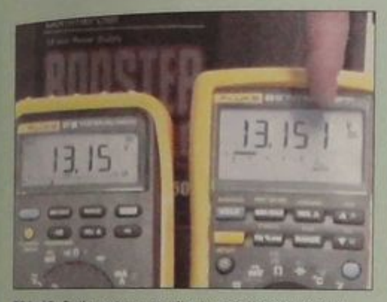
P34–7 For most automotive electrical use, select DC volts.



P34–8 This jump start battery unit measures 13.151 volts with the meter set on autoranging on the DC voltage scale.



P34–9 Another meter (Fluke 87 III) displays four digits when measuring the voltage of the battery jump start unit.



P34–10 Both meters are displayed side-by-side to show the readings of both. The Fluke 89 IV (right) is capable of measuring down to 1/1000 of a volt.



P34–11 Meters can also be set to read different ranges. A "range" button was pressed once on the meter on the left. Notice that the meter is now set to read higher voltages.



P34–12 Pressing the range button a second time on the meter results in the loss of 1/10 of a volt reading and the addition of another zero on the left of the display.



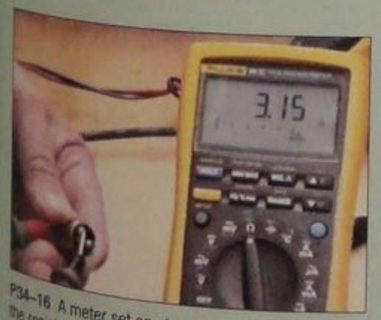
P34–13 To measure resistance turn the rotary dial to the ohm (Ω) symbol. With the meter leads separated, the meter display reads L (over limit).



P34–14 The meter can read your own body resistance if you grasp the meter lead terminals with your fingers. The reading on the display indicates 196.35 kΩ.



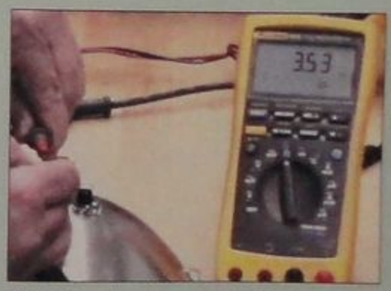
P34–15 When measuring anything, be sure to read the meter face. In this case, the meter is reading 291.10 kΩ.



P34–16 A meter set on ohms can be used to check the resistance of a light bulb filament. In this case, the meter reads 3.15 ohms. If the bulb were bad (filament open), the meter would display OL.



P34–17 A sealed beam headlight bulb is being measured. The filament being measured has 1.52 ohms.



P34–18 The other filament reads 3.53 ohms. Obviously this filament is the low beam (high resistance means less current flow and a dimmer light).

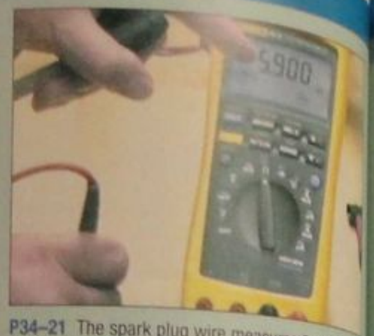
(continued)



P34–19 A digital meter set to read ohms should measure 0.00 as shown when the meter leads are touched together.



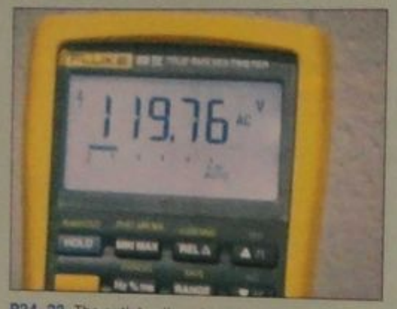
P34–20 To measure the resistance of a spark plug wire, attach one lead of the meter to one end and the other meter lead to the other.



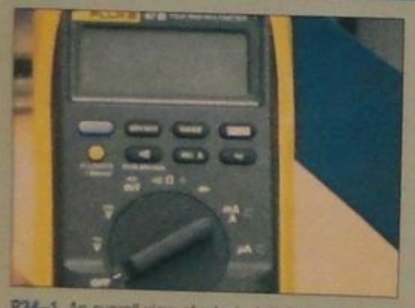
P34–21 The spark plug wire measures 5.900 kΩ (5900 ohms). This I-foot-long spark plug wire is okay because it measures less than 10,000 ohms per foot of length (5900 ohms is less than 10,000 ohms).



P34–22 A digital multimeter can also be used to check the voltage of an electrical outlet. Set the meter to read AC volts.



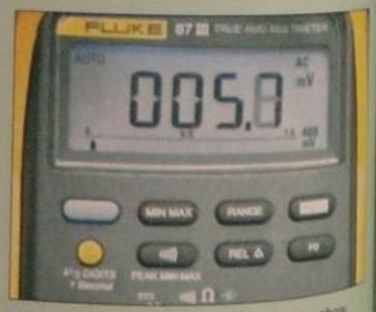
P34–23 The outlet voltage is 119.76 volts AC. Note the Z and V in the window display.



P34–1 An overall view of a typical digital multimeter. In the center is a rotary switch that can be turned to point to the various symbols around the switch.



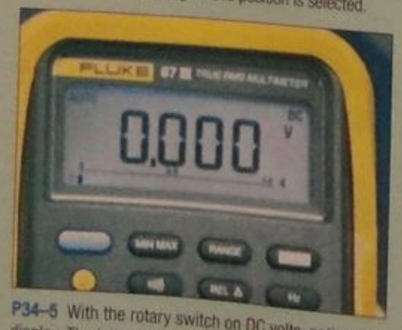
P34–2 The large letter V means volts and the wavy symbol over the V means that the meter measures alternating current (AC) voltage if this position is selected.



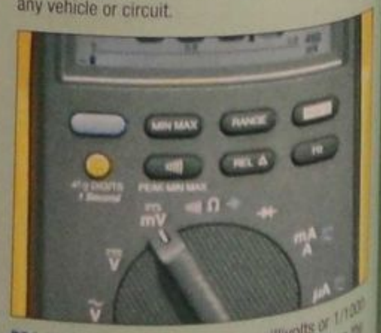
P34–3 Turning the meter on AC volts does show some voltage even if the leads are not connected to any vehicle or circuit.



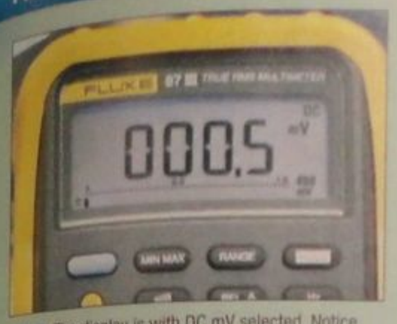
P34–4 The next symbol is a V with a dotted and a straight line overhead. This symbol stands for direct current (DC) volts. This position is most used for automotive service.



P34–5 With the rotary switch on DC volts, notice the display. The letter DC and V appear in the upper right of the display. Also note the word *auto* in the upper left.



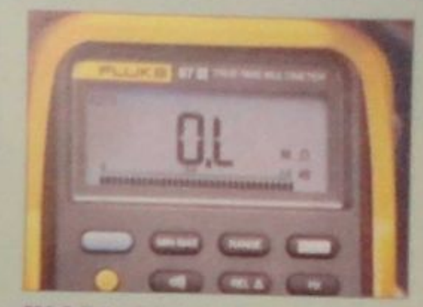
P34–6 The symbol mV indicates millivolts or 1/1000 of a volt (0.001). The solid and dashed line above the mV means DC mV. This position is not normally used in most vehicle diagnostic or service work.



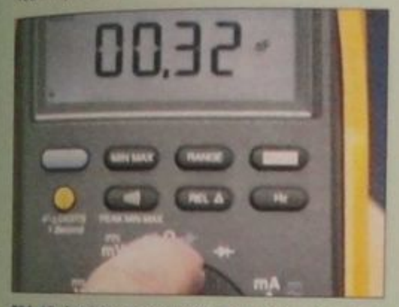
P34–7 The display is with DC mV selected. Notice the DC and mV in the display in the upper right. The display means that the meter is set to read up to 400 mV (0.400 V) DC.



P34–8 The rotary switch is turned to Ω (ohms) unit of resistance measure. The symbol to the left of the Ω symbol is the beeper or continuity indicator.



P34–9 Notice that auto is in the upper left and the MΩ is in the lower right. This MΩ means megaohms or that the meter is set to read in millions of ohms.



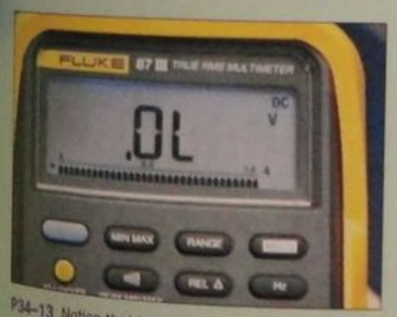
P34–10 Another symbol to the right of the Ω symbol is the symbol for capacitance which is measured in microfarads.



P34–11 When the blue button is pushed and the rotary switch is still on ohms (Ω), the meter will read capacitance in microfarads.



P34–12 The symbol shown is the symbol of a diode and the meter reads the voltage drop across the junction of a diode.



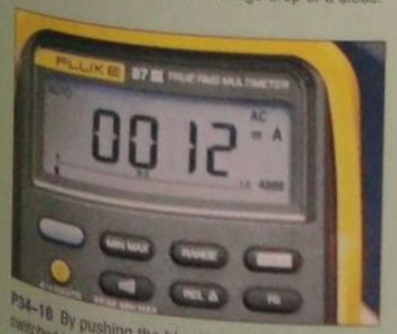
P34–13 Notice that in the diode check position, the display shows DCV in the upper right, indicating that the meter will be showing the voltage drop of a diode.



P34–14 The next position that the rotary knob is pointing to is the position used to measure amperes (A) and milliamperes (mA).



P34–15 Notice the display when mA and A are selected. The word auto in the upper left indicates that the meter is set to read whatever amperage is about to be measured.



P34–16 By pushing the blue button, the meter is switched to read AC mA. Notice that although the meter is reading some current, even though the leads are not connected to a circuit.



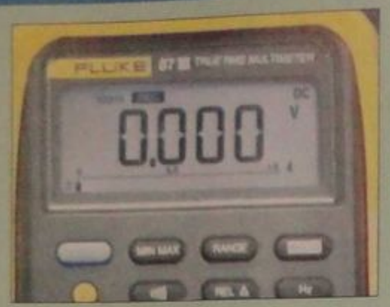
P34–17 The last position on the rotary switch is the symbol for microamperes (one millionth of an ampere or 0.000001 A). This position is not used for automotive service work.



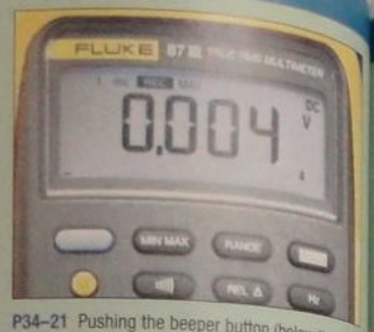
P34–18 Notice the symbol for microamperes (the Greek letter mu or μ) and DCA on the display.



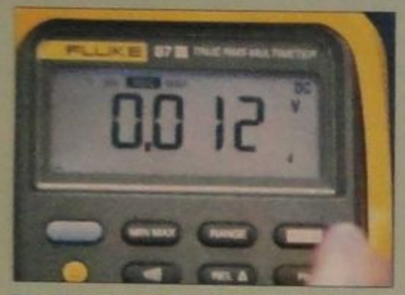
P34–19 One of the most useful features of this meter is the MIN/MAX feature. By pushing the MIN/MAX button, the meter will be able to display the highest (MAX) and the lowest (MIN) reading.



P34–20 Pushing the MIN/MAX button puts the meter into record mode. Note the 100 mS and "rec" on the display. In this position, the meter is capturing any voltage change that lasts 100 mS (0.1 sec) or longer.



P34–21 Pushing the beeper button (below the MIN/MAX button) places the meter into a 1 mS (0.001 sec) capture mode.



P34–22 The maximum reading is being displayed during the test. As long as the display shows "rec," it is recording any new high or low voltages that last longer than one-thousandth of a second (0.001 sec).



P34–23 To show the lowest voltage recorded, touch the MIN/MAX button. The lowest voltage will be displayed.



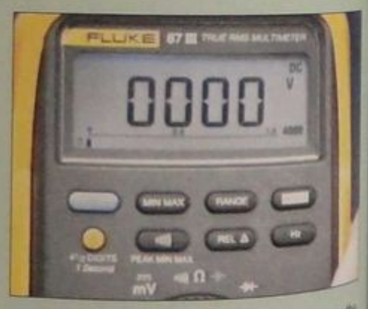
P34–24 Become some voltages or other signals change, it is often necessary to manually set the range of the meter.



P34–25 To increase the range of the meter touch the range button. Now the meter is set to read voltage up to 40 volts DC.



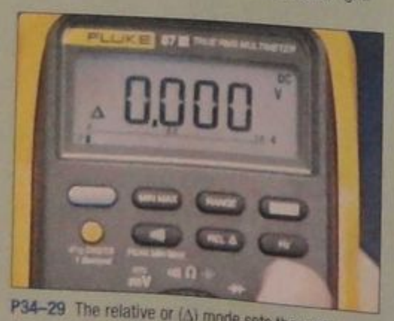
P34–26 Pushing the range button one more time changes the meter scale to the 400-voltage range. Notice that the decimal point has moved to the right.



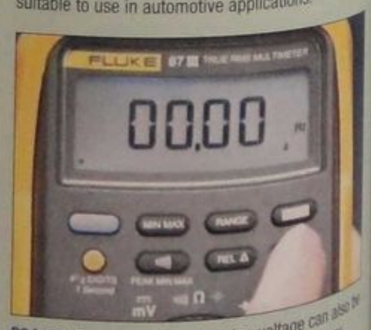
P34–27 Pushing the range button again changes the meter to the 4000-volt range. This range is not suitable to use in automotive applications.



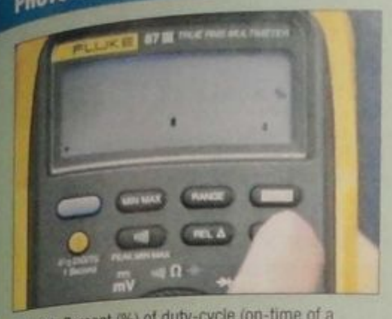
P34–28 By pushing and holding the range button, the meter will reset to autorange. Autorange is the preferred setting for most automotive measurements except when using MIN/MAX record mode.



P34–29 The relative or (Δ) mode sets the meter display to zero and is useful for eliminating any resistance in the meter leads. The relative mode is also useful for voltage drop measurements.



P34–30 Frequency of a changing voltage can also be measured by selecting hertz (Hz) while the rotary switch is on AC or sometimes DC volts. The Hz symbol will appear in the display.



P34–31 Percent (%) of duty-cycle (on-time of a signal) can be measured by pushing the Hz button.



P34–32 Two meters are being set up to measure each other. A Fluke 89 is on the left and a Fluke 87 is on the right. By connecting the meter leads, one meter can measure the other meter.



P34–33 The meter on the left is set to read DC volts and the meter on the right is set to read resistance in ohms.



P34–34 The meter on the right is reading 10.983 MΩ (10.983.000 ohms). This is a high-impedance meter and the reading should be greater than 10 MΩ to be safely used on computer controlled circuits.

CHAPTER QUIZ

1. Inductive ammeters work because of what principle?
   a. Magic
   b. Electromagnetic induction
   c. A magnetic field surrounds any wire carrying a current
   d. Voltage drop as it flows through a conductor
2. A meter used to measure amperes is called _____.
   a. An amp meter
   b. An ampmeter
   c. An ammeter
   d. A coulomb meter
3. A voltmeter should be connected to the circuit being tested _____.
   a. In series
   b. In parallel
   c. Only when no power is flowing
   d. Both a and c
4. An ohmmeter should be connected to the circuit being tested _____.
   a. In series
   b. In parallel
   c. Only when no power is flowing
   d. Both b and c
5. A high-impedance meter _____.
   a. Measures a high amount of current flow
   b. Measures a high amount of resistance
   c. Can measure a high voltage
   d. Has a high internal resistance
6. A meter is set to read DC volts on the 4-volt scale. The meter leads are connected at a 12-volt battery. The display will read _____.
   a. 0.00
   b. OL
   c. 12 V
   d. 0.012 V
7. Technician A says an analog scope can store the waveform for viewing later. Technician B says that the trigger level has to be set on most scopes to view a changing waveform. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. The highest amount of resistance that can be read by the meter set to the 2-kΩ scale is _____.
   a. 2000 ohms
   b. 200 ohms
   c. 200 kΩ (200,000 ohms)
   d. 20,000,000 ohms
9. If a digital meter face shows 0.93 when set to read kilohms, the reading means _____.
   a. 93 ohms
   b. 930 ohms
   c. 9300 ohms
   d. 93,000 ohms
10. A reading of 432 shows on the face of the meter set to the millivolts scale. The reading means _____.
    a. 0.432 volt
    b. 4.32 volts
    c. 43.2 volts
    d. 4320 volts

CHAPTER 35 Automotive Wiring and Wire Repair

OBJECTIVES: After studying Chapter 35, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain the wire gauge number system. • Describe how fusible links and fuses protect circuits and wiring. • List the steps for performing a proper wire repair.

KEY TERMS: adhesive-lined tubing • American wire gauge (AWG) • auto link • battery cables • blade-time fuse • braided ground straps • circuit breaker • cold solder joint • connector position assurance (CPA) • connectors • copper • crimp-and-seal connectors • fuse • fusible link cartridge • fusible links • heat shrink • jumper cables • lock tang • maxi fuse • metric wire gauge • mini fuse • Pacific fuse element • positive temperature coefficient (PTC) circuit protectors • primary wire • rosin-core solder • skin effect • solder • terminals • twisted pair • wiring • W-shaped crimp

AUTOMOTIVE WIRING

Most automotive wire is made from strands of copper covered by insulating plastic. **Copper** is an excellent conductor of electricity that is reasonably priced and very flexible. However, copper can break when moved repeatedly; therefore, most copper wiring is constructed of multiple small strands that allow for repeated bending and moving without breaking. Solid copper wire is generally used for components such as starter armature and alternator stator windings that do not bend or move during normal operation. Copper is the best electrical conductor besides silver, which is a great deal more expensive. See the following chart.

Conductor Rating (Starting with the Best)

1. Silver
2. Copper
3. Gold
4. Aluminum
5. Tungsten
6. Zinc
7. Brass (copper and zinc)
8. Platinum
9. Iron
10. Nickel
11. Tin
12. Steel
13. Lead

American Wire Gauge **Wiring** is sized and purchased according to gauge size as assigned by the **American wire gauge** (**AWG**) system. AWG numbers can be confusing because as the gauge number increases, the size of the conductor wire *decreases*. Therefore, a 14-gauge wire is smaller than a 10-gauge wire. The greater the amount of current (in amperes), the *larger* the conducting wire (the smaller the gauge number) required. See the chart that compares the AWG number to the actual wire diameter in inches.

Wire Gauge Diameter Table

American Wire Gauge	Wire Diameter in Inches
20	0.03196118
18	0.040303
16	0.0508214
14	0.064084
12	0.08080810
10	0.10189
8	0.128496
6	0.16202
5	0.18194
4	0.20431
3	0.22942
2	0.25763
1	0.2893
0	0.32486
00	0.3648

Following are general applications for the most commonly used wire gauge sizes.

NOTE: Always check the installation instructions or the manufacturer's specifications for wire gauge size before replacing any automotive wiring.

20–22 gauge: radio speaker wires

18 gauge: small bulbs and short leads

16 gauge: taillights, gas gauge, turn signals, windshield wipers

14 gauge: horn, radio power lead, headlights, cigarette lighter, brake lights

12 gauge: headlight switch-to-fuse box, rear window defogger, power windows and locks

10 gauge: ammeter, generator, or alternator-to-battery

Metric Wire Gauge Most manufacturers indicate on the wiring diagrams the wire sizes measured in square millimeters (mm²) of cross-sectional area. The following chart gives conversions or comparisons between **metric** and AWG **gauge** sizes. Notice that the metric wire size increases with size (area), whereas the AWG gauge size gets smaller with larger-size wire.

Metric-to-AWG Conversion Table

Metric Size mm²	AWG Size
0.5	20
0.8	18
1.0	16
2.0	14
3.0	12
5.0	10
8.0	8
13.0	6
19.0	4
32.0	2
52.0	0

The AWG gauge number should be decreased (wire size increased) with increased lengths of wire. See the following chart.

12 V Wire Gauge (for Length in Feet)*

Amps	3'	5'	7'	10'	15'	20'	25'
5	18	18	18	18	18	18	18
7	18	18	18	18	18	18	16
10	18	18	18	18	16	16	16
12	18	18	18	18	16	16	14
15	18	18	18	18	14	14	12
18	18	18	16	16	14	14	12
20	18	18	16	16	14	12	10
22	18	18	16	16	12	12	10
24	18	18	16	16	12	12	10
30	18	16	16	14	10	10	10
40	18	16	14	12	10	10	8
50	16	14	12	12	10	10	8
100	12	12	10	10	6	6	4
150	10	10	8	8	4	4	2
200	10	8	8	6	4	4	2

*When mechanical strength is a factor, use the next larger wire gauge.

For example, a trailer may require 14-gauge wire to light all the trailer lights, but if the wire required is over 25 feet long, 12-gauge wire should be used. Most automotive wire, except for spark plug wire, is often called **primary wire** (named for the voltage range used in the primary ignition circuit), because it is designed to operate at or near battery voltage.

BRAIDED GROUND STRAPS

All vehicles use ground straps between the engine and body and/or between the body and the negative terminal of the battery. Many of the engine-to-body straps are braided and uninsulated, as shown in Figure 35–1. It is not necessary to insulate a ground strap because it does not matter if it touches metal since it already attaches to ground. **Braided ground straps** are more flexible than stranded wire. Because the engine will move slightly on its mounts, the braided ground strap must be able to flex without breaking. The braided strap also dampens out some radio-frequency interference

FREQUENTLY ASKED QUESTION ???

Do They Make 13-Gauge Wire?

Yes. The American wire gauge (AWG) sizing of wire includes all gauge numbers, even though the most commonly used sizes are even numbered, such as 12, 14, or 16.

Because the sizes are so close, wire in every size is not commonly stocked, but it can be ordered for a higher price. Therefore, if a larger wire size is needed, it is common practice to select the next lower, even-numbered gauge. See the chart for a comparison of the wire size.

AWG Gauge	Diameter in Inches
0000	0.46
000	0.4096
00	0.3648
0	0.3249
1	0.2893
2	0.2576
3	0.2294
4	0.2043
5	0.1819
6	0.162
7	0.1443
8	0.1285
9	0.1144
10	0.1019
11	0.0907
12	0.0808
13	0.072
14	0.0641
15	0.0571
16	0.0508
17	0.0453
18	0.0403
19	0.0359
20	0.032
21	0.0285
22	0.0254
23	0.0226
24	0.0201
25	0.0179
26	0.0159
27	0.0142
28	0.0126
29	0.0113
30	0.01
31	0.0089
32	0.008



Figure 35–1 All lights and accessories ground to the body of the vehicle. Body ground wires such as this one are needed to conduct all of the current from these components back to the negative terminal of the battery. The body ground wire connects the body to the engine. Most battery negative cables attach to the engine.

FREQUENTLY ASKED QUESTION ???

What Is the Skin Effect?

The **skin effect** is the term used to describe how high-frequency AC electricity flows through a conductor. Direct current flows through a conductor, but alternating current tends to travel through the outside (skin) of the conductor. Because of the skin effect, most audio (speaker) cable is constructed of very small-diameter copper wires instead of fewer larger strands, because the smaller wire has a greater surface area and therefore results in less resistance to the flow of AC voltage.

that otherwise might be transmitted through standard stranded wiring. The crossing of the wires in a braided ground strap effectively shorts out any AC voltage signal that could contribute to radio interference.

NOTE: Body ground wires are necessary to provide a circuit path for the lights and accessories that ground to the body and flow to the negative battery terminal.

FREQUENTLY ASKED QUESTION ???

What Is a Twisted Pair?

A **twisted pair** is used to transmit low-voltage signals using two wires that are twisted together. Electromagnetic interference can create a voltage in a wire, and twisting the two signal wires cancels out the induced voltage. A twisted pair means that the two wires have at least 9 twists (turns) per foot.

BATTERY CABLES

Battery cables are the largest wires used in the automotive electrical system. The cables are usually 4-gauge, 2-gauge, or 1-gauge wires (19 mm² or larger). See Figure 35–2. Wires larger than 1-gauge are called 0-gauge (pronounced "ought"). Larger cables are labeled 2/0 or 00 (2 ought) and 3/0 or 000 (3 ought). Six-volt electrical systems require battery cables two sizes larger than those used for



Figure 35–2 Battery cables are designed to carry heavy starter current and are therefore usually 4-gauge or larger wire. Note that this battery is covered with a thermal blanket covering to help protect the battery from high under-hood temperatures. The wiring is also covered with plastic conduit also called split-loom tubing.

12-volt electrical systems, because the lower voltage used in antique vehicles resulted in twice the amount of current (amperes) to supply the same electrical power.

JUMPER CABLES

Jumper cables are 4- to 2/0-gauge electrical cables with large clamps attached and are used to connect a vehicle that has a discharged battery to a vehicle that has a good battery. Good-quality jumper cables are necessary to prevent excessive voltage drops caused by the cables' resistance. Aluminum wire jumper cables should not be used, because even though aluminum is a good electrical conductor (although not as good as copper), it is less flexible and can crack and break when bent or moved repeatedly. The size should be 4-gauge or larger. Ought-gauge welding cable can be used to construct an excellent set of jumper cables using welding clamps on both ends. Welding cable is usually constructed of many very fine strands of wire, which allows for easier bending of the cable as the strands of fine wire slide against each other inside the cable.

FUSES AND CIRCUIT PROTECTION DEVICES

Fuses should be used in every circuit to protect the wiring from overheating and damage caused by excessive current flow as a result of a short circuit or other malfunction. The symbol for a fuse is a wavy line between two points: • ~ •

A fuse is constructed of a fine tin conductor inside a glass, plastic, or ceramic housing. The tin is designed to melt and open the circuit if excessive current flows through the fuse. Each fuse is rated according to its maximum current-carrying capacity.

Many fuses are used to protect more than one circuit of the automobile. See Figure 35–3. A typical example is the fuse for the cigarette lighter that also protects many other circuits such as those for the courtesy lights, clock, and other circuits. A fault in one of these circuits can cause this fuse to melt, which will prevent the operation of all other circuits that are protected by the fuse.

NOTE: The SAE term for a cigarette lighter is *cigar lighter* because the diameter of the heating element is large enough for a cigar. The term *cigarette lighter* will be used throughout this book because it is the most common usage.

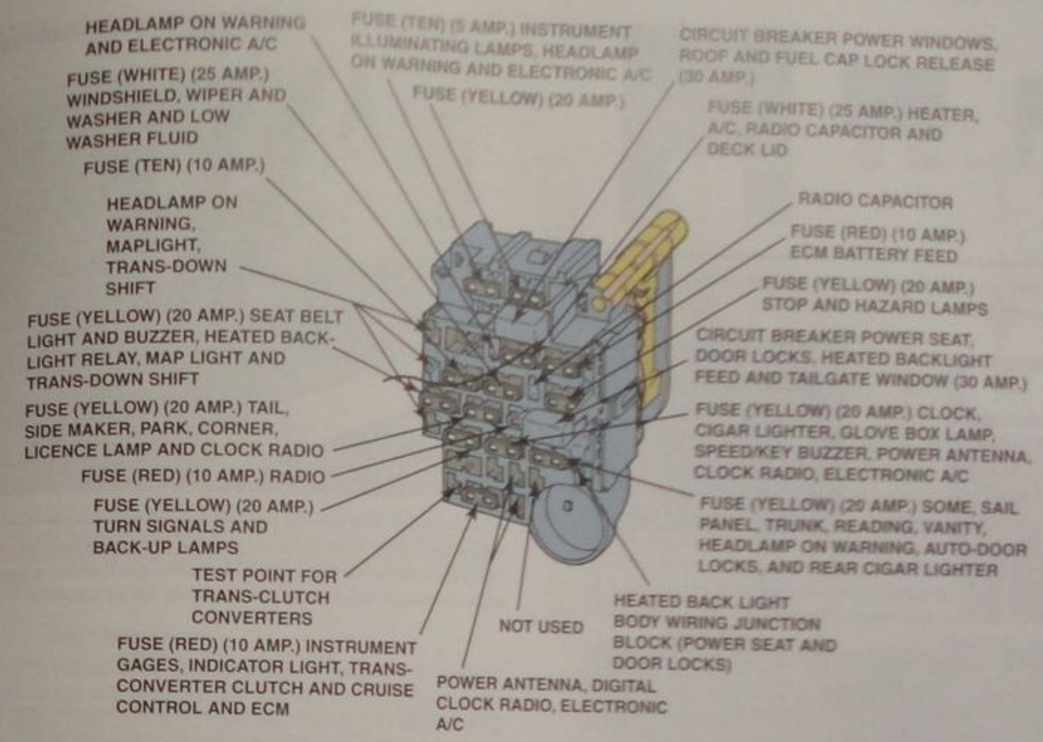


Figure 35–3 This figure shows a typical automotive fuse panel.

Blade Fuses Colored **blade-type fuses** are also referred to as ATO fuses. The color of the plastic of blade fuses indicates the maximum current flow, measured in amperes. Each fuse has an opening in the top of its plastic portion to allow access to its metal contacts for testing purposes. See Figure 35–4. The following chart lists the color and the amperage rating of blade fuses.

Amperage Rating	Color
1	Dark green
2	Gray
2.5	Purple
3	Violet
4	Pink
5	Tan
6	Gold
7.5	Brown
9	Orange
10	Red
14	Black
15	Blue
20	Yellow
25	White
30	Green

Mini Fuses To save space, many vehicles use **mini** (small) blade **fuses.** Not only do they save space but they also allow the vehicle design engineer to fuse individual circuits instead of grouping many

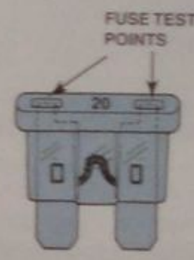


Figure 35–4 Blade-type fuses can be tested through openings in the plastic at the top of the fuse.

different components on one fuse. This improves customer satisfaction because if one component fails, it only affects that one circuit without stopping electrical power to several other circuits as well. This also makes troubleshooting much easier, because each circuit is separate. The amperage rating and corresponding fuse color for mini fuses include the following:

Amperage Rating	Color
5	Tan
7.5	Brown
10	Red
15	Blue
20	Yellow
25	Natural
30	Green



Figure 35–6 Three styles of blade-type fuses; mini on the left, standard or ATO type in the center, and maxi on the right.

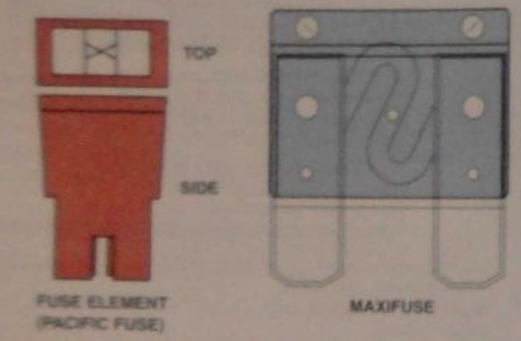


Figure 35–4 A comparison of the various types of protective devices used in most vehicles.

See Figure 35–5.

Maxi Fuses **Maxi fuses** are a large version of blade fuses and are used to replace fusible links in many vehicles. Maxi fuses are rated up to 80 amperes or more. The amperage rating and corresponding color for maxi fuses include the following:

Amperage Rating	Color
20	Yellow
30	Green
40	Amber
50	Red
60	Blue
70	Brown
80	Natural

Pacific Fuse Element First used in the late 1980s, **Pacific fuse elements** (also called a **fuse link** or **auto link**) are used to protect wiring from a direct short-to-ground. The housing contains a short link of wire sized for the rated current load. The transparent top allows inspection of the link inside. See Figure 35–6.

Testing Fuses It is important to test the condition of a fuse if the circuit being protected by the fuse does not operate. Most blown fuses can be detected quickly because the center conductor is melted. Fuses can also fail and open the circuit because of a poor connection in the fuse itself or in the fuse holder. Therefore, just because a fuse "looks okay" does not mean that it *is* okay. All fuses should be tested with a test light. The test light should be connected first to one side of the fuse and then the other. A test light should light on both sides. If the test light only lights on one side, the fuse is blown or open. If the test light does not light on either side of the fuse, then that circuit is not being supplied power. See Figure 35–7. Use an ohmmeter to test **fusible link cartridges.**

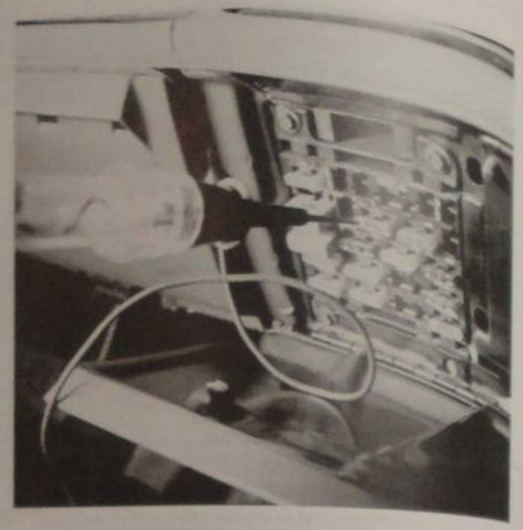


Figure 35–7 To test a fuse, use a test light to check for power at the power side of the fuse. The ignition switch and lights may have to be on before some fuses receive power. If the fuse is good, the test light should light on both sides (power side and load side) of the fuse.

Circuit Breakers **Circuit breakers** are used to prevent harmful overload (excessive current flow) in a circuit by opening the circuit and stopping the current flow to prevent overheating and possible fire caused by hot wires or electrical components. Circuit breakers are mechanical units made of two different metals (bimetallic) that deform when heated and open a set of contact points that work in the same manner as an "off" switch. See Figure 35–8.

Cycling-type circuit breakers, therefore, are reset when the current stops flowing, which causes the bimetallic strip to cool and the circuit to close again. A circuit breaker is used in circuits that could affect the safety of passengers if a conventional nonresetting fuse were used. The headlight circuit is an excellent example of the use of a circuit breaker rather than a fuse. A short or grounded circuit anywhere in the headlight circuit could cause excessive current flow and, therefore, the opening of the circuit. Obviously a sudden loss of headlights at night could have disastrous results. A circuit breaker opens and closes the circuit rapidly, thereby protecting the circuit from overheating and also providing sufficient current flow to maintain at least partial headlight operation.

Circuit breakers are also used in other circuits where conventional fuses cannot provide for the surges of high current commonly found in those circuits. See Figure 35–9 for the electrical symbols used to represent a circuit breaker. Examples are the circuits for the following accessories:

1. Power seats
2. Power door locks
3. Power windows

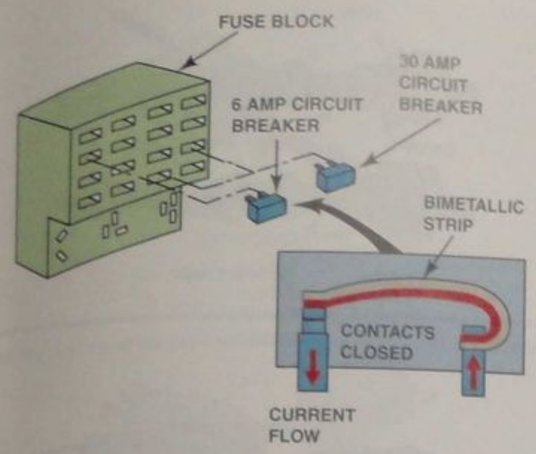


Figure 35–8 Typical blade circuit breaker fits into the same space as a blade fuse. If excessive current flows through the bimetallic strip, the strip bends and opens the contacts and stops current flow. When the circuit breaker cools, the contacts close again, completing the electrical circuit.

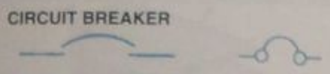


Figure 35–9 These electrical symbols are used to represent circuit breakers.

PTC Circuit Protectors **Positive temperature coefficient (PTC) circuit protectors** are solid state (without moving parts). Like all other circuit protection devices, PTCs are installed in series in the circuit being protected. If excessive current flows, the temperature and resistance of the PTC increase.

This increased resistance reduces current flow (amperes) in the circuit and may cause the electrical component in the circuit to function incorrectly. For example, when a PTC circuit protector is used in a power window circuit, the increased resistance causes the operation of the power window to be much slower than normal.

Unlike circuit breakers or fuses, PTC circuit protection devices do not open the circuit, but rather they provide a very high resistance between the protector and the component. See Figure 35–10. In other words, voltage will be available to the component. This fact has led to a lot of misunderstanding about how these circuit protection devices actually work. It is even more confusing when the circuit is opened and the PTC circuit protector cools down. When the circuit is turned back on, the component may operate normally for a short time; however, the PTC circuit protector will again get hot because of too much current flow. Its resistance again increases to limit current flow.

The electronic control unit (computer) used in most vehicles today incorporates thermal overload protection devices. See Figure 35–11. Therefore, whenever a component fails to operate, do not blame the computer. The current control device is controlling current flow to protect the computer. Components that do not operate correctly should be checked for proper resistance and current draw.

Fusible Links A **fusible link** is a type of fuse that consists of a short length of standard copper-strand wire covered with a special nonflammable insulation. This wire is usually four wire numbers smaller than the wire of the circuits it protects. For example, a 12-gauge circuit is protected by a 16-gauge fusible link. The special thick insulation over the wire may make it look larger than other wires of the same gauge number. See Figure 35–12.

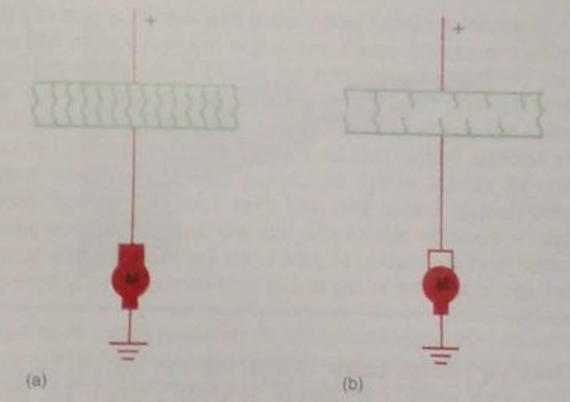


Figure 35–10 (a) Normal operation of a PTC circuit protector in a power window motor circuit. Note the many conducting paths. With normal current flow, the temperature of the PTC circuit protector remains normal. (b) When current exceeds the amperage rating of the PTC circuit protector, the polymer material that makes up the electronic circuit protector increases in resistance. As shown here, a high-resistance electrical path still exists even though the motor will stop operating as a result of the very low current flow through the very high resistance. The circuit protector will not reset or cool down until voltage is removed from the circuit.

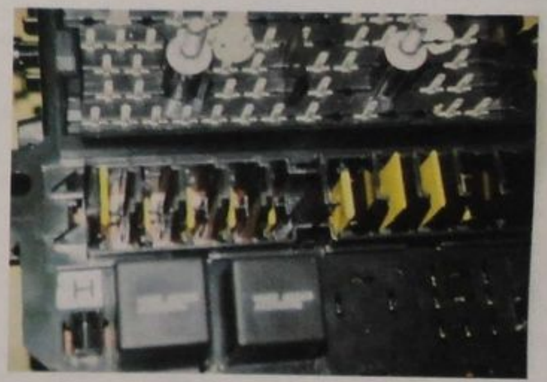


Figure 35–11 PTC circuit protectors are used extensively in the power distribution center of this Chrysler vehicle.

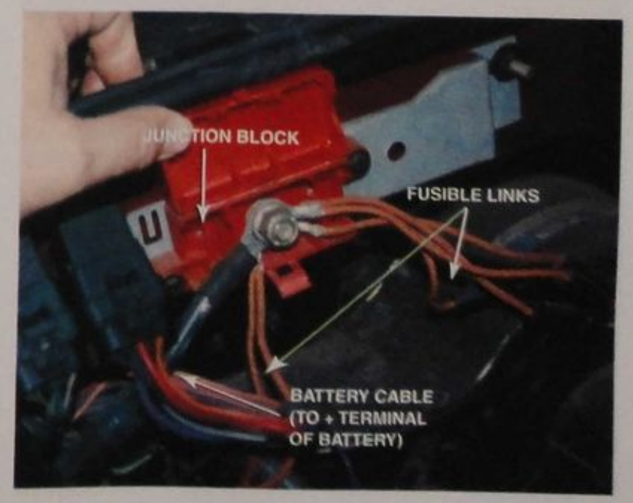


Figure 35–12 Fusible links are usually located close to the battery and are usually attached to a junction block. Notice that they are only 6 to 9 inches long and feed more than one fuse from each fusible link.

If excessive current flow (caused by a short-to-ground or a defective component) occurs, the fusible link will melt in half and open the circuit to prevent a fire hazard. Some fusible links are identified with "fusible link" tags at the junction between the fusible link and the standard chassis wiring, which represent only the junction. Fusible links are the backup system for circuit protection. All current except the current used by the starter motor flows through fusible links and then through individual circuit fuses. It is possible that a fusible link will melt and not blow a fuse. Fusible links are installed as close to the battery as possible so that they can protect the wiring and circuits coming directly from the battery.

Checking Fusible Links Fusible links can melt and not show any external evidence of damage. To check a fusible link, gently pull on each end to see if it stretches. If the insulation stretches, then the wire inside has melted and the fusible link must be replaced after determining what caused the link to fail.

Another way to check a fusible link is to use a test light or a voltmeter and check for available voltage at both ends of the fusible link. If voltage is available at only one end, then the link is electrically open and should be replaced.

TECH TIP ✓ **Look for the "Green Crud"**

Corroded connections are a major cause of intermittent electrical problems and open circuits. The usual sequence of conditions is as follows:

1. Heat causes expansion. This heat can be from external sources such as connectors being too close to the exhaust system. Another possible source of heat is a poor connection at the terminal, causing a voltage drop and heat due to the electrical resistance.
2. Condensation is created when a connector cools. The moisture in the condensation causes rust and corrosion.

The solution is that if corroded connectors are noticed, the terminal should be cleaned and the condition of the electrical connection to the wire terminal end(s) confirmed. Many automobile manufacturers recommend using a dielectric silicone or lithium-based grease inside connectors to prevent moisture from getting into and attacking the connector.

TERMINALS AND CONNECTORS

A **terminal** is a metal fastener attached to the end of a wire, which makes the electrical connection. The term **connector** usually refers to the plastic portion that snaps or connects together, thereby making the mechanical connection. Wire terminal ends usually snap into and are held by a connector. Male and female connectors can then be snapped together, thereby completing an electrical connection. Connectors exposed to the environment are also equipped with a weather-tight seal. See Figure 35–13.

Terminals are retained in connectors by the use of a **lock tang.** Removing a terminal from a connector includes the following steps:

1. Release the **connector position assurance (CPA),** if equipped, that keeps the latch of the connector from releasing accidentally.
2. Separate the male and female connector by opening the lock. See Figure 35–14.

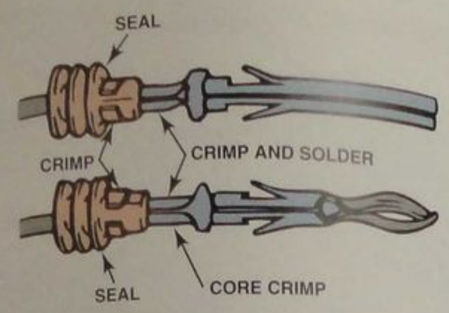


Figure 35–13 Some terminals have seals attached to help seal the electrical connection.

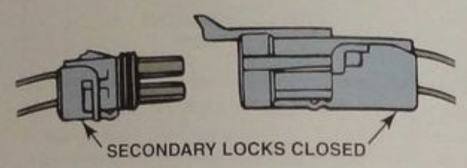


Figure 35–14 Separate a connector by opening the lock and pulling the two apart.

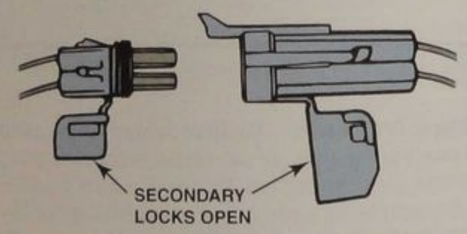


Figure 35–15 The secondary locks help retain the terminals in the connector.

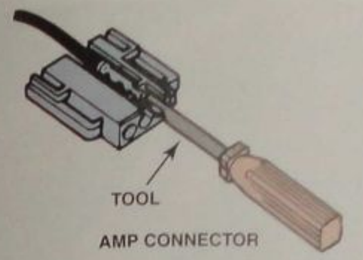
3. Release the secondary lock, if equipped. See Figure 35–15.
4. Using a pick, depress the lock tang and gently remove the terminal from the connector. See Figure 35–16.

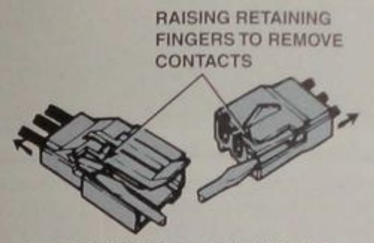
WIRE REPAIR

Many manufacturers recommend that all wiring repairs be soldered.

Solder **Solder** is an alloy of tin and lead used to make a good electrical contact between two wires or connections in an electrical circuit. However, a flux must be used to help clean the area and to help make the solder flow. Therefore, solder is made with a resin (rosin) contained in the center, called **rosin-core solder.** See Figure 35–17. An acid-core solder is also available but should only be used for soldering sheet metal. Solder is available with various percentages of tin and lead in the alloy. Ratios are used to identify these various types of solder, with the first number denoting the percentage of tin in the alloy and the second number giving the percentage of lead. The most commonly used solder is 50/50, which means that 50% of the solder is tin and the other 50% is lead. The percentages of each alloy primarily determine the melting point of the solder.

60/40 solder (60% tin/40% lead) melts at 361°F (183°C).
50/50 solder (50% tin/50% lead) melts at 421°F (216°C).
40/60 solder (40% tin/60% lead) melts at 460°F (238°C).





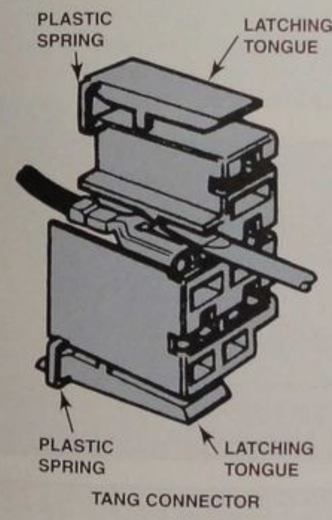


Figure 35–16 Use a small removal tool, sometimes called a pick, to release terminals from the connector.



Figure 35–17 Always use rosin-core solder for electrical or electronic soldering. Also, use small-diameter solder for small soldering irons. Use large-diameter solder only for large-diameter (large-gauge) wire and higher-wattage soldering irons (guns).



Figure 35–18 A butane soldering tool. The cap has a built-in striker to light a converter in the tip of the tool. This handy soldering tool produces the equivalent of 60 watts of heat. It operates for about 1/2 hour on one charge from a commonly available butane refill dispenser.

NOTE: The melting points stated here can vary depending on the purity of the metals used.

Because of the lower melting point, 60/40 solder is the most highly recommended solder to use, followed by 50/50. When soldering wires, be sure to heat the wires (not the solder) using a soldering gun or butane tool such as shown in Figure 35–18. Soldering a wiring splice includes the following steps.

1. While touching the soldering gun to the splice, apply solder to the junction of the gun and the wire.
2. The solder will start to flow. Do not move the soldering gun.
3. As the solder flows into and around the strands of the wire, keep feeding more solder into the splice.
4. After the solder has flowed throughout the splice, remove the soldering gun from the splice and allow the solder to cool slowly.

The solder should have a shiny appearance. Dull-looking solder may be caused by not reaching a high enough temperature, which results in a **cold solder joint.** Reheating the splice and allowing it to cool often restores the shiny appearance.

Crimping Terminals Terminals can be crimped to create a good electrical connection if the proper type of crimping tool is used. Most vehicle manufacturers recommend that a **W-shaped crimp** be used to force the strands of the wire into a tight space. See Figure 35–19.

Most vehicle manufacturers also specify that all hand-crimped terminals or splices be soldered. See Figure 35–20.

Heat Shrink **Heat shrink** tubing is usually made from polyvinyl chloride (PVC) or polyolefin and shrinks to about half of its original diameter when heated; this is usually called a 2:1 shrink ratio. Heat shrink by itself does not provide protection against corrosion, because the ends of the tubing are not sealed against moisture. Chrysler Corporation recommends that all wire repairs that may be exposed to the elements be repaired and sealed using **adhesive-lined** heat shrink tubing. The tubing is usually made from flame-retardant flexible polyolefin with an internal layer of special thermoplastic adhesive. When heated, this tubing shrinks to one-third of its original diameter (3:1 shrink ratio) and the adhesive melts and seals the ends of the tubing. See Figure 35–21.

Crimp-and-Seal Connectors General Motors Corporation and Ford Motor Company recommend the use of **crimp-and-seal connectors** as the method for wire repair. Crimp-and-seal connectors are *not* simply butt connectors. Crimp-and-seal connectors contain a sealant and shrink tubing in one piece. See Figure 35–22.

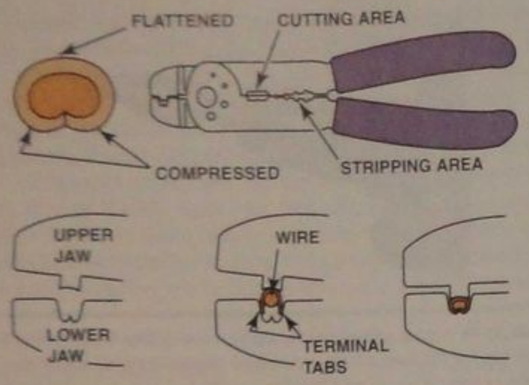


Figure 35–19 Notice that to create a good crimp the open part of the terminal is placed in the jaws of the crimping tool toward the anvil or the W-shape part.

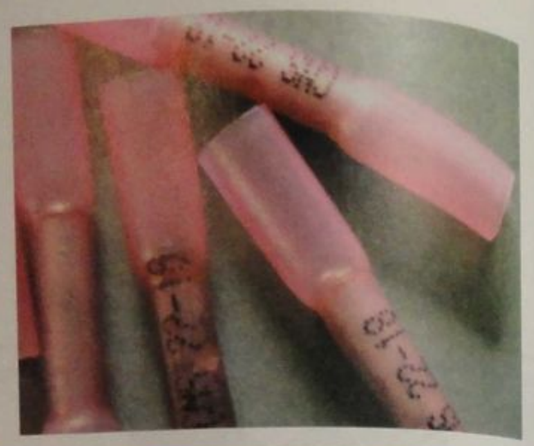


Figure 35–22 A typical crimp-and-seal connector. This type of connector is first lightly crimped to retain the ends of the wires and then it is heated. The tubing shrinks around the wire splice and a thermoplastic glue melts on the inside to provide an effective weather-resistant seal.

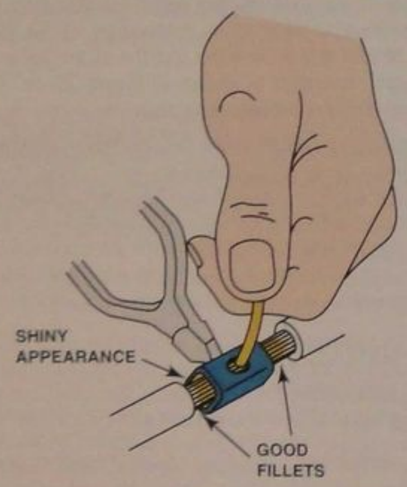


Figure 35–20 All hand-crimped splices or terminals should be soldered to be assured of a good electrical connection. "Good fillets" mean that the solder has started to flow out from around the splice clip and are smooth and shiny.



Figure 35–21 A butane torch especially designed for use on heat shrink applies heat without an open flame, which could cause damage.



Figure 35–23 Heating the crimp-and-seal connector melts the glue and forms an effective seal against moisture.

The usual procedure specified for making a wire repair using a crimp-and-seal connector is as follows:

Step #1 Strip the insulation from the ends of the wire (about 5/16 inch, or 8 millimeters).

Step #2 Select the proper size of crimp-and-seal connector for the gauge of wire being repaired. Insert the wires into the splice sleeve and crimp.

Step #3 Apply heat to the connector until the sleeve shrinks down around the wire and a small amount of sealant is observed around the ends of the sleeve, as shown in Figure 35–23.

Aluminum Wire Repair Many automobile manufacturers use plastic-coated solid aluminum wire for some body wiring. Because aluminum wire is brittle and can break as a result of vibration, it is only used where there is no possible movement of the wire, such as along the floor or sill area. This section of wire is stationary, and the wire changes back to copper at a junction terminal after the trunk or rear section of the vehicle, where movement of the wiring may be possible.

If any aluminum wire must be repaired or replaced, the following procedure should be used to be assured of a proper repair. This aluminum wire is usually found protected in a plastic conduit. The conduit is then normally slit, after which the wires can easily be removed for repair.

Step #1 Carefully strip only about 1/4 inch (6 millimeters) of insulation from the aluminum wire, being careful not to nick or damage the aluminum wire case.

Step #2 Use a crimp connector to join two wires together. Do *not* solder an aluminum wire repair. Solder will not readily adhere to aluminum because the heat causes an oxide coating on the surface of the aluminum.

Step #3 To prevent corrosion, the spliced, crimped connection must be coated with petroleum jelly.

Step #4 The coated connection should be covered with shrinkable plastic tubing or wrapped with electrical tape to seal out moisture.

FREQUENTLY ASKED QUESTION ???

What Does the Stripe on the Plastic Conduit Mean?

Most electrical wiring is protected with a plastic convoluted conduit, which comes in many different grades depending on the temperature of the surrounding area. A painted stripe usually indicates that the conduit is designed for high-temperature applications and is used where it would be placed on or near the engine. See Figure 35–24.

Do not use inexpensive conduit around wiring that will be exposed to temperatures higher than 200°F (85°C).



Figure 35–24 The color stripe on the side of the convoluted conduit indicates that the conduit is designed for high-temperature applications.

SUMMARY

1. The higher the AWG size number, the smaller the wire.
2. Metric wire is sized in square millimeters (mm^2) and the higher the number, the larger the wire.
3. All circuits should be protected by a fuse. The current in the circuit should be about 80% of the fuse rating.
4. Circuit breakers and fusible links are other circuit protection devices.
5. A terminal is the metal end of a wire, whereas a connector is the plastic housing for the terminal.
6. All wire repair should use either soldering or a crimp-and-seal connector.

REVIEW QUESTIONS

1. Describe the American wire gauge (AWG) system and compare it with the metric system.
2. Explain the difference between a wire and a cable.
3. Explain the difference between a terminal and a connector.
4. Discuss how fuses, PTC circuit protectors, circuit breakers, and fusible links protect a circuit.
5. Describe how to perform a wire repair.

CHAPTER QUIZ

1. The higher the AWG number, _____.
   a. The smaller the wire
   b. The larger the wire
   c. The thicker the insulation
   d. The more strands in the conductor core
2. Metric wire size is measured in units of _____.
   a. Meters
   b. Cubic centimeters
   c. Square millimeters
   d. Cubic millimeters
3. Which statement is true about fuse ratings?
   a. The fuse rating should be 80% of the maximum current for the circuit.
   b. The fuse rating should be higher than the normal current for the circuit.
   c. Eighty percent of the fuse rating should equal the current in the circuit.
   d. Both b and c.
4. Which statements are true about wire, terminals, and connectors?
   a. Wire is called a lead, and the metal end is a connector.
   b. A connector is usually a plastic piece where terminals lock in.
   c. A lead and a terminal are the same thing.
   d. Both a and c.
5. The type of solder that should be used for electrical work is _____.
   a. Rosin core
   b. Acid core
   c. 60/40 with no flux
   d. 50/50 with acid paste flux
6. A technician is performing a wire repair on a circuit that uses 18-gauge wire. The parts department does not have 18-gauge wire, but it does have 16-gauge wire and 20-gauge wire. Technician A says to use the 16-gauge wire. Technician B says to use the 20-gauge wire. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Two technicians are discussing fuse testing. Technician A says that a test light should light on both test points of the fuse if it is okay. Technician B says the fuse is defective if a test light only lights on one side of the fuse. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. If a wire repair, such as repairs made under the hood or under the vehicle, is exposed to the elements, which type of repair should be used?
   a. Wire nuts and electrical tape
   b. Solder and adhesive-lined heat shrink or crimp-and-seal connectors
   c. Butt connectors
   d. Rosin-core solder and electrical tape
9. Many ground straps are uninsulated and braided because _____.
   a. They are more flexible to allow movement of the engine without breaking the wire
   b. They are less expensive than conventional wire
   c. They help dampen radio-frequency interference (RFI)
   d. Both a and c.
10. What causes a fuse to blow?
    a. A decrease in circuit resistance
    b. An increase in the current flow through the circuit
    c. A sudden decrease in current flow through the circuit
    d. Both a and b.

CHAPTER 36

Wiring Schematics and Troubleshooting

OBJECTIVES: After studying Chapter 36, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A " (General Electrical/Electronics System Diagnosis). • Draw the symbols used on schematics. • Discuss the various methods that can be used to locate a short circuit. • List the electrical troubleshooting diagnosis steps.

KEY TERMS: double-pole, double-throw switch (DPDT) • double-pole, single-throw switch (DPST) • gauss gauge • momentary switch • normally closed (N.C.) • normally open (N.O.) • poles • relay • short circuit • single-pole, double-throw switch (SPDT) • single-pole, single-throw switch (SPST) • terminal • throws • tone generator tester • wiring schematic

WIRING SCHEMATICS

Automotive manufacturers' service manuals include wiring schematics of all the electrical circuits of a vehicle. A **wiring schematic,** sometimes called a diagram, shows electrical components and wiring using symbols and lines to represent components and wires. A typical wiring schematic may include all of the circuits combined on several large fold-out sheets, or they may be broken down to show individual circuits. All circuit schematics or diagrams include the power-side wiring of the circuit and all splices, connectors, electrical components, and ground return paths. The gauge and color of the wiring are also included on most wiring diagrams.

Circuit Information Many wiring schematics include numbers and letters near components and wires that may confuse readers of the schematic. Most letters used near or on a wire identify the color or colors of the wire. The first color or color abbreviation is the color of the wire insulation, and the second color (if mentioned) is the color of the strip or tracer on the base color. See Figure 36–1.

Wires with different-color tracers are indicated by both colors with a slash (/) between them. For example, BRN/WHT means a brown wire with a white stripe or tracer.

Abbreviation	Color
BRN	Brown
BLK	Black
GRN	Green
WHT	White
PPL	Purple
PNK	Pink
TAN	Tan
BLU	Blue
YEL	Yellow
ORN	Orange
DK BLU	Dark blue
LT BLU	Light blue
DK GRN	Dark green
LT GRN	Light green
RED	Red
GRY	Gray

Figure 36–2 illustrates a rear side-marker bulb circuit diagram where ".8" indicates the metric wire gauge size in square millimeters (mm^2) and "PPL" indicates a solid purple wire.



Figure 36–1 The center wire is a solid color wire, meaning that the wire has no other identifying tracer or stripe color. The two end wires could be labeled "BRN/WHT," indicating brown wire with a white tracer or stripe.

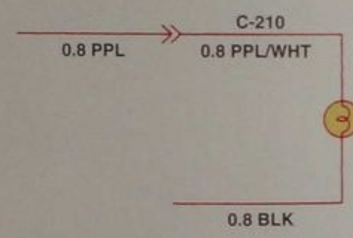


Figure 36–2 Typical section of a wiring diagram. Notice that the wire color changes at connection C210. The ".8" represents the metric wire size in square millimeters.

The wire diagram also shows that the color of the wire changes at the number C210. This stands for "connector #210" and is used for reference purposes. The symbol for the connection can vary depending on the manufacturer. The color changes from purple (PPL) to purple with a white tracer (PPL/WHT) not important except for knowing where the wire changes color in the circuit. The wire gauge has remained the same on both sides of the connection (0.8 square millimeters or 18-gauge). The ground circuit is the ".8 BLK" wire. Figure 36–3 shows electrical and electronic symbols that are used in wiring and circuit diagrams.

TECH TIP ✔ **Read the Arrows**

Wiring diagrams indicate connections by symbols that look like arrows. See Figure 36–4.

Do *not* read these "arrows " as pointers showing the direction of current flow. Also observe that the power side (positive side) of the circuit is usually the female end of the connector. If a connector becomes disconnected, it will be difficult for the circuit to become shorted to ground or to another circuit because the wire is recessed inside the connector.

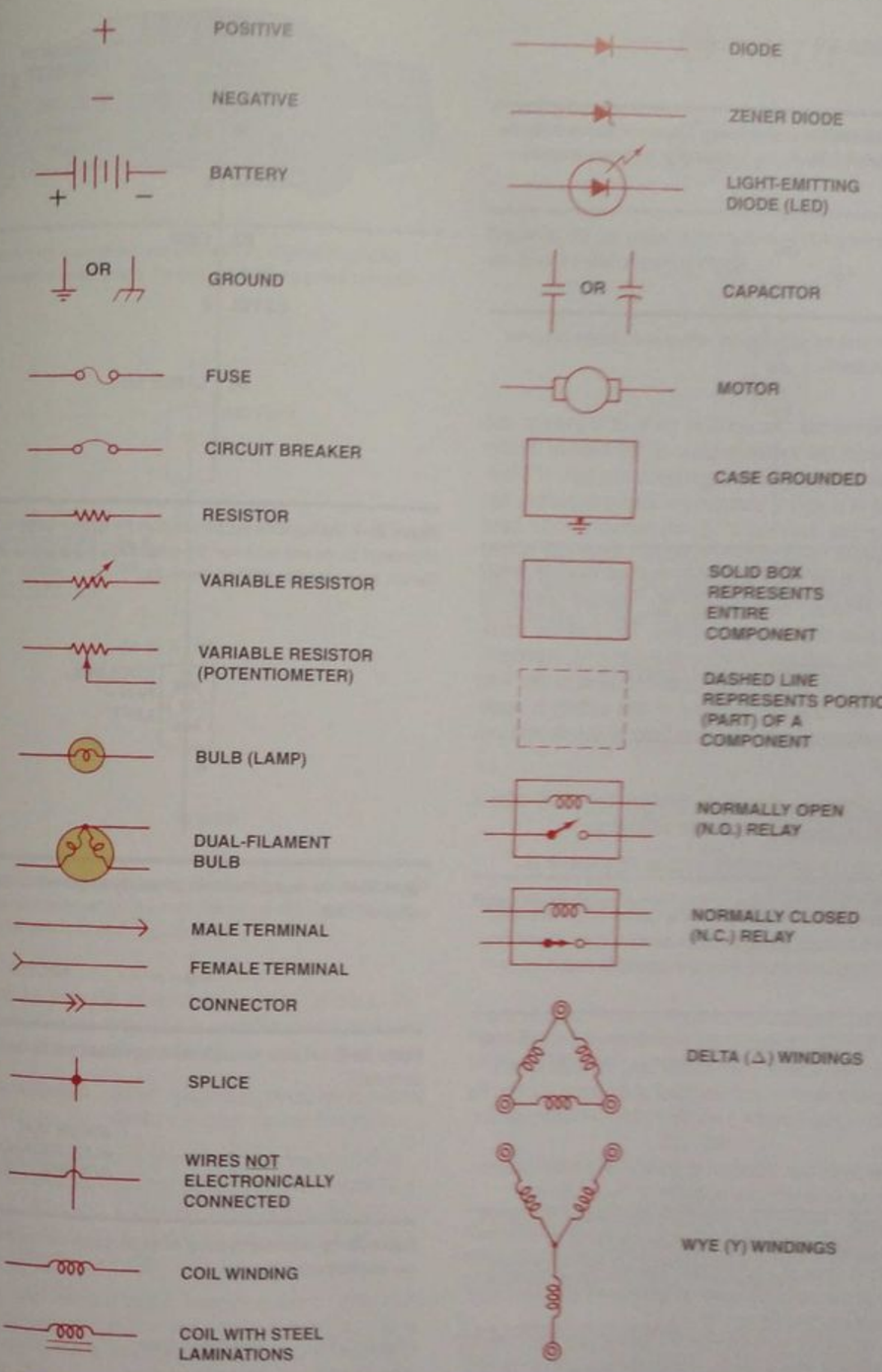


Figure 36–3 This figure shows typical electrical and electronic symbols used in automotive wiring and circuit diagrams.

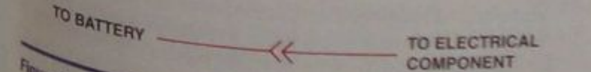


Figure 36–4 In this typical connector, note that the positive terminal is usually a female connector.

SCHEMATIC SYMBOLS

In a schematic drawing, photos, or line drawings of actual components are replaced with a symbol that represents the actual component. The symbols and their meanings include:

Battery The plates of a battery are represented by long and short lines. See Figure 36–5.

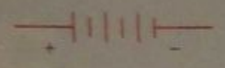


Figure 36–5 The symbol for a battery. The positive plate of a battery is represented by the longer line and the negative plate by the shorter line. The voltage of the battery is usually stated next to the symbol.

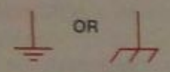


Figure 36–6 The ground symbol on the left represents earth ground. The ground symbol on the right represents a chassis ground.

The longer line represents the positive plate of a battery and the shorter line represents the negative plate of the battery. Therefore, each pair of short and long lines represents one cell of a battery. Because each cell of a typical automotive lead-acid battery has 2.1 volts, a battery symbol showing a 12-volt battery should have six pairs of lines. However, most battery symbols simply use two or three pairs of long and short lines and then list the voltage of the battery next to the symbol. As a result, the battery symbol is shorter, yet clear because the voltage is stated. The positive terminal of the battery is often indicated with a plus sign (+), representing the positive post of the battery, and is placed next to the long line of the end cell. The negative terminal of the battery is represented by a negative sign (–) and is placed next to the shorter cell line. See Figure 36–6.

Wiring Electrical wiring is shown as straight lines and with a few numbers and/or letters to indicate the following:

- **Wire size**—This can be either AWG, such as 18 gauge or in square millimeters, such as 0.8.
- **Circuit numbers**—Each wire in part of a circuit is labeled with the circuit number to help the service technician trace the wiring and allows for an explanation of how the circuit is supposed to work.
- **Wire color**—Most schematics also indicate an abbreviation for the color of the wire and place it next to the wire. Many wires have two colors: a solid color and a stripe color. In this case, the solid color is listed, and then a dark slash (/) and the color of the stripe is listed. For example, red/wht would indicate a red wire with a white tracer. See Figure 36–7.
- **Terminals**—The metal part attached at the end of a wire is called a **terminal.** A symbol for a terminal is shown in Figure 36–8.
- **Wire connections**—When two wires are electrically connected, the junction is shown with a black dot. See Figure 36–9.

  When two wires cross in a schematic that are not electrically connected, one of the wires is shown as going over the other wire and does not connect. See Figure 36–10.
- **Connectors**—An electrical connector is a plastic part that contains one or more terminals. While the terminals provide the electrical connection in a circuit, it is the plastic connector that keeps the terminals together mechanically. Connections are usually labeled with a "C" and then three numbers. The three numbers indicate the general location of the connector. Normally, the connector number represents the general area of the vehicle including:

100 to 199	Under the hood
200 to 299	Under the dash
300 to 399	Passenger compartment
400 to 499	Rear package or trunk area

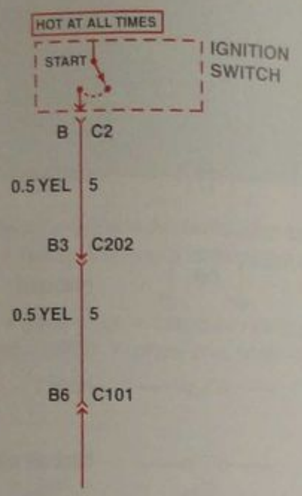


Figure 36–7 Starting at the top, the wire from the ignition switch is attached to terminal B of connector C2, the wire is 0.5 mm² (20-gauge AWG) and is yellow. The circuit marker is 5. The wire enters connector C202 at terminal B3.

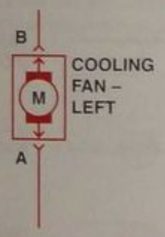


Figure 36–8 The electrical terminals are usually labeled with a letter, as shown on this cooling fan motor.

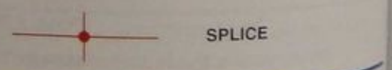


Figure 36–9 Two wires that cross at the dot indicate that the two are electrically connected.

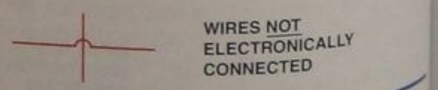


Figure 36–10 Wires that cross, but do not electrically contact each other, are shown with one wire bridging over the other.

500 to 599	Left-front door
600 to 699	Right-front door
700 to 799	Left-rear door
800 to 899	Right-rear door

Even-numbered connectors are on the right (passenger side) of the vehicle and odd-numbered connectors are on the left (driver's side) of the vehicle. For example, C-102 is a connector located under the hood (between 100 and 199) on the right side of the vehicle (even number 102). See Figure 36–11.

- **Grounds and Splices**—Grounds and splices are also labeled using the same general format as connectors. Therefore, a ground located under the dash on the driver's side could be labeled G-201 (G means ground). A splice indication is an "S" followed by three numbers, such as S-301. See Figure 36–12.

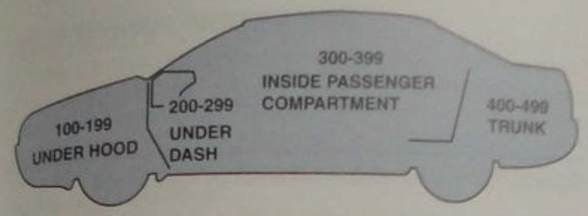


Figure 36–11 Connectors (C), grounds (G), and splices (S) are followed by a number, generally indicating the location in the vehicle. For example, G209 is a ground connection located under the dash.

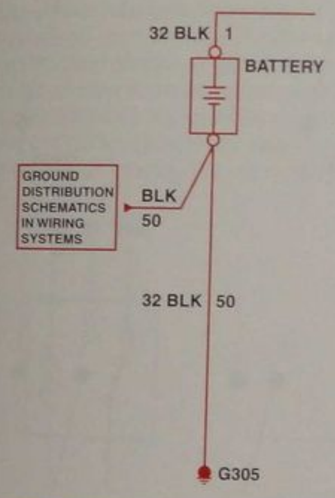


Figure 36–12 The ground for the battery is labeled G305 indicating the ground connector is located in the passenger compartment of the vehicle. The ground wire is black (BLK), the circuit number is 50, and the wire is 32 mm² (2-gauge AWG).

Electrical Components Most electrical components have their own unique symbol that shows the basic function or parts.

- **Bulbs**—Light bulbs usually use a filament, which heats and then gives off light when electrical current flows. The symbol used for a light bulb shows a circle with a filament inside. A dual-filament bulb, such as is used for taillights and brake light/turn signals, is shown with two filaments. See Figure 36–13.

Electric Motors An electric motor symbol shows a circle with the letter "M" in the center and two electrical connections, one to the top and one at the bottom. See Figure 36–14 for an example of a cooling fan motor.

Resistors While resistors are usually part of another component, the symbol does appear on many schematics and wiring diagrams. A resistor symbol is a jagged line representing resistance to current flow. If the resistor is variable, such as a Thermistor, an arrow is shown running through the symbol of a fixed resistor. A potentiometer is a three-wire variable resistor and it is shown with an arrow pointing toward the resistance part of a fixed resistor. See Figure 36–15.

A two-wire rheostat is usually shown as part of another unit, such as a fuel level sending unit. See Figure 36–16.

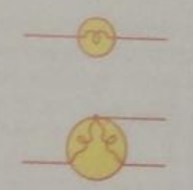


Figure 36–13 The symbol for light bulbs shows the filament inside a circle, which represents the glass ampoule of the bulb.



Figure 36–14 An electric motor symbol shows a circle with the letter "M" in the center and two black sections that represent the brushes of the motor. This symbol is used even though the motor is a cross-flow design.

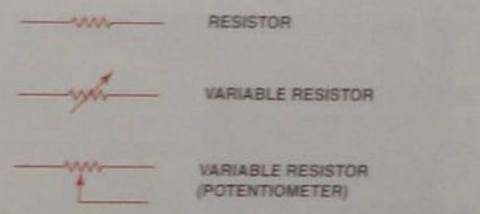


Figure 36–15 Resistor symbols vary depending on the type of resistor.

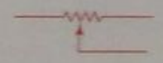


Figure 36–16 A rheostat uses just two wires—one is connected to a voltage source and the other is attached to the movable arm.

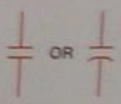


Figure 36–17 Symbols used to represent capacitors. If one of the lines is curved, this indicates that the capacitor being used has a polarity, while the one without a curved line can be installed in the circuit without concern about polarity.

Capacitors Capacitors are usually part of an electronic component and not a replaceable component unless the vehicle is an older model. Many older vehicles used capacitors to reduce radio interference and were installed inside alternators or attached to wiring connectors. See Figure 36–17.

Electric Heated Unit Electric grid-type rear window defoggers and cigarette lighters are shown with a square box-type symbol. See Figure 36–18.

Boxed Components If a component is shown in a box using a solid line, the box is the entire component. If a box uses dashed lines, it represents a part of a component. A commonly used dashed-line

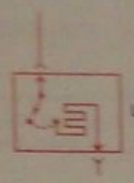


Figure 36–18 The grid-like symbol represents an electrically heated element.

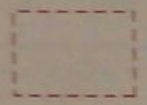


Figure 36–19 A dashed outline represents a portion (part) of a component.

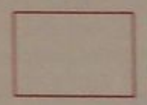


Figure 36–20 A solid box represents an entire component.

box is a fuse panel. Often, just one or two fuses are shown in a dashed-line box. This means that a fuse panel has more fuses than shown. See Figures 36–19 and 36–20.

Separate Replaceable Part Often components are shown on a schematic that cannot be replaced but rather are part of a complete assembly. When looking at a schematic of General Motors vehicles, the following is shown:

- If a part name is underlined, it is a replaceable part.
- If a part is not underlined, it is not available as a replaceable part, but is rather included with other components shown and sold as an assembly.
- If the case itself is grounded, the ground symbol is attached to the component as shown in Figure 36–21.

Switches Electrical switches are drawn on a wiring diagram in their normal position. This can be one of two possible positions.

- **Normally open.** The switch is not connected to a terminal and no current flows in this position. This type of switch is labeled **N.O.**
- **Normally closed.** The switch is electrically connected to a contact and current will flow through the switch. This type of switch is labeled **N.C.**

Other switches can use more than two contacts.

The **poles** refer to the number of circuits completed by the switch and the **throws** refer to the number of output circuits. A **single-pole, single-throw (SPST)** switch has only two positions—on or off. A **single-pole, double-throw (SPDT)** switch has three terminals—one wire in and two wires out. A headlight dimmer switch is an example of a typical SPDT switch. In one position, the current flows to the low-filament headlight; in the other, the current flows to the high-filament headlight. There are also **double-pole, single-throw (DPST)** switches and **double-pole, double-throw (DPDT)** switches. See Figure 36–22.

NOTE: All switches are shown on schematics in their normal position. This means that the headlight switch will be shown normally off, as are most other switches and controls.



Figure 36–21 This symbol represents a component that is case grounded.

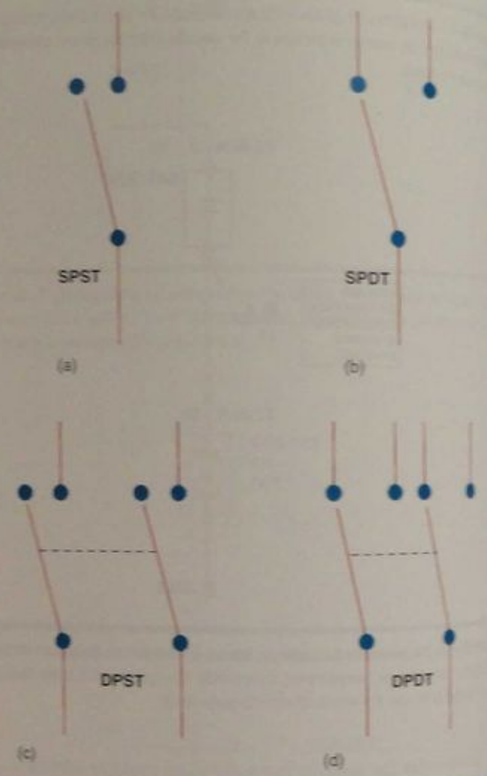


Figure 36–22 (a) A symbol for a single-pole, single-throw (SPST) switch. This type of switch is normally open (N.O.) because nothing is connected to the terminal that the switch is contacting in its normal position. (b) A single-pole, double-throw (SPDT) switch has three terminals. (c) A double-pole, single-throw (DPST) switch has two positions (off and on) and can control two separate circuits. (d) A double-pole, double-throw (DPDT) switch has six terminals—three for each pole. Note: "c" and "d" also show a dotted line between the two arms indicating that they are mechanically connected.

Another type of switch that is used on most vehicles is called a **momentary switch.** This switch is usually used to send a voltage signal to a module or controller to request that a device be turned on or off. The switch just makes momentary contact and returns to the open position. The symbol that represents a momentary switch uses two dots for the contact with a switch above them (⊥). A momentary switch, for example, can be used to lock or unlock a door or to turn the air conditioning on or off. If the device is currently operating, the signal from the momentary switch will turn it off, and if it is off, the switch will signal the module to turn it on. The major advantage of momentary switches is that they can be very lightweight and small because the switch does not carry any heavy electrical current, just a small voltage signal. Most momentary switches use a membrane constructed of foil or plastic.

RELAY TERMINAL IDENTIFICATION

A **relay** is a magnetic switch that uses a movable armature to control a heavy electrical load by using a low-amperage electrical switch. Most automotive relays adhere to common terminal identification. Knowing this terminal information will help in the correct diagnosis and troubleshooting of any circuit containing a relay. See Figures 36–23 and 36–24.

Relays are found in many circuits because they are capable of being controlled by computers, yet are able to handle enough current to power motors and accessories. Most relays use four or five terminals as follows:

- A coil that provides the magnetic pull to a movable armature (arm). The resistance of most relay coils ranges from 50 to 150 ohms, but is usually between 60 and 100 ohms. The International Standard Organization (ISO) identification of the coil terminals are 86 and 85. The terminal number 86 represents the power to the relay coil and the terminal labeled 85 represents the ground side of the relay coil. The relay coil can be controlled by supplying either power or ground to the relay coil winding. The coil winding represents the control circuit which uses low current to control the higher current through the other terminals of the relay. See Figure 36–25.
- The higher amperage current flow through a relay flows through terminals 30 and 87 and often 87a. Terminal 30 is usually where power is applied to a relay. When the relay is at rest without power and ground to the coil, the armature inside the relay electrically connects terminals 30 and 87a if the relay has five terminals. When there is power at terminal 86 and a ground at terminal 85 of the relay, a magnetic field is created in the coil winding, which draws the armature of the relay toward the coil. The armature, when energized electrically, connects terminals 30 and 87. The maximum current through the relay is determined by the resistance of the circuit and relays are designed to safely handle the designed current flow. See Figures 36–26 and 36–27.

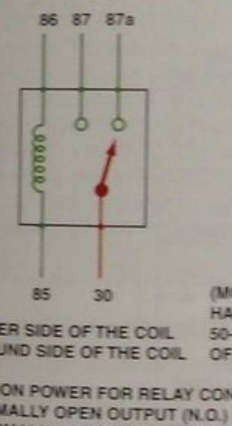


Figure 36–23 A relay uses a movable arm to complete a circuit whenever there is a power at terminal 86 and a ground at terminal 85. A typical relay only requires about 1/10 ampere through the relay coil. The movable arm then closes the contacts (#30 to #87) and can relay 30 amperes or more.

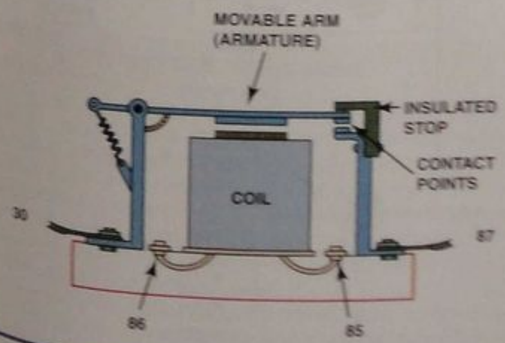


Figure 36–24 A cross-sectional view of a typical four-terminal relay. Current flowing through the coil (terminals 86 and 85) causes the movable arm (called the armature) to be drawn toward the coil magnet. The contact points complete the electrical circuit connected to terminals 30 and 87.

Relay Voltage Spike Control Relays contain a coil and whenever power is removed, the magnetic field surrounding the coil collapses, creating a voltage to be induced in the coil winding. This induced voltage can be as high as 100 volts or more and can cause problems with other electronic devices in the vehicle. For example, the short high-voltage surge can be heard as a "pop" in the radio. To reduce the induced voltage, some relays contain a



Figure 36–25 A typical relay showing the schematic of the wiring in the relay. Terminals #30 and #87 are electrically connected when the relay is energized.

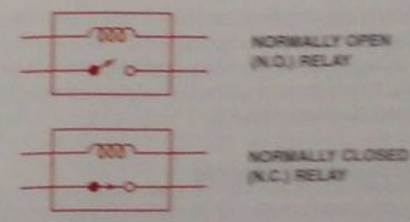


Figure 36–26 All schematics are shown in their normal, nonenergized position.

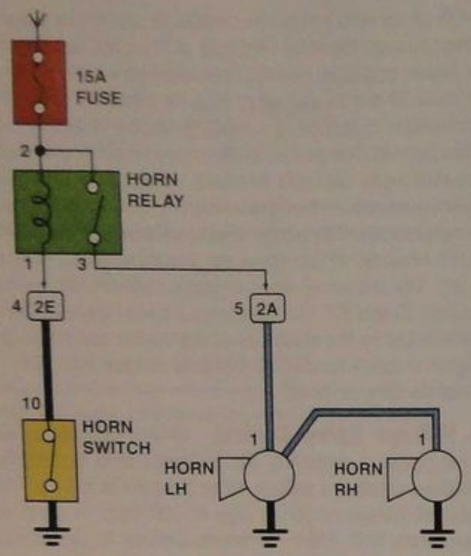


Figure 36–27 A typical horn circuit. Note that the relay contacts supply the heavy current to operate the horn when the horn switch simply completes a low current circuit to ground, causing the relay contacts to close.

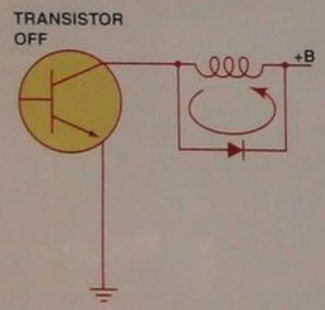


Figure 36–28 When the relay or solenoid coil current is turned off, the stored energy in the coil forward biases the clamping diode and effectively reduces voltage spike.

diode connected across the coil in the reverse bias direction. See Figure 36–28.

When the current flows through the coil, the diode is not part of the circuit because it is installed to block current. However, when the voltage is removed from the coil, the resulting voltage induced in the coil windings has a reversed polarity to the applied voltage. Therefore, the voltage in the coil is applied to the coil in a forward bias direction, which conducts the current back into the winding. As a result, the induced voltage spike is eliminated.

Most relays use a resistor connected in parallel with the coil winding. The use of a resistor, typically about 400 to 600 ohms, reduces the voltage spike by providing a path for the voltage created in the coil to flow back through the coil windings when the coil circuit is opened. See Figure 36–29.

COMMON POWER OR GROUND

Whenever diagnosing an electrical problem that affects more than one component or system, check the electrical schematic for a common power source or a common ground. See Figure 36–30 for an example where all of the following lights are powered by one fuse (power source).

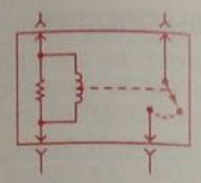


Figure 36–29 A resistor used in parallel with the coil windings is a commonly used spike reduction method used in many relays.

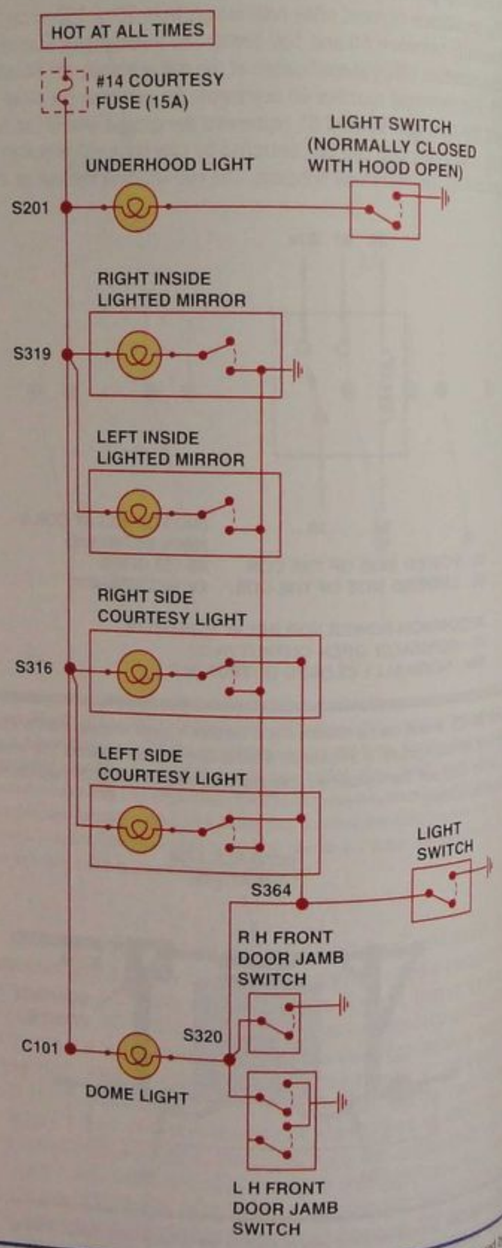


Figure 36–30 A typical wiring diagram showing multiple switches and bulbs powered by one fuse.

- Under-hood light
- Inside lighted mirrors
- Dome light
- Left-side courtesy light
- Right-side courtesy light

Therefore, if there were a customer complaint involving one or more of the items listed, check the fuse and the common part of the circuit that feeds all of the affected lights. Check for a common ground if several components that seem unrelated are not functioning correctly.

REAL WORLD FIX — **Check Everything**

Often, a customer will notice just one fault while other lights or systems may not be working correctly. For example, a customer noticed that the electric mirrors stopped working. The service technician checked all electrical components in the vehicle and discovered that the interior lights were also not working.

The interior lights were not mentioned by the customer as being a problem most likely due to the fact that the driver only used the vehicle in daylight hours.

The service technician found the interior light and power accessory fuse blown. Replacing the fuse restored the proper operation of the electric outside mirror and the interior lights. However, what caused the fuse to blow? A visual inspection of the dome light, next to the electric sunroof, showed an area where a wire was bare. Evidence was seen where the bare wire had touched the metal roof, which could cause the fuse to blow. The technician covered the bare wire with a section of vacuum hose and then taped the hose with electrical tape to complete the repair.

USING SCHEMATICS FOR TROUBLESHOOTING

Follow these steps when troubleshooting wiring problems.

Step #1 Verify the malfunction. If, for example, the backup lights do not operate, make certain that the ignition is on (key on, engine off), with the gear selector in reverse, and check for operation of the backup lights.

Step #2 Check everything else that does or does not operate correctly. For example, if the taillights are also failing to operate, the problem could be a loose or broken ground connection in the trunk area that is shared by both the backup lights and the taillights.

TECH TIP — **Do It Right—Install a Relay**

Often the owners of vehicles, especially owners of pickup trucks and sport utility vehicles (SUVs), want to add additional electrical accessories or lighting. It is tempting in these cases to simply splice into an existing circuit. However, whenever another circuit or component is added, the current that flows through the newly added component is also added to the current for the original component. This additional current can easily overload the fuse and wiring. Do not simply install a larger-amperage fuse; the wire gauge size was not engineered for the additional current and could overheat.

The solution is to install a relay, which uses a small coil to create a magnetic field that causes a movable arm to switch on a higher-current circuit. The typical relay has from 50 to 150 ohms (usually 60 to 100 ohms) of resistance and requires just 0.24 to 0.08 ampere when connected to a 12-volt source. This small additional current will not be enough to overload the existing circuit. See Figure 36–31 for an example of how additional lighting can be added.

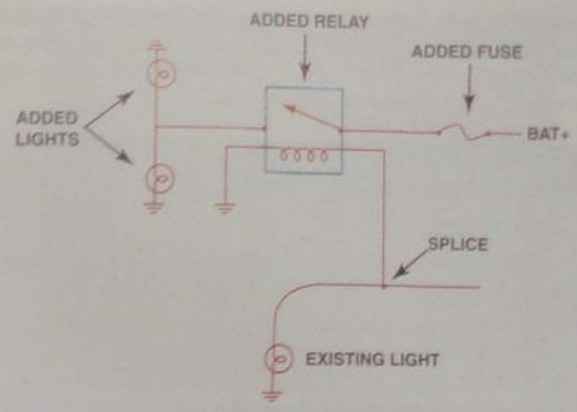


Figure 36–31 To add additional lighting, simply tap into an existing light wire and connect a relay. Whenever the existing light is turned on, the coil of the relay is energized. The arm of the relay then connects power from another circuit (fuse) to the auxiliary lights without overloading the existing light circuit.



Figure 36–32 Always check the simple things first. Check the fuse for the circuit you are testing. Maybe a fault in another circuit controlled by the same fuse could have caused the fuse to blow. Use a test light to check that both sides of the fuse have voltage.

Step #3 Check the fuse for the backup lights. See Figure 36–32.

Step #4 Check for voltage at the backup light socket. This can be done using a test light or a voltmeter.

If voltage is available at the socket, the problem is either a defective bulb or a poor ground at the socket or a ground wire connection to the body or frame. If no voltage is available at the socket, consult a wiring diagram for the type of vehicle being tested. The wiring diagram should show all of the wiring and components included in the circuit. For example, the backup light current must flow through the fuse and ignition switch to the gear selector switch before traveling to the rear backup light socket. As stated in the second step, the fuse used for the backup lights may also be used for other vehicle circuits.

The wiring diagram can be used to determine all other components that share the same fuse. If the fuse is blown (open circuit),

the cause can be a short in any of the circuits sharing the same fuse. Because the backup light circuit current must be switched on and off by the gear selector switch, an open in the switch can also prevent the backup lights from functioning.

FREQUENTLY ASKED QUESTION ???

Where to Start?

The common question is, where does a technician start the troubleshooting when using a wiring diagram (schematic)?

Hint 1 If the circuit contains a relay, start your diagnosis at the relay. The entire circuit can be tested at the terminals of the relay.

Hint 2 The easiest first step is to locate the unit on the schematic that is not working at all or not working correctly.

a. Trace where the unit gets its ground connection.

b. Trace where the unit gets its power connection.

Often a ground is used by more than one component. Therefore, ensure that everything else is working correctly. If not, then the fault may lie at the common ground (or power) connection.

Hint 3 Divide the circuit in half by locating a connector or a part of the circuit that can be accessed easily. Then check for power and ground at this midpoint. This step could save you much time.

LOCATING A SHORT CIRCUIT

A short circuit usually blows a fuse, and a replacement fuse often also blows in the attempt to locate the source of the short circuit. A **short circuit** is an electrical connection to another wire or to ground before the current flows through some or all of the resistance in the circuit. A short-to-ground will always blow a fuse and usually involves a wire on the power side of the circuit coming in contact with metal. Therefore, a thorough visual inspection should be performed around areas involving heat or movement, especially if there is evidence of a previous collision or previous repair that may not have been properly completed.

A short-to-voltage may or may not cause the fuse to blow and usually affects another circuit. Look for areas of heat or movement where two power wires could come in contact with each other. Several methods can be used to locate the short.

Fuse Replacement Method Disconnect one component at a time and then replace the fuse. If the new fuse blows, continue the process until the location of the short is determined. This method uses many fuses and is *not* a preferred method for finding a short circuit.

Circuit Breaker Method Another method is to connect an automotive circuit breaker to the contacts of the fuse holder with alligator clips. Circuit breakers are available that plug directly into the fuse panel, replacing a blade-type fuse. The circuit breaker will alternately open and close the circuit, protecting the wiring from possible overheating damage while still providing current flow through the circuit.

NOTE: A heavy-duty (HD) flasher can also be used in place of a circuit breaker to open and close the circuit. Wires and terminals must be made to connect the flasher unit where the fuse normally plugs in.

All components included in the defective circuit should be disconnected one at a time until the circuit breaker stops clicking. The unit that was disconnected and stopped the circuit breaker clicking is the unit causing the short circuit. If the circuit breaker continues to click with all circuit components unplugged, the problem is in the wiring *from* the fuse panel *to* any one of the units in the circuit. Visual inspection of all the wiring or further disconnecting will be necessary to locate the problem.

Test Light Method To use this method, simply remove the blown fuse and connect a test light to the terminals of the fuse holder (polarity does not matter). If there is a short circuit, current will flow from the power side of the fuse holder through the test light and to ground through the short circuit and the test light will then light. Unplug the connectors or components protected by the fuse until the test light goes out. The circuit that was disconnected, which caused the test light to go out, is the circuit that is shorted.

Ohmmeter Method The fourth method uses an ohmmeter connected to the fuse holder and ground. This is the recommended method of finding a short circuit, as an ohmmeter will indicate low ohms when connected to a short circuit. However, an ohmmeter should never be connected to an operating circuit. The correct procedure for locating a short using an ohmmeter is as follows:

1. Connect one lead of an ohmmeter (set to a low scale) to a good clean metal ground and the other lead to the *circuit side* of the fuse holder.

CAUTION: Connecting the lead to the power side of the fuse holder will cause current to flow through and damage to the ohmmeter.

2. The ohmmeter will read zero or almost zero ohms if the circuit is shorted.
3. Disconnect one component in the circuit at a time and watch the ohmmeter. If the ohmmeter reading goes to high ohms or infinity, the component just unplugged was the source of the short circuit.

NOTE: Some meters, such as the Fluke 189, can be set to beep (alert) when the circuit closes or when the circuit opens. This is a very useful feature.

Gauss Gauge Method If a short circuit blows a fuse, a special pulsing circuit breaker (similar to a flasher unit) can be installed in the circuit in place of the fuse. Current will flow through the circuit until the circuit breaker opens the circuit. As soon as the circuit breaker opens the circuit, it closes again. This on-and-off current flow creates a pulsing magnetic field around the wire carrying the current. A **Gauss gauge** is a handheld meter that responds to weak magnetic fields. It is used to observe this pulsing magnetic field, which is indicated on the gauge as needle movement. This pulsing magnetic field will register on the Gauss gauge even through the metal body of the vehicle. A needle-type compass can also be used to observe the pulsing magnetic field. See Figures 36–33 and 36–34.

Electronic Tone Generator Tester An electronic tone generator tester can be used to locate a short-to-ground or an open circuit. Similar to test equipment used to test telephone and cable television lines, a **tone generator tester** generates a tone that can be heard through a receiver (probe). See Figure 36–35.

The tone will be generated as long as there is a continuous electrical path along the circuit. The signal will stop if there is an open (break) or short-to-ground in the circuit. See Figures 36–36 and 36–37 on page 380. The windings in the solenoids and relays will increase the strength of the signal in these locations.



(a)



(b)

Figure 36–33 (a) After removing the blown fuse, a pulsing circuit breaker is connected to the terminals of the fuse. (b) The circuit breaker causes current to flow, then stop, then flow again, through the circuit up to the point of the short-to-ground. By observing the Gauss gauge, the location of the short is indicated near where the needle stops moving due to the magnetic field created by the flow of current through the wire.

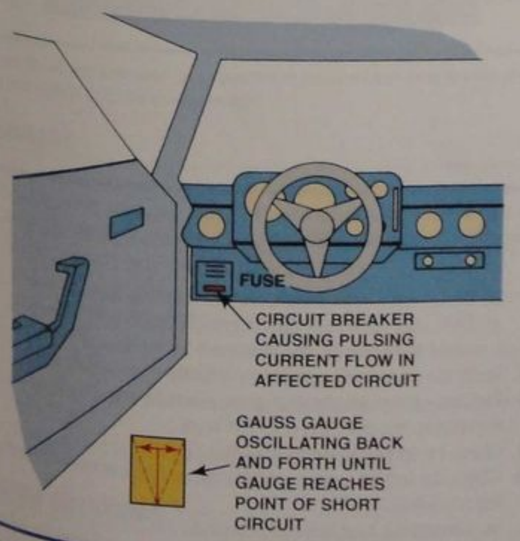


Figure 36–34 A Gauss gauge can be used to determine the location of a short circuit even behind a metal panel.



Figure 36–35 A tone generator-type tester used to locate open circuits and circuits that are shorted-to-ground. Included with this tester is a transmitter (tone generator), receiver (probe), and headphones for use in noisy shops.

TECH TIP ✓ Heat or Movement

Electrical shorts are commonly caused either by movement, which causes the insulation around the wiring to be worn away, or by heat melting the insulation. When checking for a short circuit, first check the wiring that is susceptible to heat, movement, and damage:

1. *Heat.* Wiring near heat sources, such as the exhaust system, cigarette lighter, or generator.
2. *Wire movement.* Wiring that moves, such as in areas near the doors, trunk, or hood.
3. *Damage.* Wiring subject to mechanical injury, such as in the trunk, where heavy objects can move around and smash or damage wiring. This can also occur as a result of an accident or a previous repair.

TECH TIP ✓ Wiggle Test

Intermittent electrical problems are common yet difficult to locate. To help locate these hard-to-find problems, try operating the circuit and then start wiggling the wires and connections that control the circuit. If in doubt where the wiring goes, try moving all the wiring starting at the battery. Pay particular attention to wiring running near the battery or the windshield washer container. Corrosion can cause wiring to fail, and battery acid fumes and alcohol-based windshield washer fluid can start or contribute to the problem. If you notice any change in the operation of the device being tested while wiggling the wiring, look closer in the area you were wiggling until the actual problem is located and corrected.

ELECTRICAL TROUBLESHOOTING GUIDE

When troubleshooting any electrical component, remember the following hints to find the problem faster and more easily.

1. For a device to work, it must have two things: power and ground.
2. If there is no power to a device, an open power side (blown fuse, etc.) is indicated.
3. If there is power on both sides of a device, an open ground is indicated.
4. If a fuse blows immediately, a grounded power-side wire is indicated.
5. Most electrical faults result from heat or movement.
6. Most noncomputer-controlled devices operate by opening and closing the power side of the circuit (power-side switch).

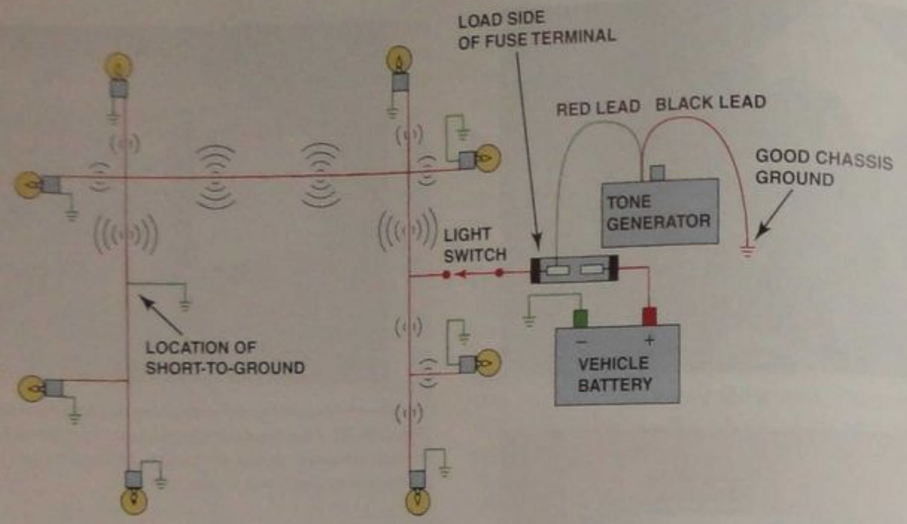


Figure 36–36 To check for a short-to-ground using a tone generator, connect the black transmitter lead to a good chassis ground and the red lead to the load side of the fuse terminal. Turn the transmitter on and check for tone signal with the receiver. Using a wiring diagram, follow the strongest signal to the location of the short-to-ground. There will be no signal beyond the fault.

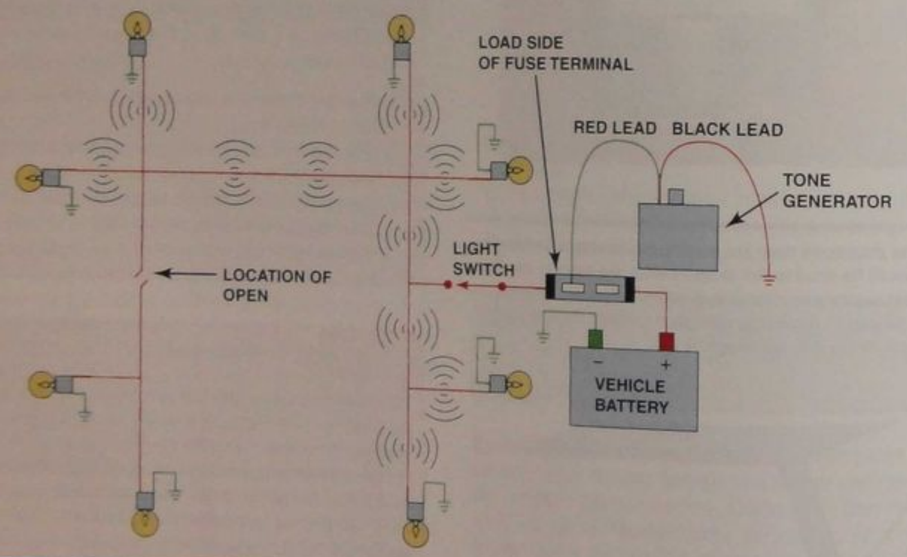


Figure 36–37 To check for an open (break), connect the red lead of the tone generator to the load side of the fuse terminal and the black lead to a good chassis ground. Turn on the transmitter and then listen for the tone signal with the receiver set in the open position. Using a wiring diagram, follow the signal along the circuit until the tone stops, indicating the location of the open.

7. Most computer-controlled devices operate by opening and closing the ground side of the circuit (ground-side switch).

STEP-BY-STEP TROUBLESHOOTING PROCEDURE

Knowing what should be done and when is a major concern for many technicians trying to repair an electrical problem. The following procedure has been field tested for many years and provides a step-by-step guide to follow when troubleshooting an electrical fault.

1. Determine the customer concern (complaint) and get as much information as possible from the customer or service advisor.
   a. When did the problem start?
   b. Under what conditions does the problem occur?
   c. Have there been any recent repairs to the vehicle which could have created the problem?
2. Verify the customer's concern by actually observing the fault.
3. Perform a thorough visual inspection and be sure to check everything that does and does not work.
4. Check for technical service bulletins (TSBs).
5. Check the factory service information and follow the troubleshooting procedure.
   a. Determine how the circuit works
   b. Determine which part of the circuit is good, based on what works and what does not work
   c. Isolate the problem area

HINT: Split the circuit in half to help isolate the problem and start at the relay (if the circuit has a relay).

6. Determine the root cause and repair the vehicle.
7. Verify the repair and complete the repair order (R.O.) by listing the three C's (complaint, cause, and correction).

REAL WORLD FIX **Shocking Experience**

A customer complained that after driving for a while, he got a shock whenever the door handle was grabbed when exiting the vehicle. The customer thought that there must be an electrical fault and that the shock was coming from the vehicle itself. In a way, the shock was caused by the vehicle, but it was not a fault. The service technician sprayed the cloth seats and carpet with an antistatic spray and the problem did not reoccur. Obviously, a static charge was being created by the movement of the driver's clothing on the seats and then discharged when the driver touched the metal door handle. See Figure 36–38.



Figure 36–38 Antistatic spray can be used to stop customers from being shocked when they touch a metal object like the door handle.

SUMMARY

1. Most wiring diagrams include the wire color, circuit number, and wire gauge.
2. The number used to identify connectors, grounds, and splices usually indicates where they are located in the vehicle.
3. All switches and relays shown on a schematic are shown in their normal position either normally closed (N.C.) or normally open (N.O.).
4. A short-to-voltage affects the power side of the circuit and usually involves more than one circuit.
5. A short-to-ground usually causes the fuse to blow and usually affects only one circuit.
6. Most electrical faults are a result of heat or movement.

REVIEW QUESTIONS

1. List the numbers used on schematics to indicate grounds, splices, and connectors and when they are used in the vehicle.
2. List and identify the terminals of a typical relay.
3. List three methods that can be used to help locate a short circuit.
4. Describe how to use a tone generator to locate a short circuit.

CHAPTER QUIZ

1. On a wiring diagram, S110 with a ".8 BRN/BLK " means _____.
   a. Circuit #.8, spliced under the hood
   b. A connector with 0.8 square millimeter wire
   c. A splice of a brown with black stripe, wire size being 0.8 square millimeters (18-gauge AWG)
   d. Both a and b
2. Where is connector C250?
   a. Under the hood
   b. Under the dash
   c. In the passenger compartment
   d. In the trunk
3. All switches illustrated in schematics are _____.
   a. Shown in their normal position
   b. Always shown in their on position
   c. Always shown in their off position
   d. Shown in their on position except for lighting switches
4. When testing a relay using an ohmmeter, which two terminals should be touched to measure the coil resistance?
   a. 87 and 30
   b. 86 and 85
   c. 87a and 87
   d. 86 and 87
5. Technician A says that a good relay should measure between 60 and 100 ohms across the coil terminals. Technician B says that OL should be displayed on an ohmmeter when touching terminals 30 and 87. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Which relay terminal is the normally closed (N.C.) terminal?
   a. 30
   b. 85
   c. 87
   d. 87a
7. Technician A says that there is often more than one circuit being protected by each fuse. Technician B says that more than one circuit often shares a single ground connector. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Two technicians are discussing finding a short-to-ground using a test light. Technician A says that the test light, connected in place of the fuse, will light when the circuit that has the short is disconnected. Technician B says that the test light should be connected to the positive (+) and negative (–) terminals of the battery during this test. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A short circuit can be located using a _____.
   a. Test light
   b. Gauss gauge
   c. Tone generator
   d. All of the above
10. For an electrical device to operate, it must have _____.
    a. Power and a ground
    b. A switch and a fuse
    c. A ground and fusible link
    d. A relay to transfer the current to the device

CHAPTER

37 Capacitance and Magnetism

OBJECTIVES: After studying Chapter 37, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems). • Explain capacitance. • Describe magnetism. • Describe electromagnetism. • Explain how electricity can create magnetism and how magnetism can create electricity.

KEY TERMS: armature • capacitance • condenser • counter electromotive force (CEMF) • dielectric • e coil • electromagnetic induction • electromagnetic interference (EMI) • electromagnetics • farads • flux density • high energy ignition (HEI) • ignition coil • ignition control module (ICM) • induced voltage • left-hand rule • lenz's law • leyden jar • magnetic flux lines • magnetism • mutual induction • permeability • polarity • pole • primary winding • radio choke coil • radio-frequency interference (RFI) • relative motion • relay • reluctance • right-hand rule • secondary winding • self-induced voltage • turns ratio

CAPACITANCE

Capacitance is the ability of an object or surface to store an electrical charge. Around 1745, Ewald Christian von Kliest and Pieter van Musschenbroek independently discovered capacitance in an electric circuit. While engaged in separate studies of electrostatics, they discovered that an electric charge could be stored for a period of time. They were using a device, now called a **Leyden jar,** that consisted of a glass jar filled with water, with a nail piercing the stopper and dipping into the water. See Figure 37–1.

They connected the nail to an electrostatic charge. After disconnecting the nail from the source of the charge, they found that a shock could be felt by touching the nail, demonstrating that the device had stored the charge.

In 1747, John Bevis lined both the inside and outside of the jar with foil. This created a capacitor with two conductors (the inside and outside metal foil layers) equally separated by the insulating glass. The Leyden jar was also used by Benjamin Franklin to store the charge from lightning and was also used in other experiments. The natural phenomenon of lightning includes capacitance because huge electric fields develop between cloud layers or between clouds and the earth prior to a lightning strike.

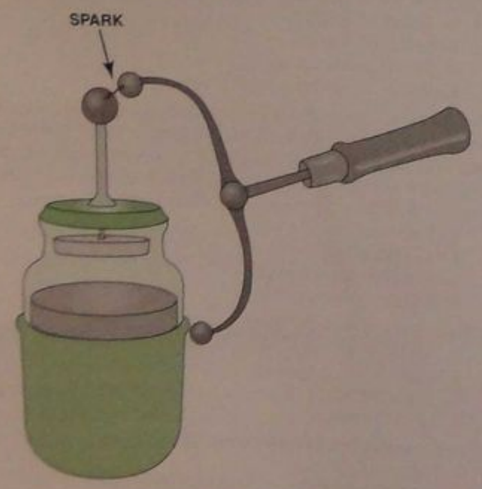


Figure 37–1 A Leyden jar can be used to store an electrical charge.

CAPACITOR CONSTRUCTION AND OPERATION

A capacitor consists of two conductive plates with an insulating material between them. The insulating material is commonly called a **dielectric.** A dielectric is a substance that is a poor conductor of electricity and can include air, mica, ceramic, glass, paper, plastic, or any similar nonconductive material. The dielectric constant is the relative strength of a material against the flow of electrical current. The higher the number, the better the insulating properties.

Material	Dielectric Constant
Vacuum	1.0
Air	1.00059
Polystyrene	2.5
Paper	3.5
Mica	5.4
Flint glass	9.9
Methyl alcohol	35
Glycerin	56.2
Pure water	81

When a capacitor is placed in a closed circuit, the voltage source (battery) forces electrons around the circuit. Because electrons cannot flow through the dielectric of the capacitor, excess electrons collect on what becomes the negatively charged plate. At the same time, the other plate loses electrons and, therefore, becomes positively charged. See Figure 37–2.

Current continues until the voltage charge across the capacitor plates becomes the same as the source voltage. At that time, the negative plate of the capacitor and the negative terminal of the battery are at the same negative potential. See Figure 37–3. The positive plate of the capacitor and the positive terminal of the battery are also at equal positive potentials. There is then a voltage charge across the battery terminals and an equal voltage charge across the capacitor plates. The circuit is in balance, and there is no current. An electrostatic field now exists between the capacitor plates because of their opposite charges. It is this field that stores energy. See Figure 37–4.

If the circuit is opened, the capacitor will hold its charge until it is connected into an external circuit through which it can discharge. When the charged capacitor is connected to an external circuit, it discharges. After discharging, both plates of the capacitor are neutral because all the energy from a circuit stored in a capacitor is returned when it is discharged. See Figure 37–5.

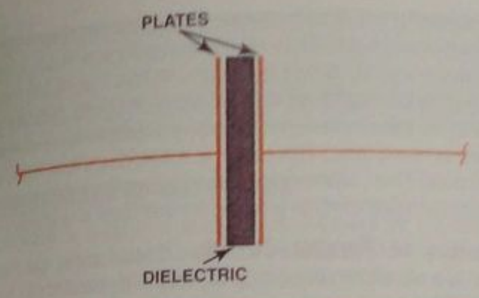


Figure 37–2 This simple capacitor, made of two plates separated by an insulating material, is called a dielectric.

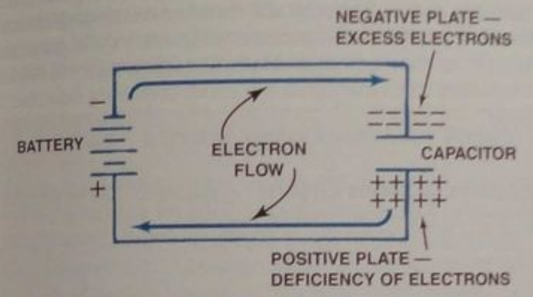


Figure 37–3 As the capacitor is charging, the battery forces electrons through the circuit.

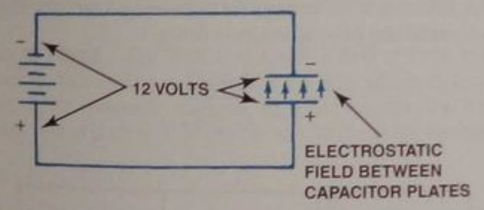


Figure 37–4 When the capacitor is charged, there is equal voltage across the capacitor and the battery. An electrostatic field exists between the capacitor plates. No current flows in the circuit.

Theoretically, a capacitor holds its charge indefinitely. Actually, the charge slowly leaks off the capacitor through the dielectric. The better the dielectric, the longer the capacitor holds its charge. To avoid an electrical shock, any capacitor should be treated as if it were charged until it is proven to be discharged. See Figure 37–6 for the symbol for capacitors as used in electrical schematics.

NOTE: Capacitors are also called **condensers**. This term developed because electric charges collect, or condense, on the plates of a capacitor much like water vapor collects and condenses on a cold bottle or glass.

FACTORS OF CAPACITANCE

Capacitance is governed by three factors:

- The surface area of the plates
- The distance between the plates
- The dielectric material

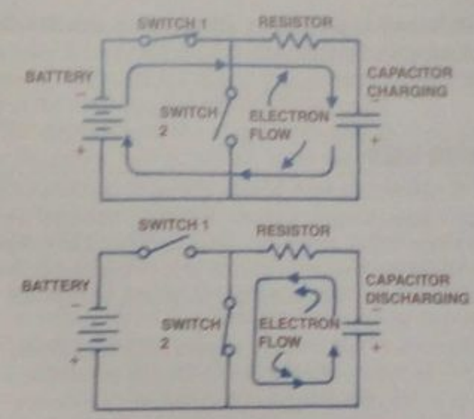


Figure 37–5 The capacitor is charged through one circuit (top) and discharged through another (bottom).

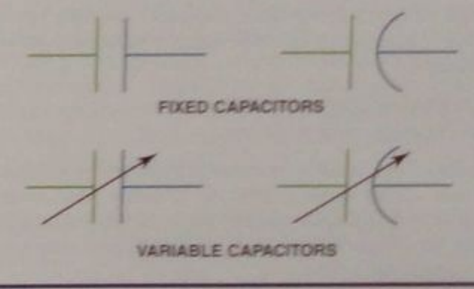


Figure 37–6 Capacitor symbols are shown in electrical diagrams. The negative plate is often shown curved.

The larger the surface area of the plates, the greater the capacitance. This is because more electrons collect on a larger plate area than on a small one.

The closer the plates are to each other, the greater the capacitance. This is because a stronger electrostatic field exists between charged bodies that are close together.

The insulating qualities of the dielectric material also affect capacitance. The capacitance of a capacitor is higher if the dielectric is a very good insulator.

Measurement of Capacitance Capacitance is measured in **farads,** which is named for Michael Faraday (1791–1867). The symbol for farads is F. If a charge of 1 coulomb is placed on the plates of a capacitor and the potential difference between them is 1 volt, the capacitance is then defined to be 1 farad. One coulomb is equal to the charge of 6.25×10^{18} electrons. One farad is an extremely large quantity of capacitance. Microfarads (0.000001 farad) or μF are more commonly used.

The capacitance of a capacitor is proportional to the quantity of charge that can be stored in it for each volt difference in potential between its plates:

$$C = Q/V$$

Where C is capacitance in farads, Q is the quantity of stored electrical charge in coulombs, and V is the difference in potential in volts.

Therefore, stored electric charge can be calculated using the formula:

$$Q = CV$$

The difference in potential or voltage of the capacitor can be calculated using the formula:

$$V = Q/C$$

CAPACITOR USES

Because a capacitor stores a voltage charge, it opposes, or slows down, any voltage change in a circuit. Therefore, capacitors are often used as voltage "shock absorbers." You sometimes find a capacitor attached to one terminal of an ignition coil. In this application, the capacitor absorbs and damps changes in ignition voltage that interfere with radio reception.

Capacitors are used in many ways in electronic circuits, such as acting as barriers to direct currents, storing memory in a computer chip, or storing a charge for an electronic flash camera.

TECH TIP ✔ **A Capacitor Makes an Excellent Sound System Noise Filter**

Interference in a sound system or radio is usually due to alternating current (AC) voltage created somewhere in the vehicle, such as in the alternator (AC generator). A capacitor:

- Blocks the flow of direct current (DC)
- Allows alternating current (AC) to pass

By connecting a capacitor (also known as a condenser) to the power lead of the radio or sound system amplifier, the AC voltage passes through the capacitor to the ground where the other end of the capacitor is connected. Therefore, the capacitor provides a path for the AC without affecting the DC power circuit. See Figure 37–7.

Computer Memory In most cases, the main memory of a computer is a high-speed random-access memory (RAM). One type of main memory, called dynamic random-access memory (DRAM), is the most commonly used type of RAM. A single memory chip is made up of several million memory cells. In a DRAM chip, each memory cell consists of a capacitor. When a capacitor is electrically charged, it is said to store the binary digit 1, and when discharged, it represents 0.

Condenser Microphones A microphone converts sound waves into an electric signal. All microphones have a diaphragm that vibrates as sound waves strike. The vibrating diaphragm in turn causes an electrical component to create an output flow of current at a frequency proportional to the sound waves. A condenser microphone uses a capacitor for this purpose.

In a condenser microphone, the diaphragm is the negatively charged plate of a charged capacitor. When a sound wave compresses the diaphragm, the diaphragm is moved closer to the positive plate. Decreasing the distance between the plates increases the electrostatic attraction between them, which results in a flow of current to the negative plate. As the diaphragm moves out in response to sound waves, the diaphragm moves farther from the positive plate. Increasing the distance between the plates decreases the electrostatic attraction between them. This results in a flow of current back to the positive plate. These alternating flows of current provide weak electronic signals which travel to an amplifier and then to a loudspeaker.

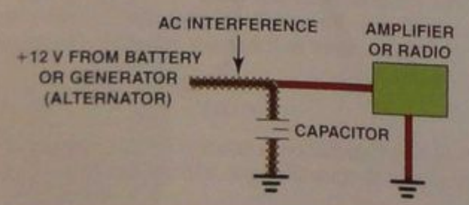


Figure 37–7 A capacitor blocks direct current (DC) but passes alternating current (AC). A capacitor makes a very good noise suppressor because most of the interference is AC and the capacitor will conduct this AC to ground before it can reach the radio or amplifier.

Capacitors in Parallel Circuits Capacitance can be increased in a circuit by connecting capacitors in parallel, as shown in Figure 37–8.

We know that capacitance of a capacitor can be increased by increasing the size of its plates. Connecting two or more capacitors in parallel in effect increases plate size. Increasing plate area makes it possible to store more charge and therefore creates greater capacitance. To determine total capacitance of several parallel capacitors, simply add up their individual values. The following is the formula for calculating total capacitance in a circuit containing capacitors in parallel:

$$C_T = C_1 + C_2 + C_3 \cdots$$

Capacitors in Series Circuits Capacitance can be decreased in a circuit by capacitors in series, as shown in Figure 37–9.

We know that capacitance of a capacitor can be decreased by placing the plates farther apart. Connecting two or more capacitors in series in effect increases the distance between the plates and thickness of the dielectric, thereby decreasing the amount of capacitance.

The following is the formula for calculating total capacitance in a circuit containing two capacitors in series:

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

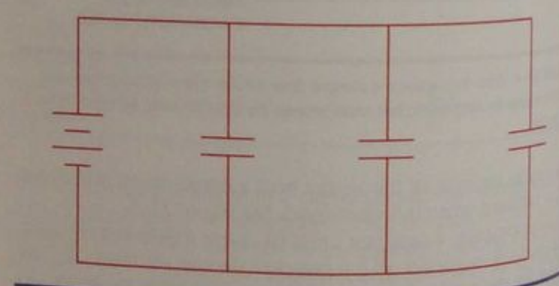


Figure 37–8 Capacitors in parallel effectively increase the capacitance.

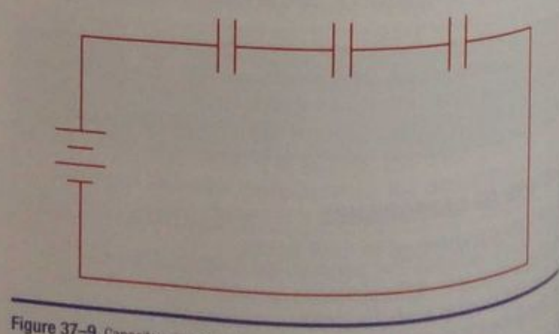


Figure 37–9 Capacitors in series decrease the capacitance.

NOTE: Capacitors are often used to reduce radio interference or to improve the performance of a high-power sound system. Additional capacitance can, therefore, be added by attaching another capacitor in parallel.

FUNDAMENTALS OF MAGNETISM

Magnetism is a form of energy that is caused by the motion of electrons in some materials. It is recognized by the attraction it exerts on other materials. Like electricity, magnetism cannot be seen. It can be explained in theory, however, because it is possible to see the results of magnetism and recognize the actions that it causes.

Iron ore exists as a magnet in nature. See Figure 37–10. Many other materials can be artificially magnetized to some degree, depending upon their atomic structure. Soft iron is very easy to magnetize, while some materials—such as aluminum, glass, wood, and plastic—cannot be magnetized at all.

TECH TIP ✔ **A Cracked Magnet Becomes Two Magnets**

Magnets are commonly used in vehicle crankshaft, camshaft, and wheel speed sensors. If a magnet is struck and cracks or breaks, the result is two smaller-strength magnets. Because the strength of the magnetic field is reduced, the sensor output voltage is also reduced. A typical problem occurs when a magnetic crankshaft sensor becomes cracked, resulting in a no-start condition. Sometimes the cracked sensor works well enough to start an engine that is cranking at normal speeds but will not work when the engine is cold. See Figure 37–11.

Lines of Force The lines that create a field of force around a magnet are believed to be caused by the way groups of atoms are aligned in the magnetic material. In a bar magnet, the lines are concentrated at both ends of the bar and form closed, parallel loops in three dimensions around the magnet. Force does not flow along these lines the way electrical current flows, but the lines *do* have direction. They come out of one end, or **pole,** of the magnet and enter at the other end. See Figure 37–12.

The opposite ends of a magnet are called its north and south poles. In reality, they should be called the "north seeking" and "south seeking" poles, because they seek the Earth's North Pole and South Pole, respectively.

The stronger the magnet, the more lines of force that are formed. The magnetic lines of force, also called **magnetic flux** or **flux lines,** form a magnetic field. The terms "magnetic field," "lines of force," "flux," and "flux lines" are used interchangeably.

Flux density refers to the number of flux lines per unit of area. To determine flux density, divide the number of flux lines by the area in which the flux exists. For example, 100 flux lines divided by an area of 10 square centimeters equals a flux density of 10. A magnetic field can be measured using a Gauss gauge, named for German scientist Johann Carl Friedrick Gauss (1777–1855).

Magnetic lines of force can be seen by spreading fine iron filings or dust on a piece of paper laid on top of a magnet. A magnetic field can also be observed by using a compass. A compass is simply a thin magnet or magnetized iron needle balanced on a pivot. The needle will rotate to point toward the opposite pole of a magnet. The needle can be very sensitive to small magnetic fields. Since it is a small magnet, a compass usually has one end marked N and the other marked S. See Figure 37–13.



Figure 37–10 A freely suspended natural magnet will point toward the magnetic north pole.

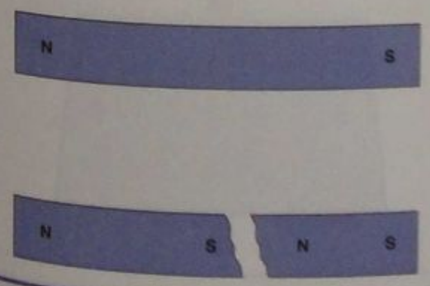


Figure 37–11 If a magnet breaks or is cracked, it becomes two weaker magnets.

TECH TIP ✔ **Magnetize a Steel Needle**

A piece of steel can be magnetized by rubbing a magnet in one direction along the steel. This causes the atoms to line up in the steel, so it acts like a magnet. The steel often won't remain magnetized, while the true magnet is permanently magnetized.

When soft iron or steel is used, such as a paper clip, it will lose its magnetism quickly. The atoms in a magnetized needle can be disturbed by heating it or by dropping the needle on a hard object, which would cause the needle to lose its magnetism. Soft iron is used inside ignition coils because it will not keep its magnetism.

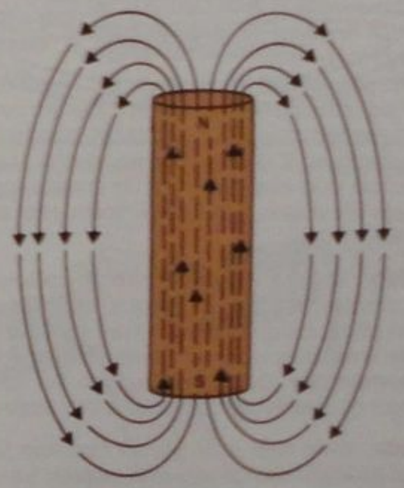


Figure 37–12 Magnetic lines of force leave the north pole and return to the south pole of a bar magnet.

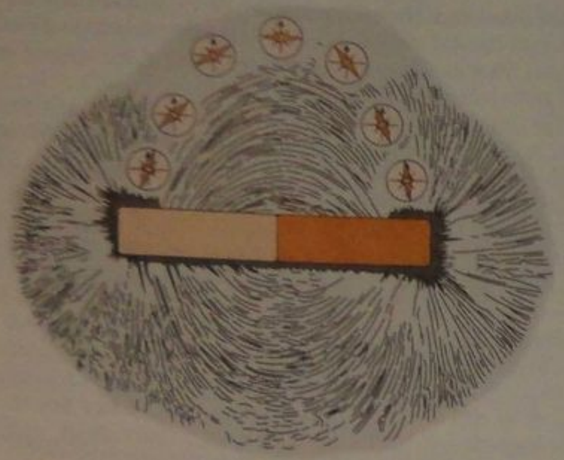


Figure 37–13 Iron filings on a compass can be used to observe the magnetic lines of force.

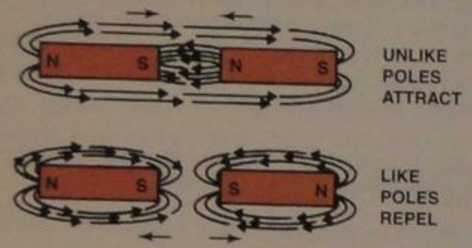


Figure 37–14 Magnetic poles behave like electrically charged particles—unlike poles attract and like poles repel.

Attracting or Repelling The poles of a magnet are called north (N) and south (S) because, when a magnet is suspended freely, the poles tend to point toward the North and South Poles of the Earth.

Magnetic flux lines exit from the north pole and bend around to enter the south pole. An equal number of lines exit and enter, so magnetic force is equal at both poles of a magnet. Flux lines are concentrated at the poles, and therefore magnetic force (flux density) is stronger at the ends.

Magnetic poles behave like positively and negatively charged particles. When unlike poles are placed close together, the lines exit from one magnet and enter the other. The two magnets are pulled together by flux lines. If like poles are placed close together, the curving flux lines meet head-on, forcing the magnets apart. Therefore, like poles of a magnet repel and the unlike poles attract. See Figure 37–14.

Permeability Magnetic flux lines cannot be insulated. There is no known material through which magnetic force does not pass, if the force is strong enough. However, some materials allow the force to pass though more easily than others. This degree of passage is called **permeability.** Iron allows magnetic flux lines to pass through much more easily than air, so iron is very permeable.

Reluctance While there is no absolute insulation for magnetism, certain materials resist the passage of magnetic force. This can be compared to resistance without an electrical circuit. Air does not allow easy passage, so air has a high **reluctance.** Magnetic flux lines tend to concentrate in permeable materials and avoid reluctant materials. As with electricity, magnetic force follows the path of least resistance.

ELECTROMAGNETISM

Scientists did not discover that current-carrying conductors also are surrounded by a magnetic field until 1820. These fields may be made many times stronger than those surrounding conventional magnets. Also, the magnetic field strength around a conductor may be controlled by changing the current. As current increases, more flux lines are created and the magnetic field expands. As current decreases, the magnetic field contracts, or collapses. This takes place when the current is shut off. These discoveries greatly broadened the practical uses of magnetism and opened an area of study known as **electromagnetics.**

Creating an Electromagnet A magnet can be created by magnetizing a piece of iron or steel or by using electricity to make an electromagnet. An easy way to create an electromagnet is to wrap a nail with 20 turns of insulated wire and connect the ends to the terminals of a 1.5-volt dry cell battery. When energized, the nail will become a magnet and will be able to pick up tacks or other small steel objects.

TECH TIP ✓ **Electricity and Magnetism**

Electricity and magnetism are closely related because whenever an electrical current is flowing through a conductor, a magnetic field is created. When a conductor is moved through a magnetic field, an electrical current is created. This relationship can be summarized as follows.

- Electricity creates magnetism.
- Magnetism creates electricity.

From a service technician's point of view, this is important because wires carrying current should always be routed as the factory intended to avoid causing interference with another circuit or electronic component. This is especially important when installing or servicing spark plug wires, which carry high voltages and can cause a lot of electromagnetic interference.

Straight Conductor The magnetic field surrounding a straight, current-carrying conductor consists of several concentric cylinders of flux that are the length of the wire. The current flow (amperes) determines how many flux lines (cylinders) there will be and how far out they extend from the surface of the wire. See Figure 37–15.

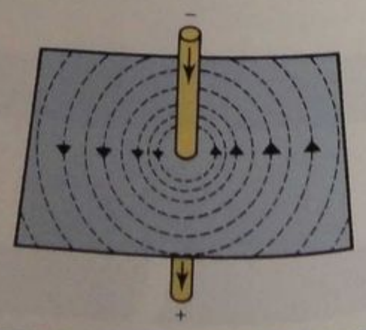


Figure 37–15 A magnetic field surrounds a straight, current-carrying conductor.

Left- and Right-Hand Rules Magnetic flux cylinders have direction, just as the flux lines surrounding a bar magnet have direction. The **left-hand rule** is a simple way to determine this direction. When you grasp a conductor with your left hand so that your thumb points in the direction of electron flow (− to +) through the conductor, your fingers curl around the wire in the direction of the magnetic flux lines. See Figure 37–16.

Most automotive circuits use the conventional theory of current (+ to −), and therefore, the **right-hand rule** is used to determine the direction of the magnetic flux lines. See Figure 37–17.

Field Interaction The cylinders of flux surrounding current-carrying conductors interact with other magnetic fields. In the following illustrations, the cross symbol (+) indicates current moving inward, or away from you. It represents the tail of an arrow. The dot symbol (·) represents an arrowhead and indicates current moving outward. If two conductors carry current in opposite directions, their magnetic fields also carry current in opposite directions (according to the left-hand rule). If they are placed side-by-side, the opposing flux lines between the conductors create a strong magnetic field. Current-carrying conductors tend to move out of a strong field into a weak field, so the conductors move away from each other. See Figure 37–18.

If the two conductors carry current in the same direction, their fields are in the same direction. The flux lines between the two conductors cancel each other out, leaving a very weak field between them. The conductors are drawn into this weak field, and they tend to move toward each other.

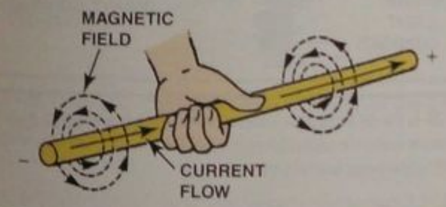


Figure 37–16 The left-hand rule for magnetic field direction is used with the electron flow theory.



Figure 37–17 The right-hand rule for magnetic field direction is used with the conventional theory of electron flow.

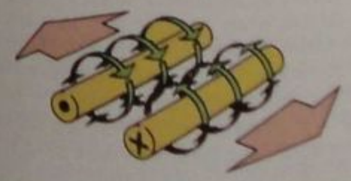


Figure 37–18 Conductors with opposing magnetic fields will move apart into weaker fields.

Motor Principle Electric motors, such as automobile starter motors, use this field interaction to convert electrical energy into mechanical energy. If two conductors carrying current in opposite directions are placed between strong north and south poles, the magnetic field of the conductor interacts with the magnetic fields of the poles. The clockwise field of the top conductor adds to the fields of the poles and creates a strong field beneath the conductor. The conductor then tries to move up to get out of this strong field. The counterclockwise field of the lower conductor adds to the field of the poles and creates a strong field above the conductor. The conductor then tries to move down to get out of this strong field. These forces cause the center of the motor, where the conductors are mounted, to turn clockwise. See Figure 37–19.

Coil Conductor If several loops of wire are made into a coil, the magnetic flux density is strengthened. Flux lines around a coil are the same as the flux lines around a bar magnet. See Figure 37–20. They exit from the north pole and enter at the south pole. Use the left-hand thread rule to determine the north pole of a coil, as shown in Figure 37–21. Grasp the coil with your left hand so that



Figure 37–19 Electric motors use the interaction of magnetic fields to produce mechanical energy.

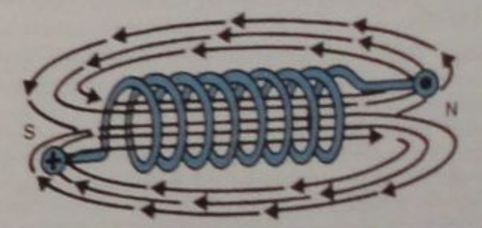


Figure 37–20 The magnetic lines of flux surrounding a coil look similar to those surrounding a bar magnet.



Figure 37–21 The left-hand rule for coils is shown.

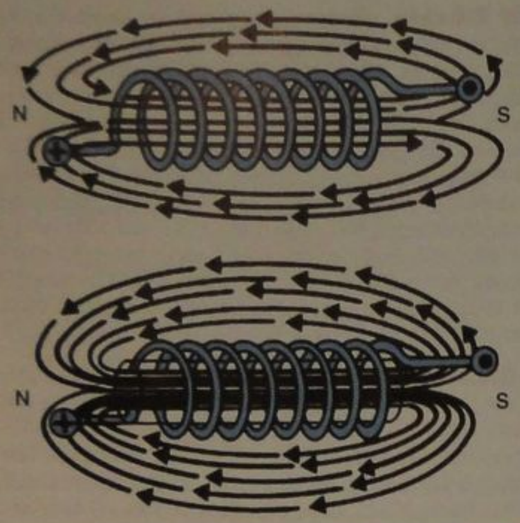


Figure 37–22 An iron core concentrates the magnetic lines of force surrounding a coil.

your fingers point in the direction of electron flow; your thumb will point toward the north pole of the coil. The magnetic field of a coil can be strengthened by increasing the number of turns in the wire, by increasing the current through the coil, or both.

Electromagnets The magnetic field surrounding a current-carrying conductor can be strengthened by using a soft-iron core. Because soft iron is very permeable, magnetic flux lines pass through it easily. If a piece of soft iron is placed inside a coiled conductor, the flux lines concentrate in the iron core, rather than pass through the air, which is less permeable. The concentration of force greatly increases the strength of the magnetic field inside the coil. See Figure 37–22. Coils with an iron core are called *electromagnets.*

Relays One common automotive use of electromagnets is in a device called a **relay.** A relay is a control device which allows a small amount of current to control a large amount of current in another circuit. A simple relay contains an electromagnetic coil in series with a battery and a switch. Near the electromagnet is a movable flat blade, or **armature,** of some material which is attracted by a magnetic field. See Figure 37–23.

The armature pivots at one end and is held a small distance away from the electromagnet by a spring (or by the spring steel of the armature itself). A contact point, made of a good conductor, is attached to the free end of the armature. Another contact point is fixed a small distance away. The two contact points are wired in series with an electrical load and the battery.

When the switch is closed:

1. Current travels from the battery through the electromagnet.
2. The magnetic field created by the current attracts the armature, pulling it down until the contact points meet.
3. Closing the contacts allows current in the second circuit from the battery to the load.

When the switch is open:

1. The electromagnet loses its current and its magnetic field.
2. Spring pressure brings the armature back.
3. The second circuit is broken by the opening of the contact points.

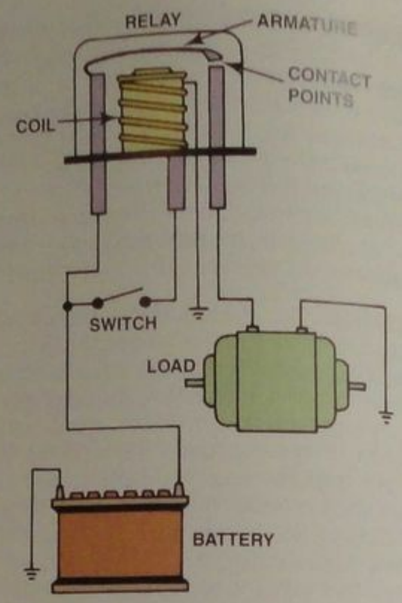


Figure 37–23 This figure shows an electromagnetic relay.

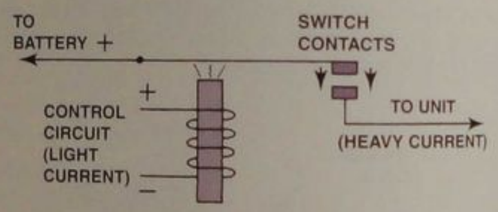


Figure 37–24 In this electromagnetic switch, a light current (low amperes) produces an electromagnet and causes the contact points to close. The contact points then conduct a heavy current (high amperes) to an electrical unit.

Relays also may be designed with normally closed contacts that open when current passes through the electromagnet. See Figure 37–24. A solenoid is an example of an electromagnetic switch. A solenoid uses a movable core rather than a movable arm and is generally used in higher-amperage applications, such as a starter solenoid.

ELECTROMAGNETIC INDUCTION

Magnetic flux lines create an electromotive force, or voltage, in a conductor if either the flux lines or the conductor is moving. This movement is called **relative motion.** This process is called induction, and the resulting electromotive force is called **induced voltage.** This creation of a voltage in a conductor by a moving magnetic field is called **electromagnetic induction.** If the conductor is in a complete circuit, current flows.

Voltage is induced when magnetic flux lines are broken by a conductor. This relative motion can be a conductor moving across a magnetic field or a magnetic field moving across a stationary conductor (as in AC generators and ignition coils). In both cases, the induced voltage is generated by relative motion between the conductor and the magnetic flux lines. See Figure 37–25.

Voltage Strength Voltage is induced when a conductor cuts across magnetic flux lines. The amount of the voltage depends upon the rate at which the flux lines are broken. The more flux lines broken per unit of time, the greater the induced voltage. If a single conductor breaks one million flux lines per second, one volt is induced.

There are four ways to increase induced voltage.

- Increase the strength of the magnetic field, so there are more flux lines.
- Increase the number of conductors that are breaking the flux lines.
- Increase the speed of the relative motion between the conductor and the flux lines so that more lines are broken per time unit.
- Increase the angle between the flux lines and the conductor to a maximum of 90 degrees. There is no voltage induced if the conductors move parallel to, and do not break any, flux lines, as shown in Figure 37–26. Maximum voltage is induced if the conductors break flux lines at 90 degrees. Induced voltage varies proportionately at angles between 0 and 90 degrees. See Figure 37–27.

Voltage can be electromagnetically induced and can be measured. Induced voltage creates current. The direction of induced voltage (and the direction in which current moves) is called **polarity** and depends upon the direction of the flux lines, as well as the direction of relative motion.

An induced current moves so that its magnetic field opposes the motion which induced the current. This principle is called **Lenz's law.** The relative motion of a conductor and a magnetic field is opposed by the magnetic field of the current it has induced.

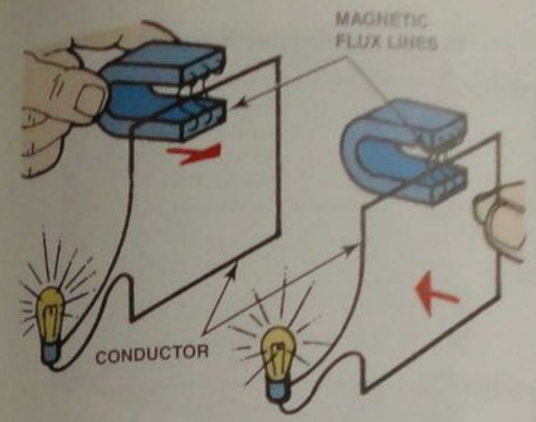


Figure 37–25 Voltage can be induced by the relative motion between a conductor and magnetic lines of force.

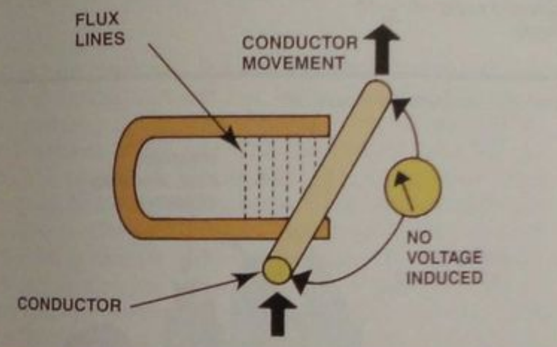


Figure 37–26 No voltage is induced if the conductor is moved in the same direction as the magnetic lines of force (flux lines).

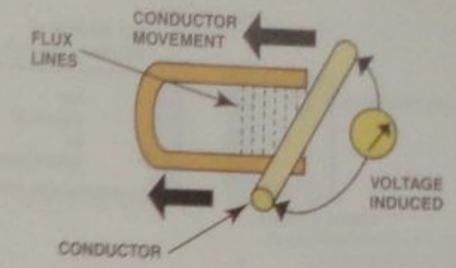


Figure 37–27 Maximum voltage is induced when conductors cut across the magnetic lines of force (flux lines) at a 90-degree angle.

Self-Induction When current begins to flow in a coil, the flux lines expand as the magnetic field forms and strengthens. As current increases, the flux lines continue to expand, cutting across the wires of the coil and actually inducing another voltage within the same coil. Following Lenz's law, this **self-induced voltage** tends to *oppose* the current that produces it. If the current continues to increase, the second voltage opposes the increase. When the current stabilizes, the counter-voltage is no longer induced because there are no more expanding flux lines (no relative motion). When current to the coil is shut off, the collapsing magnetic flux lines self-induce a voltage in the coil that tries to maintain the original current. The self-induced voltage *opposes* and *slows down the decrease* in the original current. The self-induced voltage that opposes changes in current flow is an inductor called **counter electromotive force (CEMF).**

Mutual Induction When two coils are close together, energy may be transferred from one to the other by magnetic coupling called mutual induction. **Mutual induction** means that the expansion or collapse of the magnetic field around one coil induces a voltage in the second coil.

Usually, the two coils are wound on the same iron core. One coil winding is connected to a battery through a switch and is called the **primary winding.** The other coil winding is connected to an external circuit and is called the **secondary winding.**

When the switch is open, there is no current in the primary winding. There is no magnetic field and, therefore, no voltage in the secondary winding. When the switch is closed, current is introduced and a magnetic field builds up around both windings. The primary winding thus changes electrical energy from the battery into magnetic energy of the expanding field. As the field expands, it cuts across the secondary winding and induces a voltage in it. A meter connected to the secondary circuit shows current. See Figure 37–28.

When the magnetic field has expanded to its full strength, it remains steady as long as the same amount of current exists. The flux lines have stopped their cutting action. There is no relative motion and no voltage in the secondary winding, as shown on the meter.

When the switch is opened, primary current stops, and the field collapses. As it does, flux lines cut across the secondary winding but in the opposite direction. This induces a secondary voltage with current in the opposite direction, as shown on the meter.

Mutual induction is used in ignition coils. In an ignition coil, low-voltage primary current induces a very high secondary voltage because of the different number of turns in the primary and secondary windings.

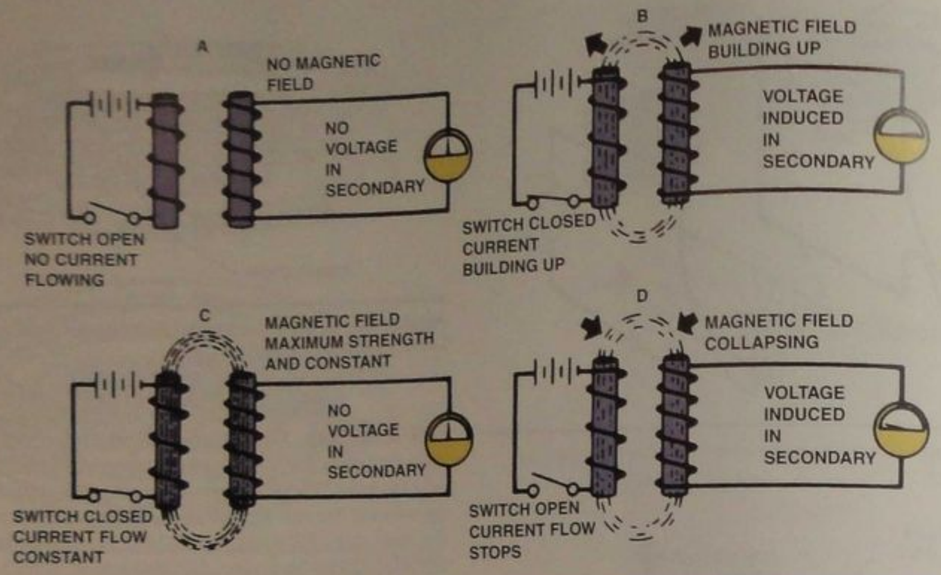


Figure 37–28 Mutual induction occurs when the expansion or collapse of a magnetic field around one coil induces a voltage in a second coil.

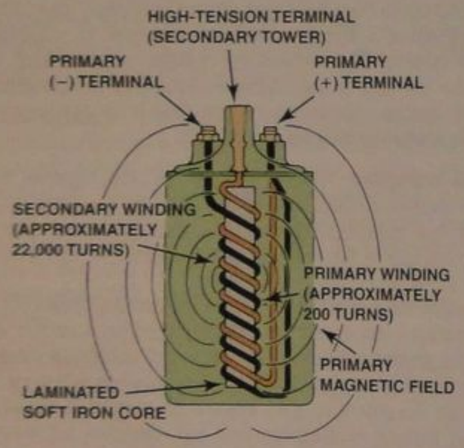


Figure 37–29 Internal construction of an oil-cooled ignition coil. Notice that the primary winding is electrically connected to the secondary winding. The polarity (positive or negative) of a coil is determined by the direction in which the coil is wound.

IGNITION COILS

The heart of any ignition system is the **ignition coil.** The coil creates a high-voltage spark by electromagnetic induction. Many ignition coils contain two separate but electrically connected windings of copper wire. Other coils are true transformers in which the primary and secondary windings are not electrically connected. See Figure 37–29.

The center of an ignition coil contains a core of laminated soft iron (thin strips of soft iron). This core increases the magnetic strength of the coil. Surrounding the laminated core are approximately 20,000 turns of fine wire (approximately 42 gauge). These windings are called the secondary coil windings. Surrounding the secondary windings are approximately 150 turns of heavy wire (approximately 21 gauge). These windings are called the primary coil windings. The secondary winding has about 100 times the number of turns of the primary winding, referred to as the **turns ratio**

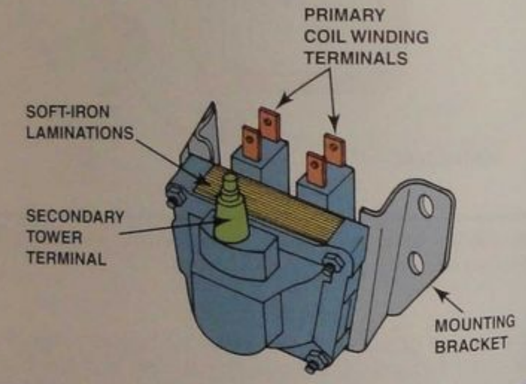


Figure 37–30 Typical air-cooled epoxy-filled E coil.

(approximately 100:1). In many coils, these windings are surrounded with a thin metal shield and insulating paper and placed into a metal container. The metal container and shield help retain the magnetic field produced in the coil windings. The primary and secondary windings produce heat because of the electrical resistance in the turns of wire. Many coils contain oil to help cool the ignition coil. Other coil designs, such as those used on GM's **high energy ignition (HEI)** systems, use an air-cooled, epoxy-sealed **E coil.** The E coil is so named because the laminated, soft iron core is E shaped, with the coil wire turns wrapped around the center "finger" of the E and the primary winding wrapped inside the secondary winding. See Figures 37–30 and 37–31.

The primary windings of the coil extend through the case of the coil and are labeled as positive and negative. The positive terminal of the coil attaches to the ignition switch, which supplies current from the positive battery terminal. The negative terminal is attached to an **ignition control module (ICM** or **igniter),** which opens and closes the primary ignition circuit by opening or closing the ground return path of the circuit. When the ignition switch is on, voltage should be available at *both* the positive terminal and the negative terminal of the coil if the primary windings

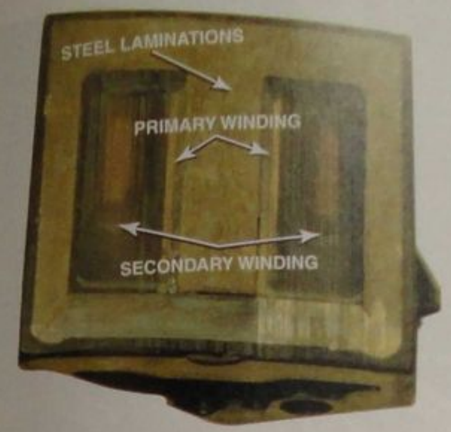


Figure 37–31 Cutaway of a General Motors Type II distributorless ignition coil. Note that the primary windings are inside of the secondary windings.

of the coil have continuity. The labeling of positive (+) and negative (−) of the coil indicates that the positive terminal is *more* positive (closer to the positive terminal of the battery) than the negative terminal of the coil. This condition is called the coil polarity. The polarity of the coil must be correct to ensure that electrons will flow from the hot center electrode of the spark plug on DI systems. *The polarity of an ignition coil is determined by the direction of rotation of the coil windings.* The correct polarity is then indicated on the primary terminals of the coil. If the coil primary leads are reversed, the voltage required to fire the spark plugs is increased by 40%. The coil output voltage is directly proportional to the ratio of primary to secondary turns of wire used in the coil.

FREQUENTLY ASKED QUESTION ???

What Is a "Married" and "Divorced" Coil Design?

An ignition coil contains two windings, a primary winding and a secondary winding, and these windings can be either connected together at one end or kept separated.

- **Married.** These are also called a *tapped transformer* design. See Figure 37–32. The primary winding is electrically connected to the secondary winding. This method is commonly used in older distributor-type ignition system coils, as well as many coil-on-plug designs. The inductive kick, also called *flyback voltage*, created when the primary field collapses is used by the PCM to monitor secondary ignition performance.
- **Divorced.** These are also called a *true transformer* design and used by most waste spark ignition coils to keep both the primary and secondary winding separated.

ELECTROMAGNETIC INTERFERENCE (EMI) SUPPRESSION

Until the advent of the onboard computer, **electromagnetic interference (EMI)** was not a source of real concern to automotive engineers. The problem was mainly one of **radio-frequency interference (RFI),** caused primarily by the use of secondary ignition cables containing a high-resistance, nonmetallic core made of carbon, linen, or fiberglass strands impregnated with graphite.

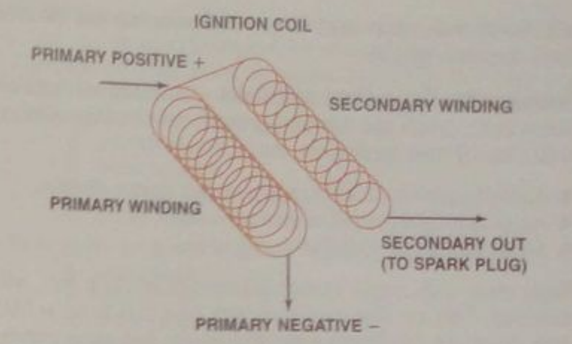


Figure 37–32 A tapped- (married) type of ignition coil where the primary winding is tapped (connected) to the secondary winding.

NOTE: Radio-frequency interference (RFI) is a part of electromagnetic interference (EMI), which deals with interference that affects radio reception.

As the use of electronic and computerized components and systems increased, the problem of electromagnetic interference increased.

Whenever there is current in a conductor, an electromagnetic field is created. When current stops and starts, as in a spark plug cable or a switch that opens and closes, field strength changes. Each time this happens, it creates an electromagnetic signal wave. If it happens rapidly enough, the resulting high-frequency signal waves, or EMI, interfere with radio and television transmission or with other electronic systems such as those under the hood. This is an undesirable side effect of the phenomenon of electromagnetism.

Static electric charges caused by friction of the tires with the road, or the friction of engine drive belts contacting their pulleys, also produce EMI. Drive axles, driveshafts, and clutch or brake lining surfaces are other sources of static electric charges.

There are four ways of transmitting EMI, all of which can be found in a vehicle.

- Conductive coupling is actual physical contact through circuit conductors.
- Capacitive coupling is the transfer of energy from one circuit to another through an electrostatic field between two conductors.
- Inductive coupling is the transfer of energy from one circuit to another as the magnetic fields between two conductors form and collapse.
- Electromagnetic radiation is the transfer of energy by the use of radio waves from one circuit or component to another.

EMI Suppression Devices There are four general ways in which EMI is reduced.

- By the addition of resistance to conductors that suppresses conductive transmission and radiation.
- By the use of capacitors and **radio choke coil** combinations to reduce capacitive and inductive coupling.
- By the use of metal or metallized plastic shielding, which reduces EMI radiation in addition to capacitive and inductive coupling.
- By an increased use of ground straps to reduce conductive transmission and radiation by bypassing the unwanted signals to ground.

Resistance Suppression Adding resistance to a circuit to suppress RFI works only for high-voltage systems. This has been done by the use of resistance spark plug cables, resistor spark plugs,

and the silicone grease used on the distributor cap and rotor of some electronic ignitions.

Suppression Capacitors and Coils Capacitors are installed across many circuits and switching points to absorb voltage fluctuations. Among other applications, they are used:

- Across the primary circuit of some electronic ignition modules.
- Across the output terminal of most alternators.
- Across the armature circuit of electric motors.

Radio choke coils reduce current fluctuations resulting from self-induction. They are often combined with capacitors to act as EMI filter circuits for windshield wiper and electric fuel pump motors. Filters also may be incorporated in wiring connectors.

Shielding Metal shields, such as the ones used in breaker point distributors, block the waves from components that create RFI signals. The circuits of onboard computers are protected to some degree from external electromagnetic waves by their metal housings.

Ground Straps Ground or bonding straps between the engine and chassis of an automobile help suppress EMI conduction and radiation by providing a low-resistance circuit ground path. Such suppression ground straps are often installed between rubber-mounted components and body parts. On some models ground straps are installed between body parts, such as between the hood and a fender panel, where no electrical circuit exists. The strap has no other job than to suppress EMI. Without it, the sheet-metal body and hood could function as a large capacitor. The space between the fender and hood could form an electrostatic field and couple with the computer circuits in the wiring harness routed near the fender panel. See Figure 37–33.

TECH TIP ✓ **Cell Phone Interference**

A cell (cellular) phone emits a weak signal if it is turned on, even though it is not being used. This signal is picked up and tracked by cell phone towers. When the cell phone is called, the cell phone emits a stronger signal to notify the tower that it is on and capable of receiving a phone call. It is this "handshake" signal that can cause interference in the vehicle. Often this signal simply causes some static in the radio speakers even though the radio is off, but it can also cause a false antilock brake (ABS) trouble code to set. These signals from the cell phone create a voltage that is induced in the wires of the vehicle. Because the cell phone usually leaves with the customer, the service technician is often unable to verify the customer concern.

Remember, the interference occurs right *before* the cell phone rings. To fix the problem, connect an external antenna to the cell phone. This step will prevent the induction of a voltage in the wiring of the vehicle.

SUMMARY

1. Capacitors (condensers) are used in numerous automotive applications. Because of their ability to block direct current and pass alternating current, they are used to control radio-frequency interference and are installed in various electronic circuits to protect and control changing current.
2. Most automotive electrical components use magnetism, and the strength of the magnetism depends on both the amount of current (amperes) and the number of turns of wire of each electromagnet.
3. The strength of electromagnets is increased by using a soft-iron core.
4. Voltage can be induced from one circuit to another.
5. Electricity creates magnetism and magnetism creates electricity.
6. Radio-frequency interference (RFI) is a part of electromagnetic interference (EMI).

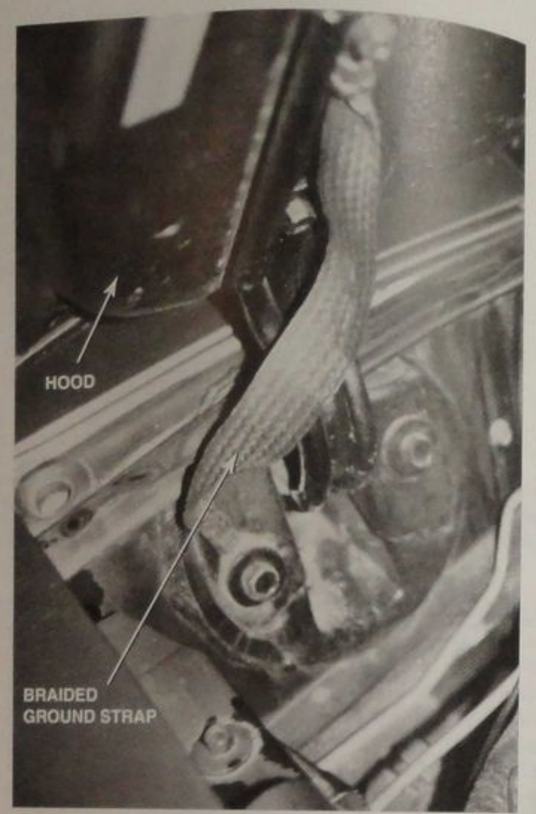


Figure 37–33 To help prevent underhood electromagnetic devices from interfering with the antenna input, it is important that the hood be grounded to the body to form one continuous metal covering around the engine compartment. This is particularly important if the vehicle has a front fender-mounted antenna. If necessary, add a braided ground strap as this Ford Mustang owner did to eliminate radio interference.

REVIEW QUESTIONS

1. How does a capacitor store an electrical charge?
2. How should two capacitors be electrically connected if greater capacitance is needed?
3. What is the result of a cracked magnet?
4. What is the relationship between electricity and magnetism?
5. What is the difference between self-induction and mutual induction?

CHAPTER QUIZ

1. A capacitor _____.
   a. Stores electrons
   b. Passes AC
   c. Blocks DC
   d. All of the above
2. To increase the capacity, capacitors should be connected in _____
   a. Series
   b. Parallel
   c. With resistors connected between the leads
   d. Series-parallel
3. Technician A says that electricity is created if a wire is moved through a magnetic field. Technician B says that a magnetic field is created if current flows through a conductor. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that magnetic lines of force can be seen by placing iron filings on a piece of paper and then holding them over a magnet. Technician B says that the effects of magnetic lines of force can be seen using a compass. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Unlike magnetic poles _____ and like magnetic poles _____.
   a. Repel; attract
   b. Attract; repel
   c. Repel; repel
   d. Attract; attract
6. The conventional theory for current flow is being used to determine the direction of magnetic lines of force. Technician A says that the left-hand rule should be used. Technician B says that the right-hand rule should be used. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Technician A says that a relay is an electromagnetic switch. Technician B says that a solenoid uses a movable core. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Two technicians are discussing electromagnetic induction. Technician A says that the induced voltage can be increased if the speed is increased between the conductor and the magnetic lines of force. Technician B says that the induced voltage can be increased by increasing the strength of the magnetic field. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. An ignition coil operates using the principle of _____.
   a. Electromagnetic induction
   b. Self-induction
   c. Mutual induction
   d. All of the above
10. Electromagnetic interference can be reduced by using a _____.
    a. Resistance
    b. Capacitor
    c. Coil
    d. All of the above

CHAPTER 38

Electronic Fundamentals

OBJECTIVES: After studying Chapter 38, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Identify semiconductor components. • Explain precautions necessary when working around semiconductor circuits. • Discuss where various electronic and semiconductor devices are used in vehicles. • Describe how to test diodes and transistors. • List the precautions that a service technician should follow to avoid damage to electronic components from electrostatic discharge (ESD).

KEY TERMS: anode • base • bipolar transistor • burn in • cathode • center high-mounted stoplight (CHMSL) • clamping diode • collector • control current • despiking diode • diode • doping • dual inline pins (DIP) • electrostatic discharge (ESD) • emitter • FET • forward bias • gate • germanium • hole theory • holes • impurities • integrated circuit (IC) • junction • light-emitting diode (LED) • metal oxide varistor (MOV) • negative temperature coefficient (NTC) • NPN transistor • N-type material • peak inverse voltage (PIV) • peak reverse voltage (PRV) • photodiodes • photons • photoresistor • phototransistor • PNP transistor • polarity • P-type material • rectifier bridge • reverse bias • semiconductors • silicon • silicon-controlled rectifier (SCR) • solar cells • spike protection resistor • suppression diode • thermistor • threshold voltage • transistor • varistors • zener diode

Electronic components are the heart of computers. Knowing how electronic components work helps take the mystery out of automotive electronics.

SEMICONDUCTORS

Semiconductors are neither conductors nor insulators. The flow of electrical current is caused by the movement of electrons in materials having *fewer* than four electrons in their atom's outer orbit. Insulators contain *more* than four electrons in their outer orbit and cannot conduct electricity because their atomic structure is stable (no free electrons).

Semiconductors are materials that contain exactly four electrons in the outer orbit of their atom structure and are, therefore, neither good conductors nor good insulators. Two examples of semiconductor materials are **germanium** and **silicon,** which have no free electrons to provide current flow. However, both of these semiconductor materials can be made to conduct current if another material is added to provide the necessary conditions for electron movement. When another material is added to a semiconductor

material in very small amounts, it is called **doping.** The doping elements are called **impurities;** and therefore, after their addition, the germanium and silicon are no longer considered *pure* elements. The material added to pure silicon or germanium to make it electrically conductive represents only one atom of impurity for every *100 million* atoms of the pure semiconductor material. The resulting atoms are still electrically *neutral,* because the number of electrons still equals the number of protons of the combined materials. These combined materials are classified into two groups depending on the number of electrons in the bonding between the two materials; N-type or P-type materials.

N-TYPE MATERIAL

N-type material is silicon or germanium that is doped with an element such as *phosphorus, arsenic,* or *antimony,* each having five electrons in its outer orbit. These five electrons are combined with the four electrons of the silicon or germanium to total nine electrons. There is room for only eight electrons in the bonding between the semiconductor material and the doping material. This leaves extra electrons, and even though the material is still electrically neutral, these extra electrons tend to repel other electrons outside the material. See Figure 38–1.

P-TYPE MATERIAL

P-type material is produced by doping silicon or germanium with the element *boron* or the element indium. These impurities have only three electrons in their outer shell and, when combined with the semiconductor material, result in a material with seven electrons, one electron *less* than is required for atom bonding. This lack of one electron makes the material able to attract electrons, even though the material still has a neutral charge. This material tends to attract electrons to fill the **holes** for the missing eighth electron in the bonding of the materials. See Figure 38–2.

HOW HOLES MOVE

Current flow is expressed as the movement of electrons from one atom to another. In semiconductor and electronic terms, the movement of electrons fills the holes of the P-type material. Therefore, as the holes are filled with electrons, the unfilled holes move opposite to the flow of the electrons. This concept of the movement of the holes is called the **hole theory** of current flow. The holes move in the direction opposite that of electron flow. See Figure 38–3.

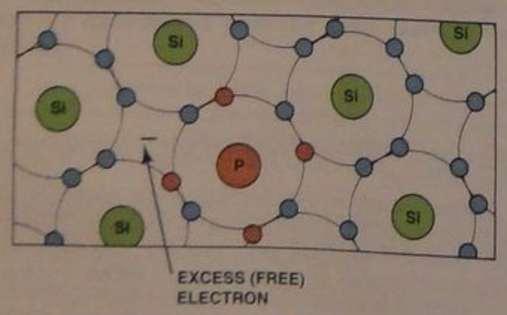


Figure 38–1 N-type material. Silicon (Si) doped with a material (such as phosphorus) with five electrons in the outer orbit results in an extra free electron.

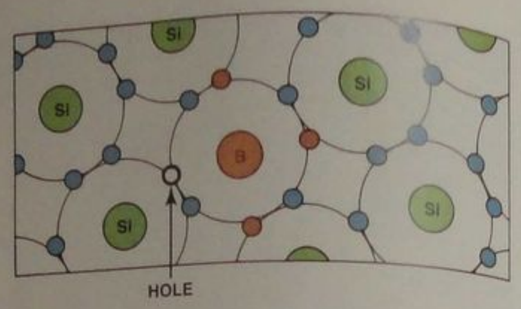


Figure 38–2 P-type material. Silicon (Si) doped with a material [such as boron (B)] with three electrons in the outer orbit results in a hole capable of attracting an electron.

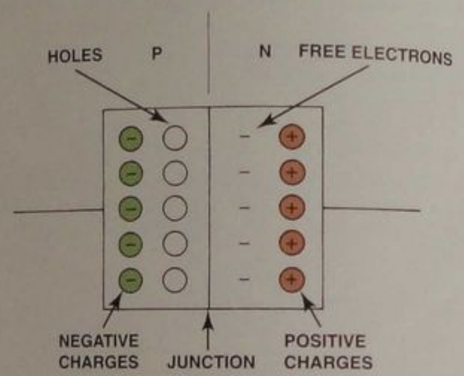


Figure 38–3 Unlike charges attract and the current carriers (electrons and holes) move toward the junction.

SUMMARY OF SEMICONDUCTORS

The following is a summary of semiconductor fundamentals.

1. The two types of semiconductor materials are P type and N type. N-type material contains extra electrons; P-type material contains holes due to missing electrons. The number of excess electrons in an N-type material must remain constant, and the number of holes in the P-type material must also remain constant. Because electrons are interchangeable, movement of electrons in or out of the material is possible to maintain a balanced material.
2. In P-type semiconductors, electrical conduction occurs mainly as the result of holes (absence of electrons). In N-type semiconductors, electrical conduction occurs mainly as the result of electrons (excess of electrons).
3. Hole movement results from the jumping of electrons into new positions.
4. Under the effect of a voltage applied to the semiconductor, electrons travel toward the positive terminal and holes move toward the negative terminal. The direction of hole current agrees with the conventional direction of current flow.

DIODES

A **diode** is an electrical one-way check valve made by combining a P-type material and an N-type material. The word *diode* means "having two electrodes." Electrodes are electrical connections; the positive electrode is called the **anode,** while the negative electrode is called the **cathode.** See Figure 38–4. The point where the two types of materials join is called the **junction.**

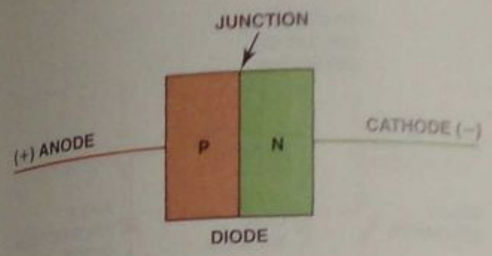


Figure 38–4 A diode is a component with P- and N-type material together. The negative electrode is called the cathode and the positive electrode is called the anode.

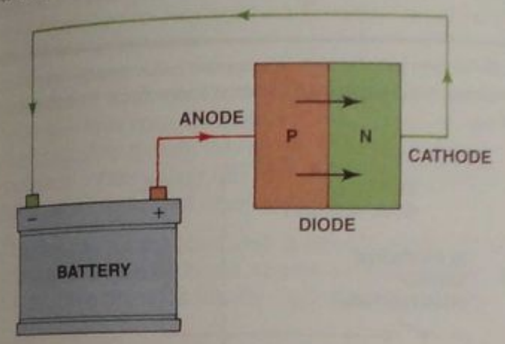


Figure 38–5 Diode connected to a battery with correct polarity (+ to + and – to –). Current flows through the diode. This condition is called forward bias.

The N-type material has one extra electron, which can flow into the P-type material. The P type has a need for electrons to fill its holes. If a battery were connected to the diode positive (+) to P-type material and negative (–) to N-type material, as illustrated in Figure 38–5, then the electrons that left the N-type material and flowed into the P-type material to fill the holes would be quickly replaced by the electron flow from the battery. As a result, current would flow through the diode with low resistance. This condition is called **forward bias.**

If the battery connections were reversed and the positive side of the battery was connected to the N-type material, the electrons would be pulled toward the battery and away from the junction of the N- and P-type materials. (Remember, unlike charges attract, whereas like charges repel.) Because electrical conduction requires the flow of electrons across the junction of the N- and P-type materials and because the battery connections are actually reversed, the diode offers very high resistance to current flow. This condition is called **reverse bias.** See Figure 38–6.

Therefore, diodes allow current flow only when current of the correct polarity is connected to the circuit. Diodes are used in alternators to control current flow in one direction. Diodes are also used in computer controls, air-conditioning circuits, and many other circuits to prevent possible damage due to reverse current flows that may be generated within the circuit. See Figure 38–7.

FREQUENTLY ASKED QUESTION ???

What Is the Difference Between Electricity and Electronics?

Electronics usually means that solid-state devices are used in the electrical circuits. Electricity as used in automotive applications usually means electrical current flow through resistance and loads without the use of diodes, transistors, or other electronic devices.

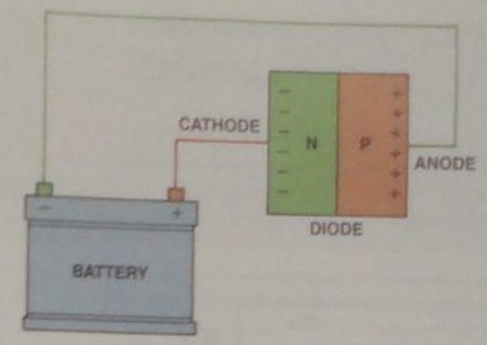


Figure 38–6 Diode connected with reversed polarity. No current flows across the junction between the P-type and N-type material. This connection is called reverse bias.

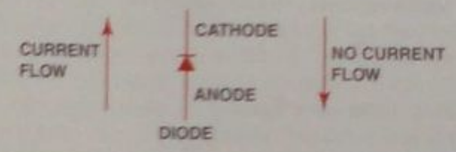


Figure 38–7 Diode symbol and electrode names.

ZENER DIODES

A **zener diode** is a specially constructed diode designed to operate with a reverse-bias current. Zener diodes were named in 1934 for their inventor, Clarence Melvin Zener, an American professor of physics. A zener diode acts as any diode in that it blocks reverse-bias current, but only up to a certain voltage. Above this certain voltage (called the breakdown voltage or the zener region), a zener diode will conduct current without damage to the diode. A zener diode is heavily doped, and the reverse-bias voltage does not harm the material. The voltage drop across a zener diode remains practically the same before and after the breakdown voltage, and this factor makes a zener diode perfect for voltage regulation. Zener diodes can be constructed for various breakdown voltages and can be used in a variety of automotive and electronic applications, especially for electronic voltage regulators. See Figure 38–8.

TECH TIP ✓ "Burn In" to Be Sure

A common term heard in the electronic and computer industry is **burn in.** Burn in means to operate an electronic device, such as a computer, for a period from several hours to several days.

Most electronic devices fail in infancy, or during the first few hours of operation. This early failure occurs if there is a manufacturing defect, especially at the P-N junction of any semiconductor device. The junction will usually fail after only a few operating cycles.

What does all of this information mean to the average person? When purchasing a personal or business computer, have the computer burned in before delivery. This step helps ensure that all of the circuits have survived infancy and that the chances of chip failure are greatly reduced. Display model sound or television equipment may be a good value, because during its operation as a display model, it has been burned in. The automotive service technician should be aware that if a replacement electronic device fails shortly after installation, the problem might be a case of early electronic failure.

NOTE: Whenever there is a failure of a replacement part, the technician should always check for excessive voltage or heat to and around the problem component.

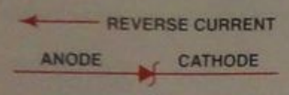


Figure 38–8 A zener diode blocks current flow until a certain voltage is reached, then it permits current to flow.

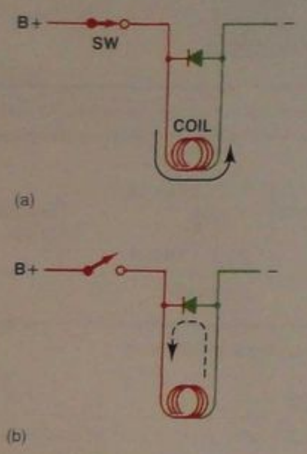


Figure 38–9 (a) Notice that when the coil is being energized, the diode is reverse biased and the current is blocked from passing through the diode. The current flows through the coil in the normal direction. (b) When the switch is opened, the magnetic field surrounding the coil collapses, producing a high-voltage surge in the reverse polarity of the applied voltage. This voltage surge forward biases the diode, and the surge is dissipated harmlessly back through the windings of the coil.

CLAMPING DIODES

Diodes can be used as a high-voltage clamping device when the power (+) is connected to the cathode (−) of the diode. If a coil is pulsed on and off, a high-voltage spike is produced whenever the coil is turned off. To control and direct this possibly damaging high-voltage spike, a diode can be installed across the leads to the coil to redirect the high-voltage spike back through the coil windings to prevent possible damage to the rest of the vehicle's electrical or electronic circuits. A diode connected across the terminals of a coil to control voltage spikes is called a **clamping diode.** See Figure 38–9. Clamping diodes can also be called **despiking** or **suppression diodes.**

Diodes were first used on AC compressor clutch coils at the same time electronic devices were first used. The diode was used to help prevent damage to delicate electronic circuits anywhere in the vehicle's electrical system. See Figure 38–10. Because most automotive circuits eventually are electrically connected to each other in parallel, a high-voltage surge anywhere in the vehicle could damage electronic components in other circuits.

NOTE: The circuits most likely to be affected by the high-voltage surge, if the diode fails, are the circuits controlling the operation of the AC compressor clutch, and any component that uses a coil, such as those of the blower motor and climate control units.

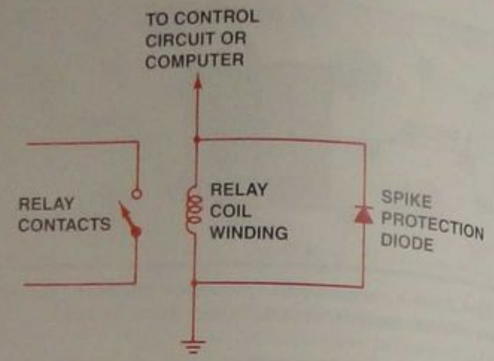


Figure 38–10 Spike protection diodes are commonly used in computer-controlled circuits to prevent damaging high-voltage surges that occur anytime current flowing through a coil is stopped.

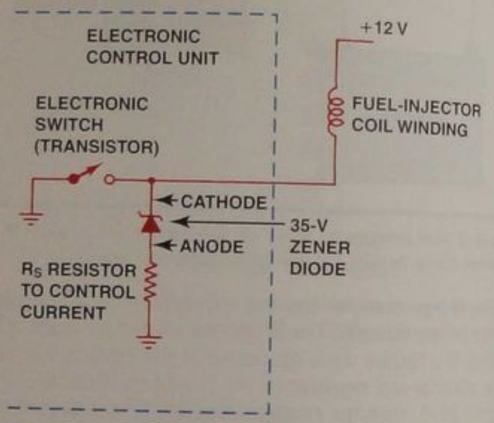


Figure 38–11 A zener diode is commonly used inside automotive computers to protect delicate electronic circuits from high-voltage spikes. A 35-volt zener diode will conduct any voltage spike resulting from the discharge of a coil safely to ground through a current-limiting resistor in series with the zener diode.

ZENER DIODE DESPIKING PROTECTION

Zener diodes can also be used to control high-voltage spikes and keep them from damaging delicate electronic circuits. Zener diodes are most commonly used in electronic fuel-injection circuits that control the firing of the injectors. If clamping diodes were used in parallel with the injection coil, the resulting clamping action would tend to delay the closing of the fuel-injector nozzle. A zener diode is commonly used to clamp only the higher-voltage portion of the resulting voltage spike without affecting the operation of the injector. See Figure 38–11.

DESPIKING PROTECTIVE RESISTORS

All coils must use some protection against high-voltage spikes that occur when the voltage is removed from any coil. Instead of a diode installed in parallel with the coil windings, a resistor can be used and is called a **spike protection resistor.** See Figure 38–12. Resistors are often preferred for two reasons:

1. Coils will usually fail when shorted rather than open, as this shorted condition results in greater current flow in the circuit. A diode installed in the reverse-bias direction cannot control this extra current, whereas a resistor in parallel can help reduce potentially damaging current flow if the coil becomes shorted.

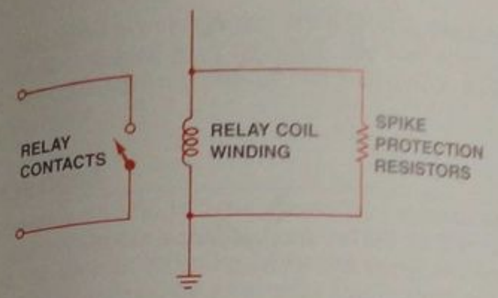


Figure 38–12 A despiking resistor is used in many automotive applications to help prevent harmful high-voltage surges from being created when the magnetic field surrounding a coil collapses when the coil circuit is opened.

2. The protective diode can also fail, and diodes usually fail shorted before they blow open. If a diode becomes shorted, excessive current can flow through the coil circuit, perhaps causing damage. A resistor usually fails open, and therefore, even in failure, could not in itself cause a problem.

Resistors on coils are often used in climate-control circuit solenoids to control vacuum to the various air management system doors as well as other electronically controlled applications.

DIODE RATINGS

Most diodes are rated according to their maximum current flow in the forward-bias direction and their resistance to high voltage in the reverse-bias direction. This rating of resistance to reverse-bias voltage is called the **peak inverse voltage (PIV)** rating; also known as the **peak reverse voltage (PRV)** rating. The peak inverse voltage is a specification for diodes. It is important that the service technician specify and use only a replacement diode that has the same or a higher rating than specified by the vehicle manufacturer. Typical 1-ampere diodes use a code that indicates the PIV rating. For example:

1N 4001-50 V PIV
1N 4002-100 V PIV
1N 4003-200 V PIV
1N 4004-400 V PIV
1N 4005-600 V PIV

The third rating in the list (1N 4003-200 V PIV) is the one most commonly used for automotive applications.

The "1N" means that the diode has one P-N junction. A higher-rating diode can be used with no problems (except for slightly higher cost, even though the highest-rated diode generally costs less than $1). Never substitute a *lower*-rated diode than is specified.

The voltage drop across a diode is about the same voltage as that required to forward bias the diode. If the diode is made from germanium, the forward voltage is 0.3 to 0.5 volt. If the diode is made from silicon, the forward voltage is 0.5 to 0.7 volts.

NOTE: When diodes are tested using a digital multimeter, the meter will display the voltage drop across the P-N junction (about 0.5 to 0.7 volts) when the meter is set to the *diode check* position.

LIGHT-EMITTING DIODES

All diodes radiate some energy during normal operation. Most diodes radiate heat because of the junction barrier voltage drop (typically 0.6 volt for silicon diodes). **Light-emitting diodes (LEDs)** radiate light when current flows through the diode in the forward-bias direction. See Figure 38–13. The forward-bias voltage required for an LED ranges between 1.5 and 2.2 volts.

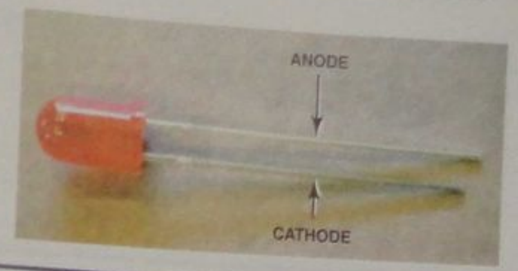


Figure 38–13 A typical light-emitting diode (LED). This particular LED is designed with a built-in resistor so that 12 volts DC may be applied directly to the leads without an external resistor. Normally a 300- to 500-Ω-watt resistor is required to be attached in series with the LED to control current flow to about 0.020 A (20 mA) or damage to the P-N junction can occur.

An LED will only light if the voltage at the anode (positive electrode) is at least 1.5 to 2.2 volts higher than the voltage at the cathode (negative electrode).

If an LED were connected across a 12-volt automotive battery, the LED would light brightly, but only for a second or two. Excessive current (amperes) that flows across the P-N junction of any electronic device can destroy the junction. A resistor *must* be connected in series with every diode (including LEDs) to control current flow across the P-N junction. This protection should include the following:

1. The value of the resistor should be from 300 to 500 ohms for each P-N junction. Commonly available resistors in this range include 470-, 390-, and 330-ohm resistors.
2. The resistors can be connected to either the anode or the cathode end. (**Polarity** of the resistor does not matter.) Current flows through the LED in series with the resistor, and the resistor will control the current flow through the LED regardless of its position in the circuit.
3. Resistors protecting diodes can be actual resistors or other current-limiting loads such as lamps or coils. Therefore, the symbol usually assigned to P-N junction protection is either R_S or R_L.

   R_S means **r**esistor in **s**eries with the P-N junction.

   R_L means **r**esistive **l**oad protecting the P-N junction.

   With the current-limiting devices to control the current, the average LED will require about 20 to 30 milliamperes (mA), or 0.020 to 0.030 ampere.

FREQUENTLY ASKED QUESTION ???

How Does an LED Emit Light?

An LED contains a chip that houses P-type and N-type materials. The junction between these regions acts as a barrier to the flow of electrons between the two materials. When a voltage of 1.5 to 2.2 volts of the correct polarity is applied, current will flow across the junction. As the electrons enter the P-type material, it combines with the holes in the material and releases energy in the form of light (called **photons**). The amount and color the light produces depends on materials used in the creation of the semiconductor material.

LEDs are very efficient compared to conventional incandescent bulbs, which depend on heat to create light. LEDs generate very little heat, with most of the energy consumed converted directly to light.

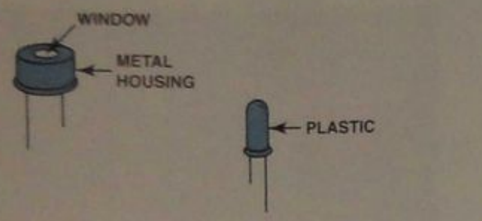


Figure 38–14 Typical photodiodes.

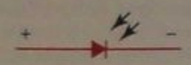


Figure 38–15 Symbol for a photodiode. The arrows represent light striking the P-N junction of the photodiode.

PHOTODIODES

All P-N junctions emit energy, mostly in the form of heat or light such as with an LED. In fact, if an LED is exposed to bright light, a voltage potential is established between the anode and the cathode. **Photodiodes** are specially constructed to respond to various wavelengths of light with a "window" built into the housing. See Figure 38–14.

Photodiodes are frequently used in steering-wheel controls. If several photodiodes are placed on the steering column end and LEDs or phototransistors are placed on the steering wheel side, data can be transmitted between the two moving points without the interference that could be caused by physical-contact types of units.

A photodiode is a diode that is sensitive to light. When light energy strikes the diode, electrons are released and the diode will conduct in the forward-bias direction. (The light energy is used to overcome the barrier voltage.)

The resistance across the photodiode decreases as the intensity of the light increases. This characteristic makes the photodiode a useful electronic device for controlling some automotive lighting systems. The symbol for a photodiode is shown in Figure 38–15.

PHOTORESISTORS

A **photoresistor** is a semiconductor material (usually cadmium sulfide) that changes resistance with the presence or absence of light.

Dark = high resistance

Light = low resistance

Because resistance is reduced when the photoresistor is exposed to light, the photoresistor can be used to control headlight dimmer relays. It is also useful in many other nonautomotive applications. See Figure 38–16 for the symbols for a photoresistor.

VARISTORS

Varistors are resistors whose resistance depends upon the level of voltage applied. A varistor, or **metal oxide varistor (MOV),** operates similarly to two back-to-back zener diodes. Varistors offer high resistance at lower voltages yet become highly conductive at higher voltage levels. Varistors are therefore commonly found in computer circuits where they help prevent high-voltage transients from damaging delicate electronic circuits. If a high-voltage surge is applied to a varistor, the varistor becomes conductive, and it can be connected with another standard resistor to conduct the high voltage to ground.

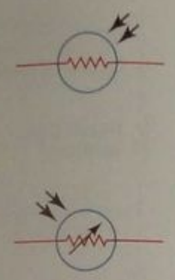


Figure 38–16 Either symbol may be used to represent a photoresistor.

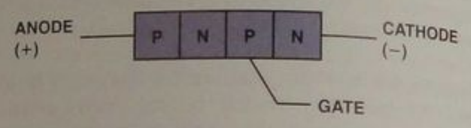


Figure 38–17 Symbol and terminal identification of an SCR.

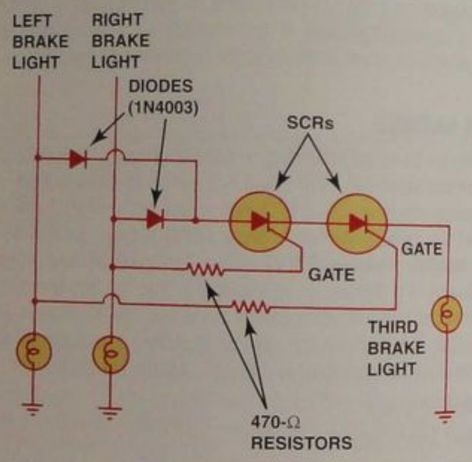


Figure 38–18 Wiring diagram for a CHMSL.

SILICON-CONTROLLED RECTIFIERS

A **silicon-controlled rectifier (SCR)** is commonly used in the electronic circuits of various automotive applications. An SCR is a semiconductor device that looks like two diodes connected end-to-end. See Figure 38–17. If the anode is connected to a higher voltage source than the cathode in a circuit, no current will flow as would occur with a diode. If, however, a positive voltage source is connected to the **gate** of the SCR, then current can flow from anode to cathode with a typical voltage drop of 1.2 volts (double the voltage drop of a typical diode—0.6 volt).

If the voltage source at the gate is shut off, the current will still continue to flow through the SCR until the source current is stopped.

See Figure 38–18 for a typical application in which SCRs can be used to construct a circuit for a **center high-mounted stoplight (CHMSL).** If this third stoplight were wired into either the left- or the right-side brake light circuit, the CHMSL would also flash whenever the turn signals were used for the side that was connected to the CHMSL. When two SCRs are used, both brake lights must be activated to supply current to the CHMSL. The current to the CHMSL is shut off when both SCRs lose their power source (when the brake pedal is released, which stops the current flow to the brake lights).

THERMISTORS

A **thermistor** is a semiconductor material such as silicon that has been doped to provide a given resistance. When the thermistor is heated, the electrons within the crystal gain energy and electrons are released. This means that a thermistor actually produces a small voltage when heated. If voltage is applied to a thermistor, its resistance decreases because the thermistor itself is acting as a current carrier rather than as a resistor at higher temperatures.

A thermistor is commonly used as a temperature-sensing device for coolant temperature and intake manifold air temperature. Because thermistors operate in a manner opposite to that of a typical conductor, they are called **negative temperature coefficient (NTC)** thermistors; their resistance decreases as the temperature increases. Thermistor symbols are shown in Figure 38–19.

RECTIFIER BRIDGES

The word *rectify* means "to set straight"; therefore, a rectifier is an electronic device (such as a diode) that is used to convert a changing voltage into a straight or constant voltage. A **rectifier bridge** is a group of diodes that is used to change alternating current into direct current. A rectifier bridge is used in alternators to rectify the alternating current produced in the stator (stationary windings) of the generator (alternator). These rectifier bridges contain six diodes: one pair of diodes for each of the three stator windings. See Figure 38–20.

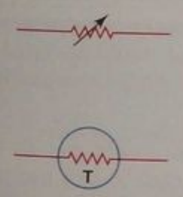


Figure 38–19 Symbols used to represent a thermistor.

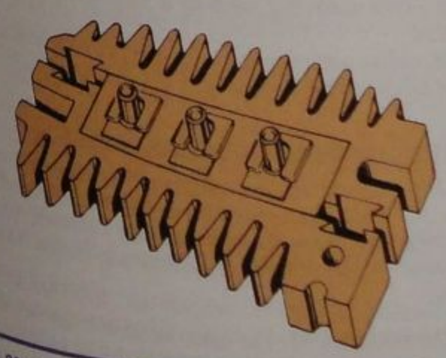


Figure 38–20 This rectifier bridge contains six diodes; three on each side and mounted in an aluminum-finned unit to help keep the diode cool during generator (alternator) operation.

TRANSISTORS

A **transistor** is a semiconductor device that can perform the following electrical functions:

1. Act as an electrical switch in a circuit.
2. Act as an amplifier of current in a circuit.
3. Regulate the current in a circuit.

The word *transistor,* derived from the words *transfer* and *resistor,* is used to describe the transfer of current across a resistor. A transistor is made of three alternating sections or layers of P- and N-type material. This type of transistor is usually called a **bipolar transistor.** A transistor that has P-type material on each end, with N-type material in the center, is called a **PNP transistor.** Another type, with the exact opposite arrangement, is called an **NPN transistor.**

The center section of a transistor is called the **base;** it controls current flow through the transistor. See Figure 38–21.

The material at one end of a transistor is called the **emitter** and the material at the other end is called the **collector.** All transistor symbols contain an arrow indicating the emitter part of the transistor. The arrow points in the direction of current flow (conventional theory).

NOTE: When an arrowhead appears in any semiconductor symbol, it stands for a P-N junction and it points from the P-type material toward the N-type material. The arrow on a transistor is always attached to the *emitter* side of the transistor.

HOW A TRANSISTOR WORKS

A transistor is similar to two back-to-back diodes that can conduct current in only one direction. As in a diode, N-type material can conduct electricity by means of its supply of free electrons, and P-type material conducts by means of its supply of positive holes.

A transistor will allow current flow if the electrical conditions allow it to switch on, in a manner similar to the working of an electromagnetic relay. The electrical conditions are determined, or switched, by means of the base or *B.* The base will carry current only when the proper voltage and polarity are applied. The main circuit current flow travels through the other two parts of the transistor: the emitter *E* and the collector *C.* See Figure 38–22.

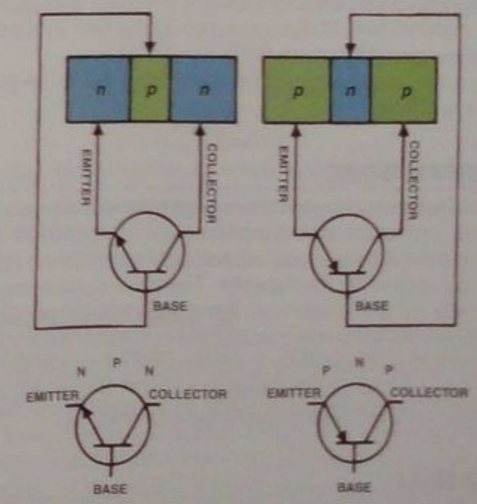


Figure 38–21 Transistor symbols and construction.

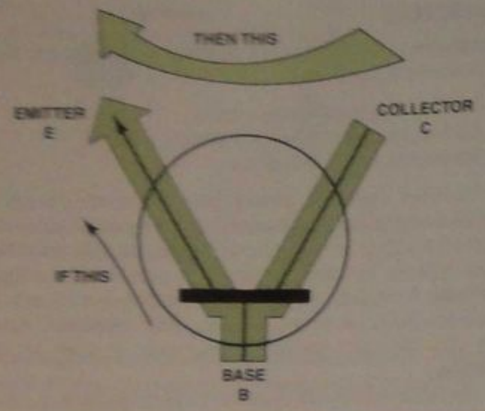


Figure 38–22 Basic transistor operation. A small current flowing through the base and emitter of the transistor turns on the transistor and permits a higher-amperage current to flow from the collector and the emitter.

If the base current is turned off or on, the current flow from collector to emitter is turned off or on. The current controlling the base is called the **control current.** The control current must be high enough to switch the transistor on or off. (This control voltage, called the **threshold voltage,** must be above approximately 0.3 volt for germanium and 0.6 volt for silicon transistors.) This control current can also "throttle" or regulate the main circuit, in a manner similar to the operation of a water faucet.

INTEGRATED CIRCUITS

Solid-state components are used in many electronic semiconductors and/or circuits. They are called "solid-state" because they have no moving parts, just higher or lower voltage levels within the circuit. Discrete (individual) diodes, transistors, and other semiconductor devices were often used to construct early electronic ignition and electronic voltage regulators. Newer-style electronic devices use the same components, but they are now combined (integrated) into one group of circuits, and are thus called an **integrated circuit (IC).**

Integrated circuits are usually encased in a plastic housing called a CHIP with two rows of inline pins, this arrangement is called the **dual inline pins (DIP)** chips. See Figure 38–23.

Therefore, most computer circuits are housed as an integrated circuit in a DIP chip.

PHOTOTRANSISTORS

Similar in operation to a photodiode, a **phototransistor** uses light energy to turn on the base of a transistor. A phototransistor is an NPN transistor that has a large exposed base area to permit light to act as the control for the transistor. Therefore, a phototransistor may or may not have a base lead. If not, they have only a collector and emitter lead. When the phototransistor is connected to a powered circuit, the light intensity is amplified by the gain of the transistor. Phototransistors are frequently used in steering-wheel controls. Figure 38–24 shows phototransistor symbols.

SOLAR CELLS

Solar cells are another type of semiconductor device where light energy is used to produce a small current flow by dislodging electrons within the structure. Solar cells are stacked and/or grouped in large sections to enable them to supply useful amounts of current.



Figure 38–23 A typical automotive computer with the case removed to show all of the various electronic devices and integrated circuits (ICs). The large red and orange devices are ceramic capacitors.

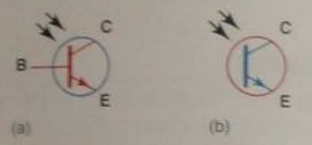


Figure 38–24 Symbols for a phototransistor. (a) Uses the line for the base; (b) does not.

HOW TO TEST DIODES AND TRANSISTORS

Diodes and transistors can be tested with an ohmmeter. The diode or transistor being tested should be disconnected from the circuit for best results. Use the *diode-check* position on a digital multimeter. See Figure 38–25.

Diodes A good diode should give an over limit (OL) reading with the test leads attached to each lead of the diode in one way, and a voltage reading of 0.400 V to 0.600 V when the leads are reversed. This reading is the voltage drop or the barrier voltage across the P-N junction of the diode.

1. A low-voltage reading with the meter leads attached both ways across a diode means that the diode is *shorted* and must be replaced.
2. An OL reading with the meter leads attached both ways across a diode means that the diode is *open* and must be replaced.

ELECTRONIC COMPONENT FAILURE CAUSES

Electronic components, such as electronic ignition modules, electronic voltage regulators, onboard computers, and any other electronic circuit, are generally very reliable; however, failure can occur. Some frequent causes of premature failure include the following.

Poor Connections It has been estimated that most engine computers returned as defective have simply had poor connections at the wiring harness terminal ends. These faults are often intermittent and hard to find.

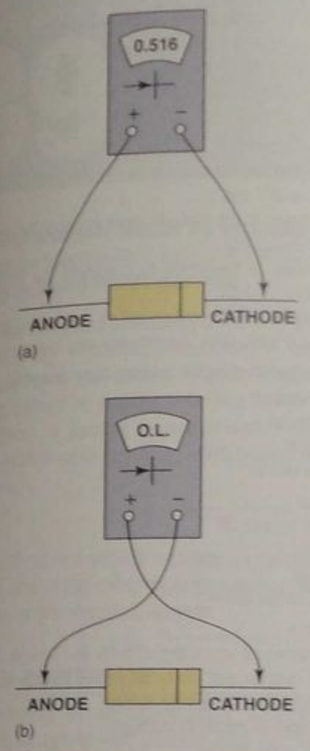


Figure 38–25 To check a diode, select "diode check" on a digital multimeter. The display will indicate the voltage drop (difference) between the meter leads. The meter itself applies a low-voltage signal (usually about 3 volts) and displays the difference on the display. (a) When the diode is forward biased, the meter should display a voltage between 0.500 and 0.700 V (500 mV to 700 mV). (b) When the meter leads are reversed, the meter should read OL (over limit) because the diode is reverse biased and blocking current flow.

HINT: When cleaning electronic contacts, use a pencil eraser. This cleans the contacts without harming the thin protective coating used on most electronic terminals.

Heat The operation and resistance of electronic components and circuits are affected by heat. Electronic components should be kept as cool as possible and never hotter than 260°F (127°C).

Voltage Spikes A high-voltage spike can literally burn a hole through semiconductor material. The source of these high-voltage spikes is often the discharge of a coil without proper (or with defective) despiking protection.

A poor electrical connection at the battery or other major electrical connection can cause high-voltage spikes to occur, because the entire *wiring harness creates its own magnetic field,* similar to that formed around a coil. If the connection is loose and momentary loss of contact occurs, a high-voltage surge can occur through the entire electrical system.

To help prevent this type of damage, ensure that all electrical connections, including grounds, are properly clean and tight.

Excessive Current All electronic circuits are designed to operate within a designated range of current (amperes). If a solenoid or relay is controlled by a computer circuit, the resistance of that solenoid or relay becomes a part of that control circuit. If a coil winding inside the solenoid or relay becomes shorted, the resulting lower resistance will increase the current through the circuit. Even though individual components are used with current-limiting resistors in series, the coil winding resistance is also used as a current-control component in the circuit. If a computer fails, always measure the resistance across all computer-controlled relays and solenoids. The resistance should be within specifications (generally over 20 ohms) for each component that is computer controlled.

TECH TIP ✓ **Blinking LED Theft Deterrent**

A blinking (flashing) LED consumes only about 5 milliamperes (5/1,000 of one ampere or 0.005 A). Most alarm systems use a blinking red LED to indicate that the system is armed. A fake alarm indicator is easy to make and install.

A 470-ohm 1/2-watt resistor limits current flow to prevent battery drain. The positive terminal (anode) of the diode is connected to a fuse that is hot at all times, such as the cigarette lighter. The negative terminal (cathode) of the LED is connected to any ignition-controlled fuse. See Figure 38–26.

When the ignition is turned off, the power flows through the LED to ground and the LED flashes. To prevent distraction during driving, the LED goes out whenever the ignition is on. Therefore, this fake theft deterrent is "auto setting" and no other action is required to activate it when you leave your vehicle except to turn off the ignition and remove the key as usual.

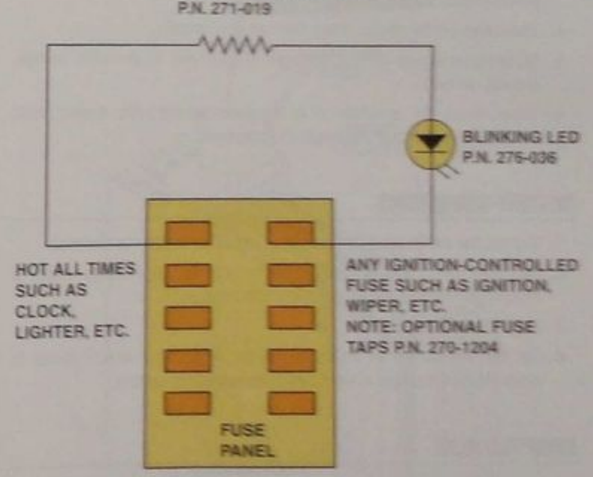


Figure 38–26 Schematic for a blinking LED theft deterrent.

ELECTROSTATIC DISCHARGE

Electrostatic discharge (ESD) is created when static charges build up on the human body whenever movement occurs. The friction of the clothing and the movement of shoes against carpet or vinyl floors cause a high voltage to build. Then when we touch a conductive material, such as a doorknob, the static charge is rapidly discharged. These charges, although just slightly painful to us, can cause severe damage to delicate electronic components. The following are typical static voltages.

- If you can feel it, it is at least 3,000 volts.
- If you can hear it, it is at least 5,000 volts.
- If you can see it, it is at least 10,000 volts.

Although these voltages seem high, the current, in amperes, is extremely low. However, sensitive electronic components such as vehicle computers, radios, and instrument panel clusters can be ruined if exposed to as little as 30 volts. This is a problem, because harm can occur to components at voltages lower than we can feel. To help prevent damage to components, follow these easy steps.

1. Keep the replacement electronic component in the protective wrapping until just before installation.
2. Before handling any electronic component, ground yourself to a good conductor to drain away any static charge.
3. Do not touch the terminals of electronic components.

If these precautions are observed, ESD damage can be eliminated or reduced. Remember, just because the component works after being touched does not mean that damage has not occurred. Often, a section of the electronic component may be damaged, yet will not fail until several days or weeks later.

SUMMARY

1. Semiconductors are constructed by doping semiconductor materials such as silicon.
2. N-type and P-type materials can be combined to form diodes, transistors, SCRs, and computer chips.
3. Diodes can be used to direct and control current flow in circuits and to provide despiking protection.
4. Transistors are electronic relays that can also amplify.
5. All semiconductors can be damaged if subjected to excessive voltage, current, or heat.
6. Never touch the terminals of a computer or electronic device; static electricity can damage electronic components.

REVIEW QUESTIONS

1. Explain the difference between P-type material and N-type material.
2. Describe how a diode can be used to suppress high-voltage surges in automotive components or circuits containing a coil.
3. Explain how a transistor works.
4. List the precautions to which all service technicians should adhere in order to avoid damage to electronic and computer circuits.

CHAPTER QUIZ

1. A semiconductor is a material _____.
   a. With fewer than four electrons in the outer orbit of its atoms
   b. With more than four electrons in the outer orbit of its atoms
   c. With exactly four electrons in the outer orbit of its atoms
   d. Determined by other factors besides the number of electrons
2. The arrow in a symbol for a semiconductor device _____.
   a. Points toward the negative
   b. Points away from the negative
   c. Is attached to the emitter
   d. Both a and c.
3. To forward bias a silicon diode _____.
   a. The voltage at the anode must exceed the voltage at the cathode by 0.5 to 0.7 volt.
   b. The voltage at the cathode must exceed the voltage at the anode by 0.3 to 0.5 volt.
   c. The voltage at the anode must exceed the voltage at the cathode by 0.3 to 0.5 volt.
   d. The anode must be connected to a resistor (300 to 500 ohms) and 12.0 volts, with the cathode also connected to 12.0 volts.
4. A transistor is controlled by the polarity and current at _____.
   a. The collector
   b. The emitter
   c. The base
   d. Both a and b.
5. A transistor can _____.
   a. Switch on and off
   b. Amplify
   c. Throttle
   d. Do all of the above
6. Clamping diodes _____.
   a. Are connected into a circuit with the positive (+) voltage source to the cathode and the negative (−) voltage to the anode
   b. Are also called despiking diodes
   c. Can suppress transient voltages
   d. Are all of the above
7. A zener diode is normally used for voltage regulation. A zener diode, however, can also be used for high-voltage spike protection if connected _____.
   a. Positive to anode, negative to cathode
   b. Positive to cathode, ground to anode
   c. Negative to anode, cathode to a resistor then to a lower-voltage terminal
   d. Both a and c.
8. The forward-bias voltage required for an LED is _____.
   a. 0.3 to 0.5 volt
   b. 0.5 to 0.7 volt
   c. 1.5 to 2.2 volts
   d. 4.5 to 5.1 volts
9. A good NPN transistor should test low resistance (low-voltage drop) between the _____ and _____, and high resistance (over limit voltage drop) between the _____ and _____.
   a. Base; emitter; emitter; collector
   b. Emitter; collector; gate; trigger
   c. Trigger; base; collector; gate
   d. Collector; base; emitter; base
10. ESD is at least how many volts if you feel a shock?
    a. 1,000 volts
    b. 3,000 volts
    c. 5,000 volts
    d. 10,000 volts

CHAPTER 39

Batteries and Battery Testing

OBJECTIVES: After studying Chapter 39, the reader will be able to: Prepare for the ASE battery diagnosis and service (A6) certification test content area "B". • Describe how a battery works. • List the precautions necessary whenever working with batteries. • Explain how to safely charge a battery. • Discuss how to perform a battery drain test.

KEY TERMS: absorbed glass mat (AGM) battery • ampere-hour (Ah) rating • antimony • battery electrical drain test • calcium • cells • cold-cranking amperes (CCA) • conductance testing • cranking amperes (CA) • deep cycling • dynamic voltage • electrolyte • element • flooded cell battery • gassing • gell battery • grids • ignition off draw (IOD) test • jump-starting • lead dioxide (peroxide) • lead sulfate • load test • low-water-loss battery • maintenance-free battery • marine cranking amperes (MCA) • meniscus • open circuit battery voltage test • parasitic load test • partitions • pasting • porous lead • radial-grid design • recombinant design battery • reserve capacity (RC) • sealed lead-acid (SLA) battery • sealed valve regulated (SVR) battery • sediment chamber • separators • specific gravity • sponge lead • valve regulated lead-acid (VRLA) battery

Everything electrical in a vehicle receives its current from the battery. The battery is one of the most important parts of a vehicle and is the foundation for the entire electrical system.

PURPOSE OF A BATTERY

The primary purpose of an automotive battery is to provide a source of electrical power for starting and for electrical demands that exceed generator output. The battery also acts as a stabilizer to the voltage for the entire electrical system. The battery is a voltage stabilizer because it acts as a reservoir where large amounts of current (amperes) can be removed quickly during starting and replaced gradually by the generator during charging. The battery must be in good (serviceable) condition before the charging system and the cranking system can be tested. For example, if a battery is discharged, the cranking circuit (starter motor) could test as being defective because the battery voltage might drop below specifications. The charging circuit could also test as being defective because of a weak or discharged battery. It is important to test the vehicle battery before further testing of the cranking or charging system.

BATTERY CONSTRUCTION

Most automotive battery cases (container or covers) are constructed of polypropylene, a thin (approximately 0.08 inch [.0 millimeters] thick), strong, and lightweight plastic. Containers for industrial batteries and some truck batteries are constructed of a hard, thick, rubber material.

Inside the case, there are six cells (for a 12-volt battery). Each cell has positive and negative plates. See Figure 39–1. Built into the bottom of many batteries are ribs that support the lead-alloy plates and provide a space for sediment to settle. This space, or **sediment chamber,** prevents spent active material from causing a short circuit between the plates at the bottom of the battery. Some maintenance-free batteries do not have a sediment chamber, but rather they have plates enclosed in an envelope-type separator that prevents material from settling to the bottom of the battery case.

"Maintenance-free" describes batteries that use little water during normal service because of the alloy material used to construct the battery plate grids. Maintenance-free batteries also are called **low-water-loss** batteries.

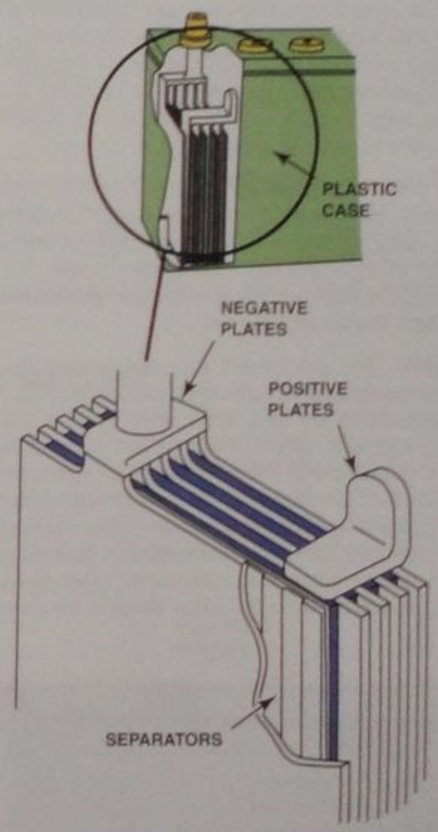


Figure 39–1 Batteries are constructed of plates grouped into cells and installed in a plastic case.

GRIDS

Each positive and negative plate in a battery is constructed on a framework or **grid** made primarily of lead. Lead is a soft material and must be strengthened for use in an automotive battery grid. Adding antimony or calcium to the pure lead adds strength to the lead grids. Battery grids hold the active material and provide the electrical pathways for the current created in the plate.

Maintenance-Free versus Standard Battery Grids A normal battery uses up to 5% **antimony** in the construction of the plate grids to add strength. However, the greater the amount of antimony, the greater the amount of gassing (hydrogen gas and oxygen gas released), and therefore the more water the battery will use. Maintenance-free batteries use **calcium** instead of antimony, because 0.2% calcium has the same strength as 6% antimony. A typical lead-calcium grid uses only 0.09% to 0.12% calcium.

Low-maintenance batteries use a low percentage of antimony (about 2% to 3%) or use antimony only in the positive plates and use calcium for the negative plates. *The percentages that make up the alloy of the plate grids constitute the major difference between standard and maintenance-free batteries.* The chemical reactions that occur inside each battery are identical regardless of the type of material used to construct the grid plates.

Radial-Grid Design Some batteries use a grid design with only vertical and horizontal strips. The battery plate creates electrical energy from chemical energy, and this current must flow from where it is generated to where it is connected to the outside battery post. The current must move over and up along the grid strips.

A grid with a **radial-grid design** has lower resistance and can provide more current more rapidly than can the non-radial-grid design used in conventional batteries. The radial spokes act as a superhighway system for the current to travel from all areas of the grid to the battery post. See Figure 39–2.

Positive versus Negative Plates The positive plates have **lead dioxide (peroxide)** placed onto the grid framework. This process is called **pasting.** This active material can react with the sulfuric acid of the battery and is dark brown in color.

The negative plates are pasted with a pure **porous lead,** called **sponge lead,** and are gray in color.

Separators The positive and the negative plates must be installed alternately next to each other without touching. Nonconducting **separators** are used, which allow room for the reaction of the acid with both plate materials yet which insulate the plates to prevent short circuits. These separators are porous (with many small holes) and have ribs facing the positive plate. Some batteries also use a glass fiber between the positive plate and the separator to help prevent the loss of the active material from the grid plate. Separators can be made from resin-coated paper, porous rubber, fiberglass, or expanded plastic. Many batteries use envelope-type separators that encase the entire plate and help prevent any material that may shed from the plates from causing a short circuit between plates at the bottom of the battery.

Cells Cells are constructed of positive and negative plates with insulating separators between each plate. Most batteries use one more negative plate than positive plate in each cell. Many newer batteries use the same number of positive and negative plates. A cell is also called an **element.** Each cell is actually a 2-volt battery, regardless of the number of positive or negative plates used. The greater the number of plates used in each cell, the greater the amount of *current* that can be produced. Typical batteries contain four positive plates and five negative plates per cell. A 12-volt battery contains six cells connected in series, which produce the 12 volts (6 × 2 = 12) and contain 54 plates (9 plates per cell × 6 cells). If the same 12-volt battery had five positive plates and six negative plates, for a total of 11 plates per cell (5 + 6), or 66 plates (11 plates × 6 cells), it would have the same voltage, but the amount of current that the battery could produce would be increased. The capacity of a battery is determined by the amount of active plate material in the battery and the area of the plate material exposed to the liquid, called **electrolyte,** in the battery.

Partitions Each cell is separated from the other cells by **partitions,** which are made of the same material as that used for the outside case of the battery. Electrical connections between cells are provided by lead connectors that loop over the top of the partition and connect the plates of the cells together. Many batteries connect the cells directly through the partition connectors, which provides the shortest path for the current and the lowest resistance. See Figure 39–3. Older-style truck and industrial batteries commonly used connectors that extended through the top of the case and over and then down through the case to connect the cells.



Figure 39–2 A radial grid from a battery used in both positive and negative plates.



Figure 39–3 A cutaway battery showing the connection of the cells to each other through the partition.

Electrolyte The electrolyte used in automotive batteries is a solution (liquid combination) of 36% sulfuric acid and 64% water. This electrolyte is used for both lead-antimony and lead-calcium (maintenance-free) batteries. The chemical symbol for this sulfuric acid solution is H_2SO_4.

H = Symbol for hydrogen (the subscript 2 means that there are two atoms of hydrogen)

S = Symbol for sulfur

O = Symbol for oxygen (the subscript 4 indicates that there are four atoms of oxygen)

This electrolyte is sold premixed in the proper proportion and is factory installed. Additional electrolyte must *never* be added to a battery after the original electrolyte fill. It is normal for some water (H_2O) to escape during charging as a result of the **gassing** that is produced by the chemical reactions. Only pure distilled water should be added to a battery. If distilled water is not available, clean drinking water can be used.

HOW A BATTERY WORKS

A fully charged lead-acid battery has a positive plate of lead dioxide (peroxide) and a negative plate of lead surrounded by a sulfuric acid solution (electrolyte). The difference in potential (voltage) between lead peroxide and lead in acid is approximately 2.1 volts.

During Discharging The positive-plate lead dioxide (PbO_2) combines with the SO_4 from the electrolyte and releases its O_2 into the electrolyte, forming H_2O. The negative plate also combines with the SO_4 from the electrolyte and becomes **lead sulfate** ($PbSO_4$). See Figure 39–4.

The Fully Discharged State When the battery is fully discharged, both the positive and the negative plates are $PbSO_4$ (lead sulfate) and the electrolyte has become water (H_2O). It is usually not possible for a battery to become 100% discharged. However, as the battery is being discharged, the plates and electrolyte approach the completely dead situation. There is also the danger of freezing when a battery is discharged, because the electrolyte is mostly water.

During Charging During charging, the sulfate ion (acid) leaves both the positive and the negative plates and returns to the electrolyte, where it becomes normal-strength sulfuric acid solution. The positive plate returns to lead dioxide (PbO_2) and the negative plate is again pure lead (Pb). See Figure 39–5.

TECH TIP ✓ **An Easy Way to Remember Battery Chemical Reactions**

A battery engineer explains to the employees of the plant how a battery works by stating these very easy-to-remember statements:

- When the battery is charged, the acid (SO_4) is in the liquid.
- When the battery is discharged, the acid (SO_4) is on the plates.

When the battery is being discharged, the acid leaves the liquid and is deposited on the plates. When the battery is being charged, the current flows into the battery, forcing the acid from the plate and back into the liquid (electrolyte).

SPECIFIC GRAVITY

The amount of sulfate in the electrolyte is indicated by the electrolyte's **specific gravity.** Specific gravity is the ratio of the weight of a given volume of a liquid to the weight of an equal volume of water. In other words, the more dense the material (liquid), the higher its specific gravity. Pure water is the basis for this measurement and is given a specific gravity of 1.000 at 80°F. Pure sulfuric acid has a specific gravity of 1.835; the *correct* concentration of water and sulfuric acid (called *electrolyte*—64% water, 36% acid) is 1.260 to 1.280 at 80°F. The higher the battery's specific gravity, the more fully it is charged. See Figure 39–6.

CHARGE INDICATORS

Some batteries are equipped with a built-in state-of-charge indicator. This indicator is simply a small ball-type hydrometer that is installed in one cell. This hydrometer uses a plastic ball that floats if the electrolyte density is sufficient (which it is when the battery is about 65% charged). When the ball floats, it appears in the hydrometer's sight glass, changing its color. See Figures 39–7 and 39–8. Because

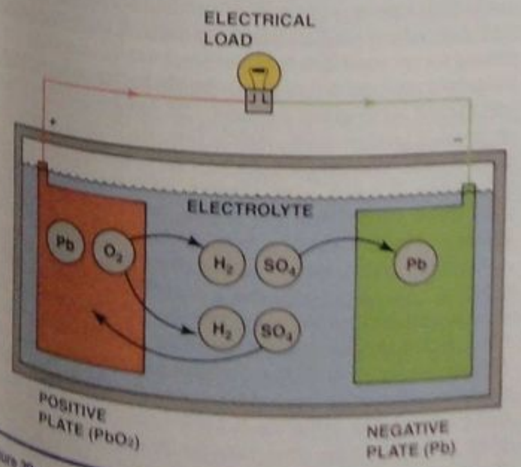


Figure 39–4 Chemical reaction for a lead-acid battery that is fully charged being discharged by the attached electrical load.

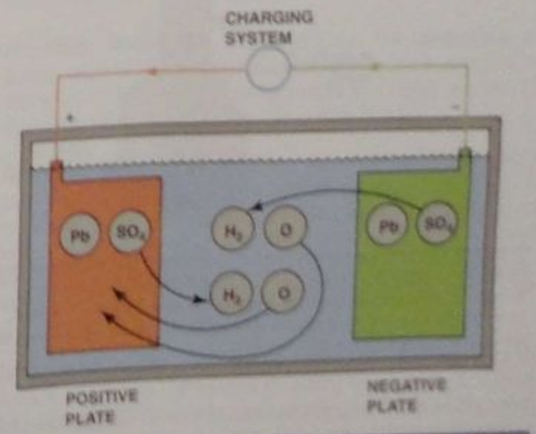


Figure 39–5 Chemical reaction for a lead-acid battery that is fully discharged being charged by the attached generator.

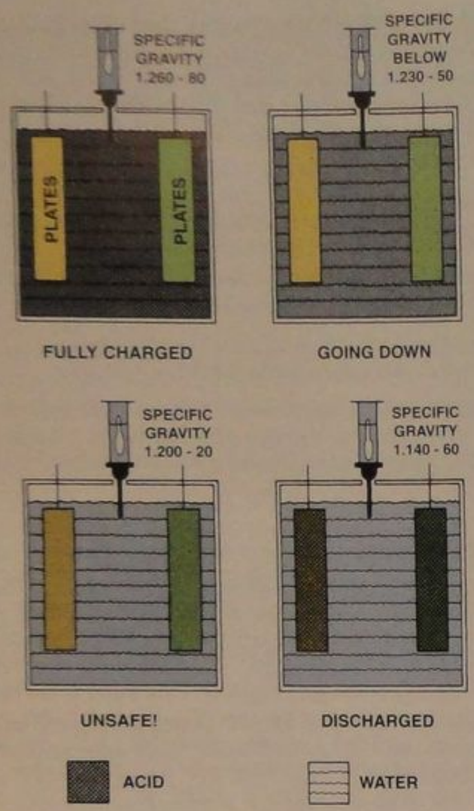


Figure 39–6 As the battery becomes discharged, the specific gravity of the battery acid decreases.

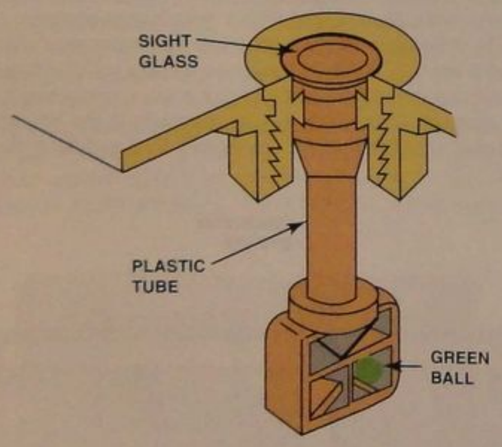


Figure 39–7 Typical battery charge indicator. If the specific gravity is low (battery discharged), the ball drops away from the reflective prism. When the battery is charged enough, the ball floats and reflects the color of the ball (usually green) back up through the sight glass and the sight glass is dark.

the hydrometer is only testing one cell (out of six on a 12-volt battery), and because the hydrometer ball can easily stick in one position, it should not be trusted to give accurate information about a battery's state of charge.



Figure 39–8 Cutaway of the battery showing the charge indicator. If the electrolyte level drops below the bottom of the prism, the sight glass shows clear (light). Most battery manufacturers warn that if the electrolyte level is low on a sealed battery, the battery must be replaced. Attempting to charge a battery that has a low electrolyte level can cause a buildup of gases and possibly an explosion.

Specific Gravity versus State of Charge and Battery Voltage Values of specific gravity, state of charge, and battery voltage at 80°F (27°C) are given in the following table:

Specific Gravity	State of Charge	Battery Voltage (V)
1.265	Fully charged	12.6 or higher
1.225	75% charged	12.4
1.190	50% charged	12.2
1.155	25% charged	12.0
Lower than 1.120	Discharged	11.9 or lower

VALVE REGULATED LEAD-ACID BATTERIES

There are two basic types of **valve regulated lead-acid (VRLA)**, also called **sealed valve regulated (SVR)** or **sealed lead-acid (SLA),** batteries. These batteries use a low-pressure venting system that releases excess gas and automatically reseals if a buildup of gas is created due to overcharging. The two types include the following:

- **Absorbed glass mat (AGM).** The acid used in an **absorbed glass mat (AGM) battery** is totally absorbed into the separator, making the battery leakproof and spillproof. The battery is assembled by compressing the cell about 20% then inserting it into the container. The compressed cell helps reduce damage caused by vibration and helps keep the acid tightly against the plates. The sealed maintenance-free design uses a pressure release valve in each cell. Unlike conventional batteries, called **flooded cell** batteries, most of the hydrogen and oxygen given off during charging remains inside the battery. The separator or mat is only 90% to 95% saturated with electrolyte, thereby allowing a portion of the mat to be filled with gas. The gas spaces provide channels to allow the hydrogen and oxygen gases to recombine rapidly and safely. Because the acid is totally absorbed into the glass mat separator, an AGM battery can be mounted in any direction. AGM batteries also have a longer service life, often lasting 7 to 10 years. See Figure 39–9. Absorbed glass mat batteries are used as standard equipment in some vehicles such as the Chevrolet Corvette.
- **Gelled electrolyte batteries.** In a gelled electrolyte battery, silica is added to the electrolyte, which turns the electrolyte into a substance similar to gelatin. This type of battery is also called a **gel battery.**

Both types of valve regulated lead-acid batteries are also called **recombinant design.** A recombinant-type battery means that the



Figure 39–9 An absorbed glass mat battery is totally sealed and is more vibration resistant than conventional lead-acid batteries.

oxygen gas generated at the positive plate travels through the dense electrolyte to the negative plate. When the oxygen reaches the negative plate it reacts with the lead, which consumes the oxygen gas and prevents the formation of hydrogen gas. It is because of this oxygen recombination that VRLA batteries do not use water.

FREQUENTLY ASKED QUESTION ???

Should Batteries Be Kept off of Concrete Floors?

All batteries should be stored in a cool, dry place when not in use. Many technicians have been warned to not store or place a battery on concrete. According to battery experts, it is the temperature difference between the top and the bottom of the battery that causes a difference in the voltage potential between the top (warmer section) and the bottom (colder section). It is this difference in temperature that causes self-discharge to occur.

In fact, submarines cycle seawater around their batteries to keep all sections of the battery at the same temperature to help prevent self-discharge.

Therefore, always store or place batteries up off the floor and in a location where the entire battery can be kept at the same temperature, avoiding extreme heat and freezing temperatures. Concrete cannot drain the battery directly, because the case of the battery is a very good electrical insulator.

BATTERY HOLD-DOWNS

All batteries must be attached securely to the vehicle to prevent battery damage. Normal vehicle vibrations can cause the active materials inside the battery to shed. Battery hold-down clamps or brackets help reduce vibration, which can greatly reduce the capacity and life of any battery.

BATTERY RATINGS

Batteries are rated according to the amount of current they can produce under specific conditions.

Cold-Cranking Amperes Every automotive battery must be able to supply electrical power to crank the engine in cold weather and still provide battery voltage high enough to operate the ignition system for starting. The cold-cranking power of a battery is the number of amperes that can be supplied by a battery at 0°F (–18°C) for 30 seconds while the battery still maintains a voltage of 1.2 volts



Figure 39–10 This battery has a cranking amperes (CA) rating of 1000. This means that this battery is capable of cranking an engine for 30 seconds at a temperature of 32°F (0°C) at a minimum of 1.2 volts per cell (7.2 volts for a 12-volt battery).

FREQUENTLY ASKED QUESTION ???

What Causes a Battery to Wear Out?

Every automotive battery has a limited service life of approximately three to seven years. During the life of a battery, the active material sheds from the surface of the positive plates. This gradually limits the power of the battery. This cycling also can cause the negative plates to become sulfated, which will also cause eventual battery failure.

NOTE: A battery becomes sulfated when the lead sulfate (SO_4) remains on the plates and does not return to the electrolyte when the battery is charged.

Excessive parasitic drains also can cause a battery to fail prematurely due to constant deep cycling of the battery.

per cell or higher. This means that the battery voltage would be 7.2 volts for a 12-volt battery and 3.6 volts for a 6-volt battery. The cold-cranking performance rating is called **cold-cranking amperes (CCA).** Try to purchase a battery with the highest CCA for the money. See vehicle manufacturers' specifications for recommended battery capacity.

Cranking Amperes The designation **CA (cranking amperes)** refers to the number of amperes that can be supplied by a battery at 32°F (0°C). This rating results in a higher number than the more stringent CCA rating. See Figure 39–10.

Ampere-Hour Rating **Marine cranking amperes (MCA)** are similar to cranking amperes and are tested at 32°F (0°C). Another type of battery rating is called the **ampere-hour (Ah) rating,** which is the number of amperes that can be discharged from the battery before dropping at 10.5 volts over a 20-hour period. A battery that is able to supply 3.75 amperes for 20 hours has a rating of 75 ampere-hours ($3.75 \times 20 = 75$).

Reserve Capacity The **reserve capacity (RC)** rating for batteries is *the number of minutes* for which the battery can produce 25 amperes and still have a battery voltage of 1.75 volts per cell (10.5 volts for a 12-volt battery). This rating is actually a measurement of the time for which a vehicle can be driven in the event of a charging system failure.

FREQUENTLY ASKED QUESTION ???

What Determines Battery Capacity?

The capacity of any battery is determined by the amount of active material in the battery. A battery with a large number of thin plates can produce high current for a short period. If a few thick plates are used, the battery can produce low current for a long period. A trolling motor battery used for fishing must supply a low current for a long period of time. An automotive battery is required to produce a high current for a short period for cranking. Therefore, every battery is designed for a specific application.

DEEP CYCLING

Deep cycling is almost fully discharging a battery and then completely recharging it. Golf cart batteries are an example of lead-acid batteries that must be designed to be deep cycled. A golf cart must be able to cover two 18-hole rounds of golf and then be fully recharged overnight. Charging is hard on batteries because the internal heat generated can cause plate warpage, so these specially designed batteries use thicker plate grids that resist warpage. Normal automotive batteries are not designed for repeated deep cycling.

FREQUENTLY ASKED QUESTION ???

What Can Cause a Battery to Explode?

Batteries discharge hydrogen gas and oxygen when being charged. If there happens to be a flame or spark, the hydrogen will burn. The oxygen can also help contribute to an explosion of a small pocket of hydrogen. This is likely what happened to the battery in Figure 39–11 when the battery charger was left on the battery over 24 hours. Apparently, a small electrical arc occurred inside the battery and the resulting explosion sounded like a shotgun being fired.

FREQUENTLY ASKED QUESTION ???

What Are Some Symptoms of a Weak or Defective Battery?

There are several warning signs that may indicate that a battery is near the end of its useful life, including:

- *Uses water in one or more cells*—This indicates that the plates are sulfated and that during the charging process, the water in the electrolyte is being turned into separate hydrogen and oxygen gases.
- *Excessive corrosion on battery cables or connections*—Corrosion is more likely to occur if the battery is sulfated, creating hot spots on the plates. When the battery is being charged, the acid fumes are forced out of the vent holes and get onto the battery cables and connections and even on the battery tray underneath the battery. See Figure 39–12.
- *Slower than normal engine cranking*—When the capacity of the battery is reduced due to damage or age, it is less likely to be able to supply the necessary current for starting the engine, especially during cold weather.

BATTERY SERVICE SAFETY CONSIDERATIONS

Batteries contain acid and release explosive gases (hydrogen and oxygen) during normal charging and discharging cycles. To help prevent physical injury or damage to the vehicle, always adhere to the following safety procedures:

1. Whenever working on any electrical component on a vehicle, disconnect the negative battery cable from the battery. When the negative cable is disconnected, all electrical circuits in the vehicle will be open, which will prevent accidental electrical contact between an electrical component and ground. Any electrical spark has the potential to cause explosion and personal injury.
2. Wear eye protection whenever working around any battery.
3. Wear protective clothing to avoid skin contact with battery acid.
4. Always adhere to all safety precautions as stated in the service procedures for the equipment used for battery service and testing.
5. Never smoke or use an open flame around any battery.



(a)



(b)

Figure 39–11 (a) A small spark inside the battery was the most likely cause of this battery explosion. Parts of the battery were thrown 30 feet (10 m) and luckily no one was around the vehicle at the time. (b) Because battery acid was spilled and sprayed around the battery, the entire area was rinsed with water after unplugging the battery charger.

BATTERY MAINTENANCE

Most new-style batteries are of maintenance-free design that use lead-calcium instead of lead-antimony plate grid construction. Because lead-calcium batteries do not release as much gas as the older-style lead-antimony batteries, there is less consumption of water during normal service. Also, with less gassing, less corrosion is observed on the battery terminals, wiring, and support trays. Side-terminal battery design also has reduced the self-discharge that can often occur as a result of dirt and moisture on the top of the battery, which provide a conductive path for the current to flow between the terminals that can lead to battery discharge.

Battery maintenance includes making certain that the battery case is clean and checking and adding clean water, if necessary. See Figure 39–13. Distilled water is recommended by all battery manufacturers, but if distilled water is not available, clean ordinary drinking water, low in mineral content, can be used. Because water is the only thing in a battery that is consumed, acid should never be added to a battery. Battery electrolyte is an exact mixture of acid and water (64% water and 36% acid). Some of the water in the electrolyte escapes during the normal operation of charging and discharging, but the acid content of the electrolyte remains in the battery. Adding electrolyte simply increases the acid content of the electrolyte and will shorten the life of the battery. Do not overfill a battery, because normal bubbling (gassing) of the electrolyte will cause the electrolyte to escape and start corrosion on the battery terminals, hold-down brackets, and battery tray. Fill batteries to the indicator that is approximately 1/2 inches (3.8 centimeters) from the top of the filler tube. Another method is to fill the battery until the water becomes "puckered," indicating that the electrolyte level is even with the bottom of the filler tube. This puckering of water in a tube is called the **meniscus.**

The battery also should be secured with a hold-down bracket to prevent vibration from damaging the plates inside the battery. The hold-down bracket should be snug enough to prevent battery movement, yet not so tight as to cause the case to crack. Factory-original hold-down brackets are often available through local automobile dealers, and universal hold-down units are available through local automotive parts stores.

Battery cable connections should be checked and cleaned to prevent voltage drop at the connections. One common reason for an engine to not start is loose or corroded battery cable connections. Replacement battery cable terminal ends are available at most automotive parts stores.



Figure 39–12 Corrosion on a battery cable could be an indication that the battery itself is either being overcharged or is sulfated, creating a lot of gassing of the electrolyte.



Figure 39–13 A visual inspection on this battery showed that the electrolyte level was below the plates in all cells.

TECH TIP ✓ Dynamic versus Open Circuit Voltage

Open circuit voltage is the voltage (usually of a battery) that exists *without* a load being applied. **Dynamic voltage** is the voltage of the power source (battery) with the circuit in operation. A vehicle battery, for example, may indicate that it has 12.6 volts or more, but that voltage may drop when the battery is put under a load such as cranking the engine. If the battery voltage drops too much, the starter motor will rotate more slowly and the engine may not start.

If the dynamic voltage is lower than specified, the battery may be weak or defective or the circuit may be defective, resulting in too much current being drawn from the battery.

BATTERY VOLTAGE TEST

Testing the battery voltage with a voltmeter is a simple method for determining the state of charge of any battery. See Figure 39–14. The voltage of a battery does not necessarily indicate whether the battery can perform satisfactorily, but it does indicate to the technician more about the battery's condition than a simple visual inspection. A battery that "looks good" may not be good. This test is commonly called an **open circuit battery voltage test** because it is conducted with an open circuit—with no current flowing and no load applied to the battery.

1. If the battery has just been charged or if the vehicle has been driven recently, it is necessary to remove the surface charge from the battery before testing. A surface charge is a charge of higher-than-normal voltage that is just on the surface of the battery plates. The surface charge is quickly removed when the battery is loaded and therefore does not accurately represent the true state of charge of the battery.
2. To remove the surface charge, turn the headlights on high beam (brights) for 1 minute, then turn the headlights off and wait 2 minutes.
3. With the engine and all electrical accessories off, and the doors shut (to turn off the interior lights), connect a voltmeter to the battery posts. Connect the red positive lead to the positive post and the black negative lead to the negative post.

NOTE: If the meter reads negative, the battery has been reverse charged (has reversed polarity) and should be replaced, or the meter has been connected incorrectly.

4. Read the voltmeter and compare the results with the following state-of-charge chart. The voltages shown are for a battery at or near room temperature (70° to 80°F or 21° to 27°C).

Battery Voltage (V)	State of Charge
12.6 or higher	100% charged
12.4	75% charged
12.2	50% charged
12.0	25% charged
11.9 or lower	Discharged

HYDROMETER TESTING

If the battery has removable filler caps, the specific gravity of the electrolyte also can be checked. This test also can be performed on most maintenance-free batteries because the filler caps are



(a)



(b)

Figure 39–14 (a) A battery voltage of 12.28 volts is definitely not fully charged and should be charged before testing. (b) A battery that measures 12.60 volts or higher after the surface charge has been removed is 100% charged.

removable from most maintenance-free batteries (except for those produced by Delco Battery). The specific gravity test indicates the state of charge of the battery and can indicate a defective battery if the specific gravity of one or more cells varies by more than 0.050 from the value of the highest-reading cell. See Figure 39–15.

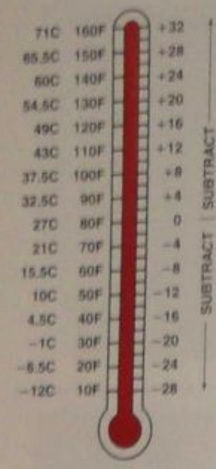


Figure 39–15 When testing a battery using a hydrometer, the reading must be corrected if the temperature is above or below 80°F (27°C).

Specific Gravity	Battery Voltage (V)	State of Charge
1.265	12.6 or higher	100% charged
1.225	12.4	75% charged
1.190	12.2	50% charged
1.155	12.0	25% charged
Lower than 1.120	11.9 or lower	Discharged

BATTERY LOAD TESTING

The most accurate test to determine the condition of any battery is the **load test.** Most automotive starting and charging testers use a carbon pile to create an electrical load on the battery. The amount of the load is determined by the original capacity of the battery being tested. The capacity is measured in cold cranking amperes, which is the number of amperes that a battery can supply at 0°F (−18°C) for 30 seconds. *The proper electrical load to be used to test a battery is one-half of the CCA rating or three times the ampere-hour rating, with a minimum of a 150-ampere load.* See Figure 39–16. Apply the load for a full 15 seconds and observe the voltmeter at the end of the 15-second period while the battery is still under load. A good battery should indicate above 9.6 V. Many battery manufacturers recommend performing the load test twice, using the first load period to remove the surface charge on the battery and the second test to provide a truer indication of the condition of the battery. Wait 30 seconds between tests to allow time for the battery to recover. See Figures 39–17 and 39–18.

If the battery fails the load test, recharge the battery and retest. If the load test is failed again, replacement of the battery is required.

TECH TIP ✓ **The One-Minute Test**

A high-rate battery load test should take one minute.

- Load for 15 seconds to remove the surface charge.
- Allow 30 seconds for the battery to recover.
- Load for 15 seconds to test the battery.

FREQUENTLY ASKED QUESTION ???

How Should You Test a Vehicle Equipped with Two Batteries?

Many vehicles equipped with a diesel engine use two batteries. Usually these batteries are electrically connected in parallel to provide additional current (amperes) at the same voltage. See Figure 39–19.

Some heavy-duty trucks and buses connect two batteries in series to provide about the same current as one battery but with twice the voltage, as shown in Figure 39–20.

To successfully test the batteries, they should be disconnected and tested separately. If just one battery is found to be defective, most experts recommend that both batteries be replaced to help prevent future problems. Because the two batteries are electrically connected, a fault in one battery can cause the good battery to discharge into the defective battery, thereby affecting both batteries even if just one battery is at fault.



Figure 39–16 This battery has cold-cranking amperes (CCA) of 550 A, cranking amperes (CA) of 680 A, and load test amperes of 270 A listed right on the top label. Note all batteries have all of this information.



Figure 39–17 An alternator regulator battery starter tester (ARBST) automatically loads the battery with a fixed load for 15 seconds to remove the surface charge, then removes the load for 30 seconds to allow the battery to recover, and then reapplies the load for another 15 seconds. The results of the test are then displayed.

ELECTRONIC CONDUCTANCE TESTING

General Motors Corporation, Chrysler Corporation, and Ford specify that an electronic **conductance tester** be used to test batteries in vehicles still under factory warranty. This tester sends a signal through the battery and the conductance of the cells are determined by the electronics and program inside the unit. The unit can determine the CCA, state-of-charge, and voltage of the battery. See Figure 39–21. Connect the unit to the positive and negative terminals of the battery and after entering the CCA rating (if known), push the arrow keys. The tester determines one of the following:

- **Good battery**—the battery can return to service
- **Charge and retest**—fully recharge the battery and return it to service
- **Replace the battery**—the battery is not serviceable and should be replaced
- **Bad cell—replace**—the battery is not serviceable and should be replaced

CAUTION: Test results can be incorrectly reported on the display if improper, unclean connections to the battery are made. Also be sure the ignition switch and all accessories are in the off position.

BATTERY TEMPERATURE °F (°C)	MINIMUM TEST VOLTAGE
70° (21°) or above	9.6 volts
60° (16°)	9.5 volts
50° (10°)	9.4 volts
40° (4°)	9.3 volts
30° (-1°)	9.1 volts
20° (-7°)	8.9 volts
10° (-12°)	8.7 volts
0° (-18°)	8.5 volts

Figure 39–18 The minimum capacity test voltage varies with battery temperature.

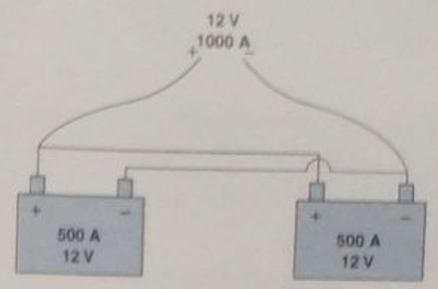


Figure 39–19 Most light-duty vehicles equipped with two batteries are connected in parallel as shown. Two 500-A, 12-volt batteries are capable of supplying 1,000 amperes at 12 volts, which is needed to start many diesel engines.

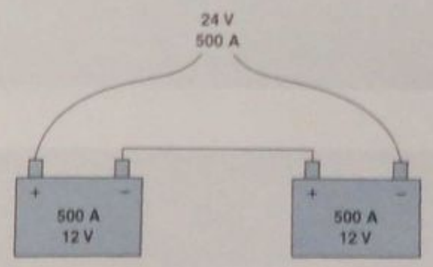
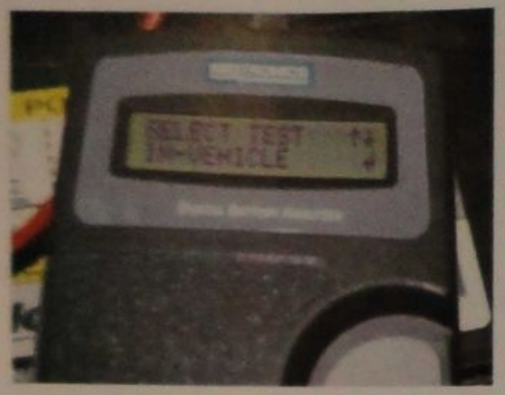


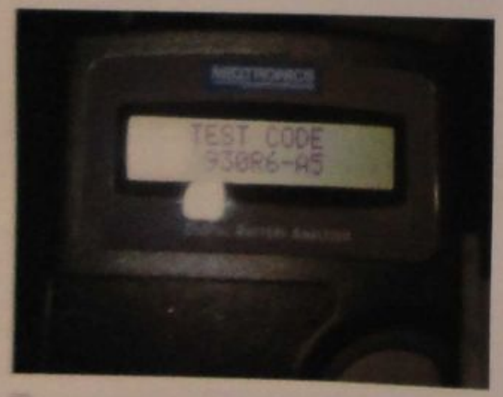
Figure 39–20 Many heavy-duty trucks and buses use two 12-volt batteries connected in series to provide 24 volts.



(a)



(b)



(c)

Figure 39–21 A conductance-type battery tester. (a) The up-and-down arrow keys are used to answer questions about the battery before it is tested. (b) This battery shows a calculated CCA of 726 amperes and a voltage of 12.37 volts. The display indicates that the battery is good, but should be charged before returning the vehicle to service. (c) A test code is displayed for warranty record-keeping purposes.

BATTERY CHARGING

If the state of charge of a battery is low, it must be recharged. It is best to slow-charge any battery to prevent possible overheating damage to the battery. See Figure 39–22 for the recommended charging rate. Remember, it may take 8 hours or more to charge a fully discharged *battery.* See Figure 39–23. When charging a maintenance-free (lead-calcium) battery, the initial charge rate should be about 35 amperes for 30 minutes to help start the charging process. Fast-charging a battery increases the temperature of the battery and can cause warping of the plates inside the battery. Fast-charging also increases the amount of gassing (release of hydrogen and oxygen), which can create a health and fire hazard. The battery temperature should not exceed 125°F (hot to the touch). *Most batteries should be charged at a rate equal to 1% of the battery's CCA rating.*

Fast charge: 15 amperes maximum

Slow charge: 5 amperes maximum

CAUTION: Always use a battery charger designed for absorbed glass mat (AGM) batteries because that type of battery can be damaged if charged above 14.5 volts. While AGM batteries can be charged at a high average rate (about 75% amp hour rating) the voltage must be lower than the conventional charger.

TECH TIP ✓ **Always Use Adapters on Side-Post Batteries**

Side-post batteries require that an adapter be used whenever charging the battery if it is removed from the vehicle. If a bolt is threaded into the terminal, only the parts of the threads that contact the battery terminal will be conducting all of the charging current. An adapter or a bolt with a nut attached is needed to achieve full contact with the battery terminals. See Figure 39–24.

JUMP-STARTING

To **jump-start** another vehicle with a dead battery, connect good-quality copper jumper cables using another vehicle or a battery jump box. See Figure 39–25. The last connection made should always be on the engine block or on an engine bracket as far from the battery as possible. It is normal for a spark to be created when the jumper cables finally complete the jumping circuit, and this spark could cause an explosion of the gases around the battery. Many newer vehicles have special ground connections built away from the battery just for the purpose of jump-starting. Check the owner's manual or service information for the exact location.

CAUTION: To help avoid the possibility of a voltage surge causing damage to the computer or electronic circuits of the vehicle, be sure that the ignition is in the off position of both vehicles before attaching the jumper cables. After the last connection has been made, start the good vehicle, and then start the disabled vehicle.

BATTERY DATE CODES

All major battery manufacturers stamp codes on the battery case that give the date of manufacture and other information. Most battery manufacturers use a number to indicate the year of manufacture and a letter to indicate the month of manufacture, skipping the letter I, because it can be confused with the number 1. For example:

A = January
B = February
C = March
D = April
E = May
F = June
G = July
H = August
J = September
K = October
L = November
M = December

OPEN CIRCUIT VOLTAGE	BATTERY SPECIFIC GRAVITY*	STATE OF CHARGE	CHARGING TIME TO FULL CHARGE AT 80° F**					
			at 60 amps	at 50 amps	at 40 amps	at 30 amps	at 20 amps	at 10 amps
			FULL CHARGE					
12.6	1.265	100%	15 min.	20 min.	27 min.	35 min.	48 min.	90 min.
12.4	1.225	75%	35 min.	45 min.	55 min.	75 min.	95 min.	180 min.
12.2	1.190	50%	50 min.	65 min.	85 min.	115 min.	145 min.	260 min.
12.0	1.155	25%	65 min.	85 min.	110 min.	150 min.	195 min.	370 min.
11.8	1.120	0%						

*Correct for temperature **If colder, it'll take longer

Figure 39–22 Battery charging guide. Battery charging times vary according to state-of-charge, temperature, and charging rate.



Figure 39–23 A typical industrial battery charger. Be sure that the ignition switch is in the off position before connecting any battery charger. Connect the cables of the charger to the battery before plugging the charger into the outlet. This helps prevent a voltage spike that could occur if the charger happened to be accidentally left on. Always follow the battery charger manufacturer's instructions.

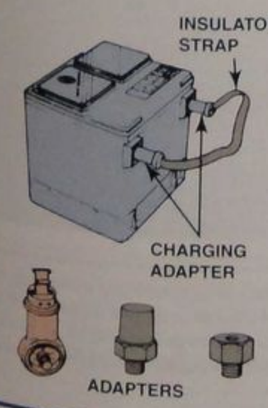


Figure 39–24 Adapters should be used on side-terminal batteries whenever charging.



Figure 39–25 A typical battery jump box used to jump-start vehicles. These hand-portable units have almost made jumper cables obsolete.

The shipping date from the manufacturing plant is usually indicated by a *sticker* on the end of the battery. Almost every battery manufacturer uses just one letter and one number to indicate the month and year. See Figure 39–26.

TECH TIP ✓ **It Could Happen to You!**

The owner of a Toyota replaced the battery. After replacing the battery, the owner noted that the amber "airbag" warning lamp was lit and the radio was locked out. The owner had purchased the vehicle used from a dealer and did not know the four-digit security code needed to unlock the radio. Determined to fix the problem, the owner tried three four-digit numbers, hoping that one of them would work. However, after three tries, the radio became permanently disabled.

Frustrated, the owner went to a dealer. It cost over $300 to fix the problem. A special tool was required to easily reset the airbag lamp. The radio had to be removed and sent out of state to an authorized radio service center and then reinstalled into the vehicle.

Therefore, before disconnecting the battery, please check with the owner to be certain that the owner has the security code for a security-type radio. A "memory saver" may be needed to keep the radio powered up when the battery is being disconnected. See Figure 39–27.



Figure 39–26 The date 5/07 indicates that this battery was shipped from the manufacturing plant in May 2007.

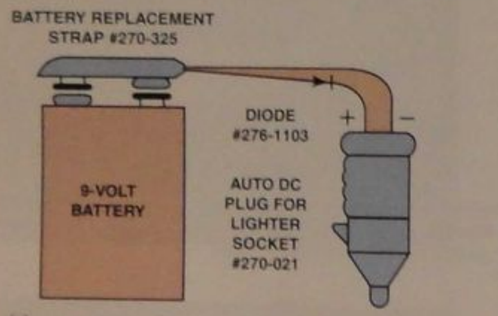


Figure 39–27 (a) Memory saver. The part numbers represent components from Radio Shack. (b) A schematic drawing of the same memory saver. Some experts recommend using a 12-volt lantern battery instead of a small 9-volt battery to help ensure that there will be enough voltage in the event that a door is opened while the vehicle battery is disconnected. Interior lights could quickly drain a small 9-volt battery.

BATTERY ELECTRICAL DRAIN TEST

The **battery electrical drain test** determines if some component or circuit in a vehicle is causing a drain on the battery when everything is off. This test is also called the **ignition off draw (IOD)** or **parasitic load test.** This test should be performed whenever one of the following conditions exists:

1. Whenever a battery is being charged or replaced (a battery drain could have been the cause for charging or replacing the battery)
2. Whenever the battery is suspected of being drained

PROCEDURE FOR BATTERY ELECTRICAL DRAIN TEST

The fastest and easiest method to measure battery electrical drain is to connect an inductive DC ammeter that is capable of measuring low current (10 mA). See Figure 39–28 for an example of a clamp-on digital multimeter being used to measure battery drain. Following is the procedure for performing the battery electrical drain test using a test light:

1. Make certain that all lights, accessories, and ignition are off.
2. Check all vehicle doors to be certain that the interior courtesy (dome) lights are off.
3. Disconnect the *negative* (–) battery cable and install a parasitic load tool as shown in Figure 39–29.
4. Start the engine and drive the vehicle about 10 minutes, being sure to turn on all the lights and accessories including the radio.
5. Turn off the engine and all accessories including the underhood light.
6. Connect an ammeter across the parasitic load tool switch and wait 10 minutes for all computers and circuits to shut down.
7. Open the switch on the load tool and read the battery electrical drain on the meter display.

Results: Normal = 10 to 30 mA (0.02 to 0.03 A)

Maximum allowable = 50 mA (0.05 A)

Be sure to reset the clock and antitheft radio if equipped. See Figure 39–30.

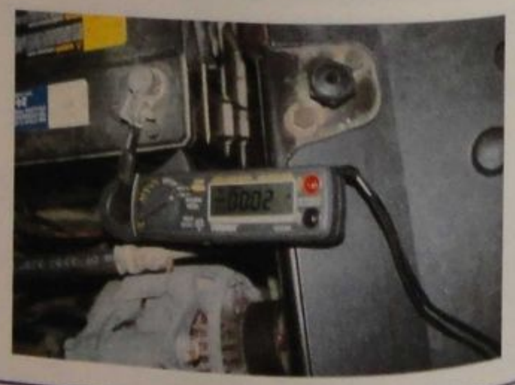


Figure 39–28 This mini clamp-on digital multimeter is being used to measure the amount of battery electrical drain that is present. In this case, a reading of 20 mA (displayed on the meter as 00.02A) is within the normal range of 20 to 30 mA. Be sure to clamp around all of the positive battery cable or all of the negative battery cable, whichever is easiest to get the clamp around.



Figure 39–29 After connecting the shutoff tool, start the engine and operate all accessories. Stop the engine and turn off everything. Connect the ammeter across the shutoff switch in parallel. Wait 20 minutes. This time allows all electronic circuits to "time out" or shut down. Open the switch—all current now will flow through the ammeter. A reading greater than specified (usually greater than 50 milliamperes [0.05 amperes]) indicates a problem that should be corrected.



Figure 39–30 The battery was replaced in this Acura and the radio displayed "code" when the replacement battery was installed. Thankfully, the owner had the five-digit code required to unlock the radio.

NOTE: Many electronic components draw a continuous, slight amount of current from the battery when the ignition is off. These components include:

1. Digital clocks
2. Electronically tuned radios for station memory and clock circuits (if the vehicle is so equipped)
3. The engine control computer (if the vehicle is so equipped), through slight diode leakage
4. The generator (alternator), through slight diode leakage

These components may cause a voltmeter to read full battery voltage if it is connected between the negative battery terminal and the removed end of the negative battery cable.

CAUTION: Using a voltmeter to measure battery drain is not recommended by most vehicle manufacturers. The high internal resistance of the voltmeter results in an irrelevant reading that does not provide the technician with adequate information about a problem.

FINDING THE SOURCE OF THE DRAIN

If there is a drain, check and temporarily disconnect the following components:

1. Light under the hood
2. Glove compartment light
3. Trunk light

If after disconnecting all three of these components the battery drain can draw more than 50 milliamperes (0.05 A), disconnect one fuse at a time and leave it disconnected until the draw is reduced. If the excessive draw is reduced after one fuse is disconnected, the source of the drain is located in that particular circuit, as labeled on the fuse box. Continue to disconnect *the power-side* wire connectors from each component included in that particular circuit until the test light goes off. The source of the battery drain can then be traced to an individual component or part of one circuit.

WHAT TO DO IF A BATTERY DRAIN STILL EXISTS

If all the fuses have been disconnected and the drain still exists, the source of the drain has to be between the battery and the fuse box. The most common sources of drain under the hood include the following:

1. **The generator.** Disconnect the generator wires and retest. If the excessive battery drain stops, the problem is a defective diode(s) in the generator.
2. **The starter solenoid (relay) or wiring near its components.** These are also a common source of battery drain, due to high current flows and heat, which can damage the wire or insulation.

HIDDEN BATTERIES

Many vehicle manufacturers today place the battery under the backseat or under the front fender. Often, the battery is not visible even if it is located under the hood. Whenever testing or jump-starting a vehicle, look for a battery access point as shown in Figure 39–31.



Figure 39–31 Many newer vehicles have batteries that are sometimes difficult to find. Some are located under plastic panels under the hood, under the front fender, or even under the rear seat. The jump-start instructions indicate that the spare tire hold-down bolt is to be used as the ground connection if jump-starting is necessary.

FREQUENTLY ASKED QUESTION ???

Why Should a Discharged Battery Be Recharged or Replaced Before Further Testing?

A discharged or defective battery has lower voltage potential than a good battery that is at least 75% charged. A weak battery could prevent the charging voltage from reaching the voltage regulator cutoff point. This lower voltage could be interpreted as indicating a defective generator (alternator) and/or voltage regulator. If the vehicle continues to operate with low system voltage, the stator winding in the generator (alternator) can be overheated, causing alternator failure.

BATTERY SYMPTOM GUIDE

The following list will assist technicians in diagnosing batteries.

Problem	Possible Causes and/or Solutions
1. Headlights are dim.	1. Discharged battery or poor connections on the battery, engine, or body.
2. Solenoid clicks.	2. Discharged battery or poor connections on the battery or the engine.
3. Engine is slow in cranking.	3. Discharged battery, high-resistance battery cables, or defective starter or solenoid.
4. Battery will not accept a charge.	4. If the battery is a maintenance-free type, attempt to fast-charge the battery for several hours. If the battery still will not accept a charge, replace the battery.
5. Battery is using water.	5. Check the charging system for too high a voltage. If the voltage is normal, the battery is showing signs of gradual failure. Load test and replace the battery if necessary.

SUMMARY

1. Maintenance-free batteries use lead-calcium grids instead of lead-antimony grids to reduce gassing.
2. When a battery is being discharged, the acid (SO_4) is leaving the electrolyte and being deposited on the plates. When the battery is being charged, the acid (SO_4) is forced off the plates and back into the electrolyte.
3. Batteries are rated according to CCA and reserve capacity.
4. All batteries should be securely attached to the vehicle with hold-down brackets to prevent vibration damage.
5. Batteries can be tested with a voltmeter to determine the state of charge. A battery load test loads the battery to one-half of its CCA rating. A good battery that is at least 75% charged should be able to maintain higher than 9.6 volts for the entire 15-second test period.
6. A battery drain test should be performed if the battery runs down.

REVIEW QUESTIONS

1. Explain why discharged batteries can freeze.
2. Identify the two most commonly used battery rating methods.
3. Describe how to perform a voltmeter test of a battery to determine its state of charge.
4. List the steps for performing a battery load test.
5. Explain how to perform a battery drain test.

CHAPTER QUIZ

1. When a battery becomes completely discharged, both positive and negative plates become _____ and the electrolyte becomes _____.
   a. H_2SO_4; Pb
   b. $PbSO_4$; H_2O
   c. PbO_2; H_2SO_4
   d. $PbSO_4$; H_2SO_4
2. A fully charged 12-volt battery should indicate _____.
   a. 12.6 volts or higher
   b. A specific gravity of 1.265 or higher
   c. 12 volts
   d. Both a and b.
3. Deep cycling means _____.
   a. Overcharging the battery
   b. Overfilling or underfilling the battery with water
   c. The battery is fully discharged and then recharged
   d. The battery is overfilled with acid (H_2SO_4)
4. Many vehicle manufacturers recommend that a special electrical connector be installed between the battery and the battery cable when testing for _____.
   a. Battery drain (parasitic drain)
   b. Specific gravity
   c. Battery voltage
   d. Battery charge rate
5. Reserve capacity for batteries means _____.
   a. The number of *hours* the battery can supply 25 amperes and remain higher than 10.5 volts.
   b. The number of *minutes* the battery can supply 25 amperes and remain higher than 10.5 volts.
   c. The number of *minutes* the battery can supply 20 amperes and remain higher than 9.6 volts.
   d. The number of *minutes* the battery can supply 10 amperes and remain higher than 9.6 volts.
6. The maximum allowable difference between the highest and lowest hydrometer (specific gravity) reading is _____.
   a. 0.010
   b. 0.020
   c. 0.050
   d. 0.50
7. A battery high-rate discharge (load capacity) test is being performed on a 12-volt battery. Technician A says that a good battery should have a voltage reading of higher than 9.6 volts while under load at the end of the 15-second test. Technician B says that the battery should be discharged (loaded to twice its CCA rating). Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. When charging a maintenance-free (lead-calcium) battery, _____.
   a. The initial charging rate should be about 35 amperes for 30 minutes
   b. The battery may not accept a charge for several hours yet may still be a good (serviceable) battery
   c. The battery temperature should not exceed 125°F (hot to the touch)
   d. All of the above
9. Normal battery drain (parasitic drain) with a vehicle with many computer and electronic circuits is _____.
   a. 20 to 30 milliamperes
   b. 2 to 3 amperes
   c. 150 to 300 milliamperes
   d. None of the above
10. When jump-starting, _____.
    a. The last connection should be the positive post of the dead battery
    b. The last connection should be the engine block of the dead vehicle
    c. The alternator must be disconnected on both vehicles.
    d. Both a and c.

CHAPTER 40 Cranking System Operation and Diagnosis

OBJECTIVES: After studying Chapter 40, the reader will be able to: Prepare for the ASE electrical/electronic systems (A6) certification test content area "C" (starting system diagnosis and repair). • Discuss how to test the cranking circuit. • Describe how to perform cranking system testing procedures.

KEY TERMS: ampere-turns • armature • bench testing • brush-end housing • brushes • commutator-end housing • commutator segments • compound motor (compound-wound) • compression spring • counter electromotive force (CEMF) • cranking circuit • drive coil • drive-end (DE) housing • electromagnetic switch • field coils • field poles • gear-reduction starters • ground brushes • growler tester • holding coil • hold-in winding • hot brushes • lap winding • main field housing • mesh spring • mica • movable pole shoe • neutral safety switch • overrunning clutch • permanent-magnet field • permanent-magnet starter motors • plunger lever • pole shoes • positive-engagement starter • pull-in winding • remote vehicle start (RVS) • series motor • shift fork lever • shunt motor • solenoid-operated starter • starter drive • starter solenoid • through bolts • undercut • voltage-drop testing • wave winding

For any engine to start, it must first be rotated. It is the purpose and function of the cranking circuit to create the necessary power by converting electrical energy from the battery into mechanical energy at the starter motor and rotate the engine.

CRANKING CIRCUIT

The **cranking circuit** includes those mechanical and electrical components required to crank the engine for starting. In the early 1900s, the cranking force was the driver's arm. Modern cranking circuits include the following:

1. **Starter motor.** The starter is normally a 0.5- to 2.6-horsepower (0.4 to 2.0 kilowatts) electric motor that can develop nearly 8 horsepower (6 kilowatts) for a very short time when first cranking a cold engine. See Figure 40–1.
2. **Battery.** The battery must be of the correct capacity and be at least 75% charged to provide the necessary current and voltage for correct operation of the starter.
3. **Starter solenoid or relay.** The high current required by the starter must be able to be turned on and off. A large switch would be required if the current were controlled by the driver directly. Instead, a small current switch (ignition switch) operates a solenoid or relay that controls the high starter current.
4. **Starter drive.** The starter drive uses a small gear that contacts the engine flywheel gear and transmits starter motor power to rotate the engine.
5. **Ignition switch.** The ignition switch and safety control switches control the starter motor operation. See Figures 40–2 and 40–3.



Figure 40–1 A typical solenoid-operated starter.

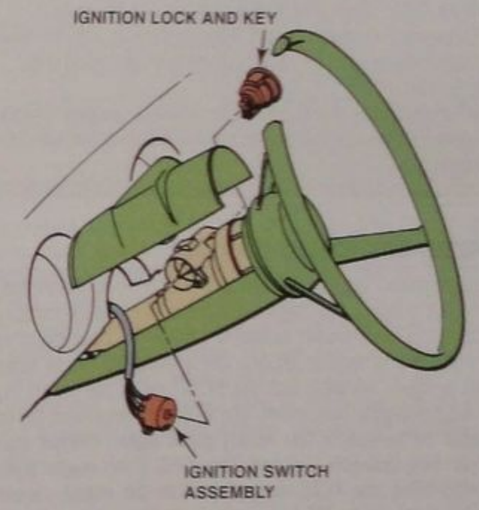


Figure 40–2 Some column-mounted ignition switches act directly on the contact points, whereas others use a link from the lock cylinder to the ignition switch.

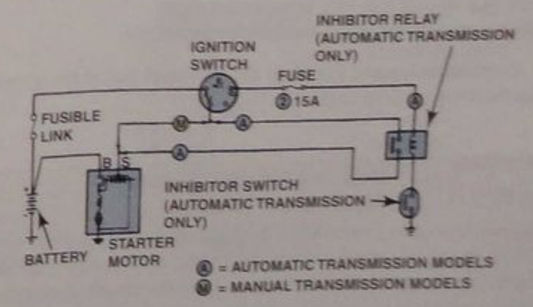


Figure 40–3 A typical wiring diagram of a starter circuit.

The engine is cranked by an electric motor that is controlled by a key-operated ignition switch. The ignition switch will not operate the starter unless the automatic transmission is in neutral or park. This is to prevent an accident that might result from the vehicle moving forward or rearward when the engine is started. Many automobile manufacturers use an electric switch called a **neutral safety switch** that opens the circuit between the ignition switch and the starter to prevent starter motor operation unless the gear selector is in neutral or park. The safety switch can be attached either to the steering column inside the vehicle near the floor or on the side of the transmission.

Many neutral safety switches can be adjusted by loosening the hold-down screws and moving the switch slightly to be certain that the engine will crank only with the transmission in the neutral and park positions. Many manufacturers use a mechanical blocking device in the steering column to prevent the driver from turning the key switch to the start position unless the gear selector is in neutral or park. Many manual transmission vehicles also use a safety switch to permit cranking only if the clutch is depressed.

TECH TIP ✔ **Watch the Dome Light**

Whenever diagnosing any starter-related problem, open the door of the vehicle and observe the brightness of the dome or interior light(s) while attempting to crank the engine.

- The brightness of any electrical lamp is proportional to the voltage.
- Normal operation of the starter results in a slight dimming of the dome light.
- If the light remains bright, the problem is usually an open circuit in the control circuit.
- If the light goes out or almost goes out, the problem is usually a discharged or defective battery or a shorted or grounded armature of field coils inside the starter.

COMPUTER-CONTROLLED STARTING

Some key-operated ignition systems and most push-button-to-start systems use the computer to crank the engine. The ignition switch start position on the push-to-start button is used as an input signal to the power train control module (PCM). The ignition key can be turned to the start position, released, and the PCM cranks the engine until it senses that the engine has started. The PCM can detect that the engine has started by looking at the engine speed signal. Normal cranking speed can vary between 100 and 250 RPM. If the engine speed exceeds 400 RPM, the PCM determines that the engine started and opens the circuit to the "S" (start) terminal of the starter solenoid. Before the PCM cranks the engine, the following conditions must be met:

- The brake pedal is depressed.
- The gear selector is in Park or Neutral.
- The correct key fob (code) is present in the vehicle.

Computer-controlled starting is almost always part of the system if a push-button start is used.

TECH TIP ✔ **Check That Extended Cranking May Be Normal Operation**

Some customers have complained that the engine cranks after they release the ignition key and assume that there is a fault with the ignition switch or starter circuit. If the vehicle is equipped with computer-controlled starting, it is normal for the engine to crank until it starts and it may crank longer than the customer thinks it should especially in cold weather.

Remote vehicle start (RVS) is a system that allows the driver to start the engine of the vehicle from inside the house or building from a distance of about 200 feet (65 meters). The doors remain locked so the possibility of theft is reduced. This feature allows the heater or air-conditioning system to start before the driver arrives. See Figure 40–4.

NOTE: Most remote start systems will turn off the engine after 10 minutes of run time unless reset by the use of the remote.

HOW THE STARTER MOTOR WORKS

A starter consists of a **main field housing,** one end of which is called a **commutator-end** (or **brush-end) housing** and the other end a **drive-end housing.** The drive-end housing contains the drive pinion gear, which meshes with the engine flywheel gear teeth to start the engine. The commutator-end plate supports the end containing the starter brushes. **Through bolts** hold the three components together. See Figure 40–5.

A starter motor uses electromagnetic principles to convert electrical energy from the battery (up to 500 amperes) to mechanical power [up to 8 horsepower (6 kilowatts)] to crank the engine. The steel housing of the starter motor contains four electromagnets that are connected directly to the positive post of the battery



Figure 40–4 The top button on this key fob is the remote start button.

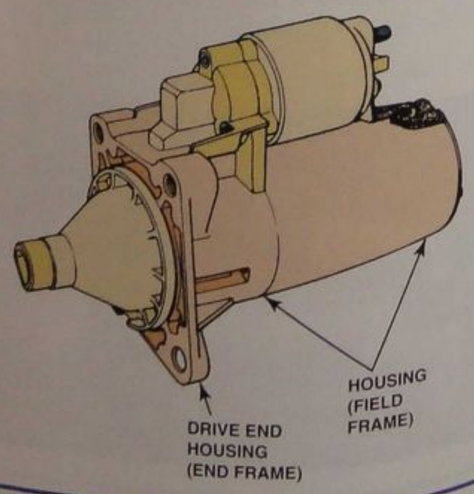


Figure 40–5 A typical starter motor.

to provide a strong magnetic field inside the starter. Current for the starter is controlled by a solenoid or relay that is controlled by the driver-operated ignition switch. The four electromagnets use heavy copper or aluminum wire wrapped around a soft-iron core. The core is contoured to fit against the rounded internal surface of the starter frame. The soft-iron cores are called **pole shoes.** Two of the four pole shoes are wrapped with copper wire in one direction to create a north pole magnet, and the other two pole shoes are wrapped in the opposite direction to create a south pole magnet. These magnets, when energized, create strong magnetic fields inside the starter housing and therefore are called **field coils.** The soft-iron cores (pole shoes) are often called **field poles.**

Inside the field coils is an **armature** that is supported with bushings at both ends, which permit it to rotate. The armature is constructed of thin, circular disks of steel laminated together and wound lengthwise with heavy-gauge insulated copper wire. The laminated iron core supports the copper loops of wire and helps concentrate the magnetic field produced by the coils. The ends of the copper armature windings are soldered to **commutator segments.** The electrical current that passes through the field coils is then connected to the commutator of the armature by brushes that can move over the segments of the rotating armature. These **brushes** are made of a combination of copper and carbon. The copper is a good conductor material, and the carbon added to the starter brushes helps provide the graphite-type lubrication needed to reduce wear of the brushes and the commutator segments.

The starter uses four brushes—two brushes to transfer the current from the field coils to the armature, and two brushes to provide the ground return path for the current that flows through the armature. See Figure 40–6. Therefore, two **hot brushes** are in holders, which are insulated from the housing, and two **ground brushes** primarily use bare, stranded copper wire connections to the brushes. The ground brush holders are not insulated and attach directly to the field housing.

The current travels through the brushes and into the armature windings, where other magnetic fields are created around each copper wire loop in the armature. The two strong magnetic fields created inside the starter housing create the force that rotates the armature.

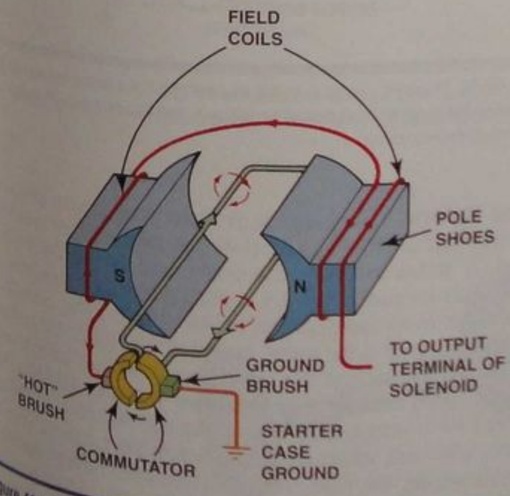


Figure 40–6 This series-wound electric motor shows the basic operation with only two brushes, one hot brush and one ground brush. The current flows through both field coils, then through the hot brush and through the loop winding of the armature before reaching ground through the ground brush.

HOW MAGNETIC FIELDS TURN AN ARMATURE

One basic principle of electromagnetism is that a magnetic field surrounds every conductor carrying a current. The strength of the magnetic field is increased as the current flow (in amperes) is increased.

Inside the starter housing is a strong magnetic field created by the field coil magnets. The armature, a conductor, is installed inside this strong magnetic field, with very little clearance between the armature and the field coils.

The two magnetic fields act together, and their lines of force "bunch up" or are strong on one side of the armature loop wire and become weak on the other side of the conductor. This causes the conductor (armature) to move from the area of strong magnetic field strength toward the area of weak magnetic field strength. See Figures 40–7 and 40–8. This causes the armature to rotate. This rotation force (torque) is increased as the current flowing through the starter motor increases. The torque of a starter is determined by the strength of the magnetic fields inside the starter. Magnetic field strength is measured in **ampere-turns.** If the current or the number of turns of wire are increased, the magnetic field strength is increased. The magnetic field of the starter motor is provided by two or more pole shoes and field windings. The pole shoes are made of iron and are attached to the frame with large screws. See Figure 40–9. Figure 40–10 shows the paths of magnetic flux lines within a four-pole motor. The field windings are usually made of a heavy copper ribbon to increase their current-carrying capacity and electromagnetic field strength. See Figure 40–11. Automotive starter motors usually have four pole shoes and two to four field windings to provide a strong magnetic field within the motor. Pole shoes that do not have field windings are magnetized by flux lines from the wound poles.

TYPES OF STARTER MOTORS

Starter motors must provide high power at low starter motor speeds to crank an automotive engine at all temperatures and at the cranking speed required for the engine to start (60 to 250 engine RPM). Electric motors are classified according to the internal electrical motor connections. The method used determines the power-producing characteristics of the electric motor. Many starter motors are series wound, which means that the current flows first through the field coils, then in series through the armature, and finally to a ground through the ground brushes. See Figure 40–12.

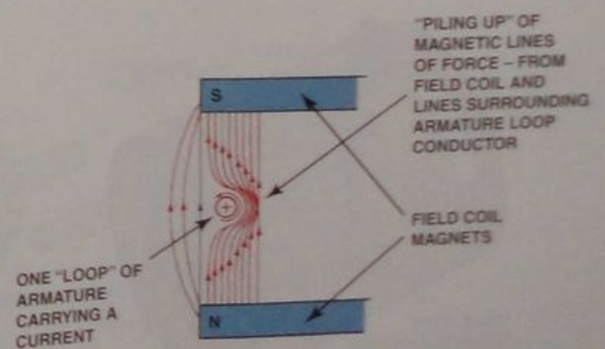


Figure 40–7 The interaction of the magnetic fields of the armature loops and field coils creates a stronger magnetic field on the right side of the conductor, causing the armature loop to move toward the left.

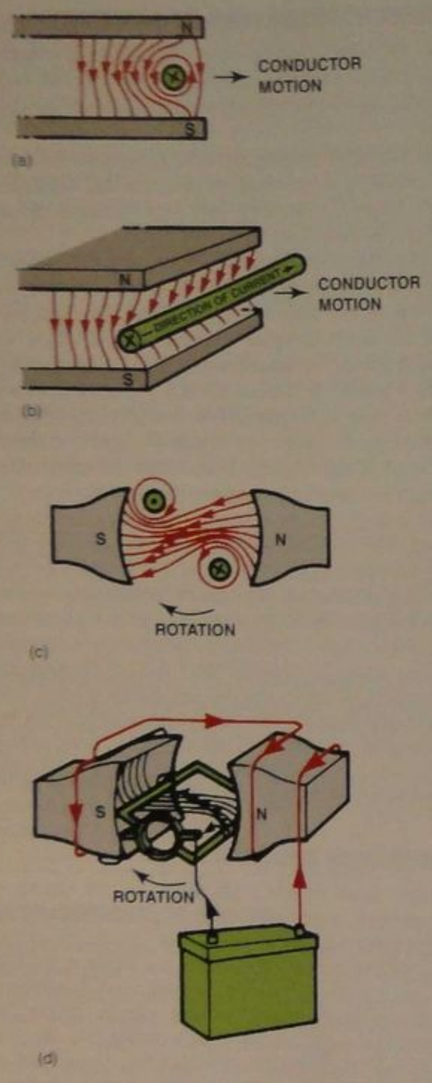


Figure 40–8 The armature loops rotate due to the difference in the strength of the magnetic field. The loops move from a strong magnetic field strength toward a weaker magnetic field strength.

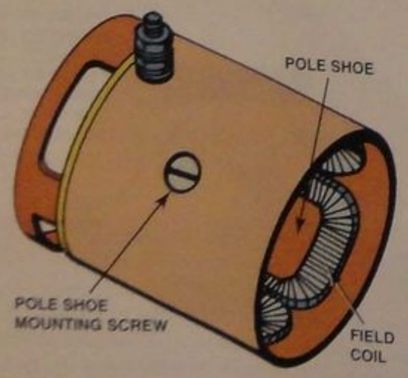


Figure 40–9 Pole shoes and field windings installed in the housing.

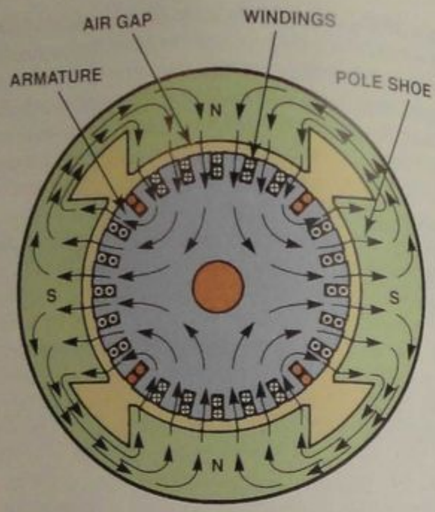


Figure 40–10 Magnetic lines of force in a four-pole motor.

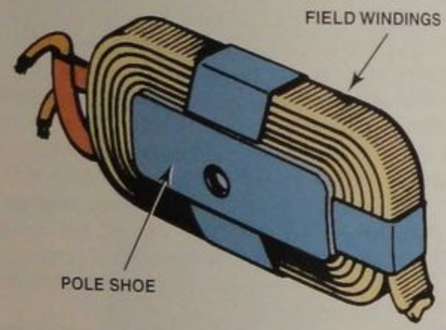


Figure 40–11 A pole shoe and field winding.

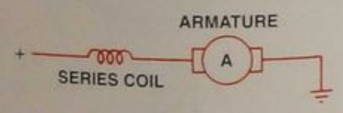


Figure 40–12 This wiring diagram illustrates the construction of a series-wound electric motor. Notice that all current flows through the field coils, then through the armature (in series) before reaching ground.

Series Motors A series motor develops its maximum torque at the initial start (0 RPM) and develops less torque as the speed increases. A **series motor** is commonly used for an automotive starter motor because of its high starting power characteristics. A series starter motor develops less torque at high RPM, because a current is produced in the starter itself that acts against the current from the battery. Because this current works against battery voltage, it is called **counter electromotive force** or **CEMF.** This counter EMF is produced by electromagnetic induction in the armature conductors, which are cutting across the magnetic lines of force formed by the field coils. This induced voltage operates against the applied voltage supplied by the battery, which reduces the strength of the magnetic field in the starter and reduces the current draw of the starter.

Because the power (torque) of the starter depends on the strength of the magnetic fields, the torque of the starter decreases as the starter speed increases. It is also characteristic of series-wound motors to keep increasing in speed under light loads. This could lead to the destruction of the starter motor unless controlled or prevented.

Shunt Motors Shunt-type electric motors have the field coils in parallel (or shunt) across the armature as shown in Figure 40–13. A **shunt motor** does not decrease in torque at higher motor RPM, because the CEMF produced in the armature does not decrease the field coil strength. A shunt motor, however, does not produce as high a starting torque as that of a series-wound motor, and is not used for starters. Many small electric motors used in automotive blower motors, windshield wipers, power windows, and power seats use permanent magnets rather than electromagnets. Because these permanent magnets maintain a constant field strength, the same as a shunt-type motor, they have similar operating characteristics. To compensate for the lack of torque, all PM starters use gear reduction to multiply starter motor torque.

Compound Motors A **compound-wound,** or **compound, motor** has the operating characteristics of a series motor *and* a shunt-type motor, because some of the field coils are connected to the armature in series and some (usually only one) are connected directly to the battery in parallel (shunt) with the armature. See Figure 40–14.

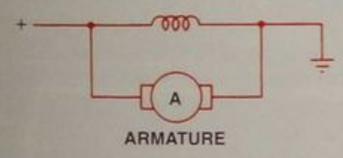


Figure 40–13 This wiring diagram illustrates the construction of a shunt-type electric motor. Shunt-type electric motors have the field coils in parallel (or shunt) across the armature as shown.

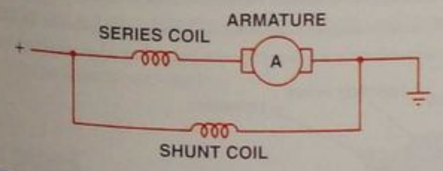


Figure 40–14 A compound motor is a combination of series and shunt types, using part of the field coils connected electrically in series with the armature and some in parallel (shunt).

Compound-wound starter motors are commonly used in Ford, Chrysler, and some GM starters. The shunt-wound field coil is called a shunt coil and is used to limit the maximum speed of the starter. Because the shunt coil is energized as soon as the battery current is sent to the starter, it is used to engage the starter drive on Ford positive-engagement starters.

ARMATURE AND COMMUTATOR ASSEMBLY

The motor armature shown in Figure 40–15 has a laminated core. Insulation between the laminations helps to reduce eddy currents in the core. For reduced resistance, the armature conductors are made of a thick copper wire. Motor armatures are connected to the commutator in one of two ways. In a **lap winding,** the two ends of each conductor are attached to two adjacent commutator bars. See Figure 40–16. In a **wave winding,** the two ends of a conductor are attached to commutator bars that are 180 degrees apart (on opposite sides of the commutator). A lap-wound armature is more commonly used because it offers less resistance.

The commutator is made of copper bars insulated from each other by **mica** or some other insulating material. The armature core, windings, and commutator are assembled on a long armature shaft. This shaft also carries the pinion gear that meshes with the

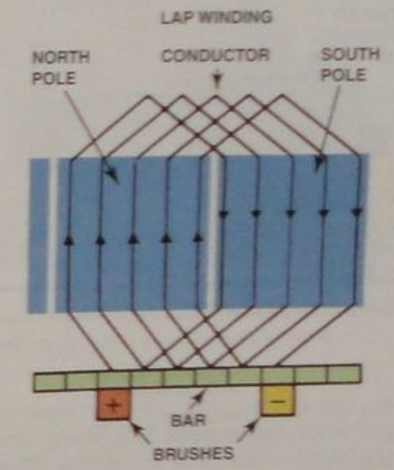


Figure 40–16 An armature lap winding.

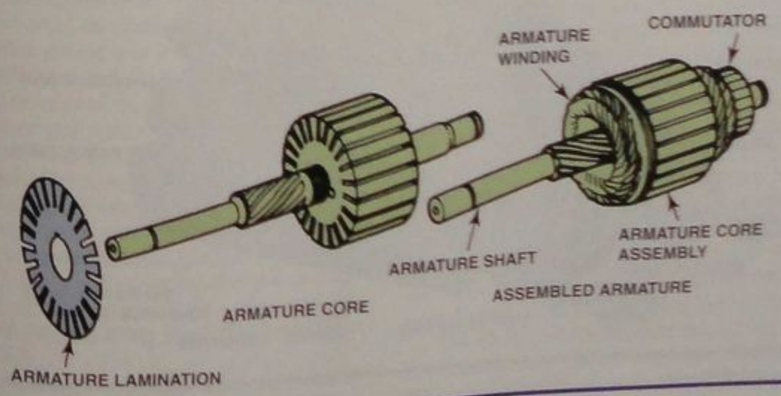


Figure 40–15 A typical starter motor armature.

engine flywheel ring gear. See Figure 40–17. The shaft is supported by bearings or bushings in the end housings.

To supply the proper current to the armature, a four-pole motor must have four brushes riding on the commutator. Most automotive starters have two grounded and two insulated brushes, which are held against the commutator by spring force. See Figure 40–18.

PERMANENT-MAGNET FIELDS

Permanent-magnet starter motors were developed by General Motors for automotive use in the mid-1980s. The permanent magnets used are an alloy of neodymium, iron, and boron. This magnet is almost 10 times more powerful than permanent magnets used previously. The permanent-magnet, planetary-drive starter motor is the first significant advance in starter design in decades. It was first introduced on Chrysler and GM models. Permanent magnets are used in place of the electromagnetic field coils and pole shoes. This eliminates the motor field circuit, which in turn eliminates the potential for field wire-to-frame shorts, field coil welding, and other electrical problems. The motor has only an armature circuit.

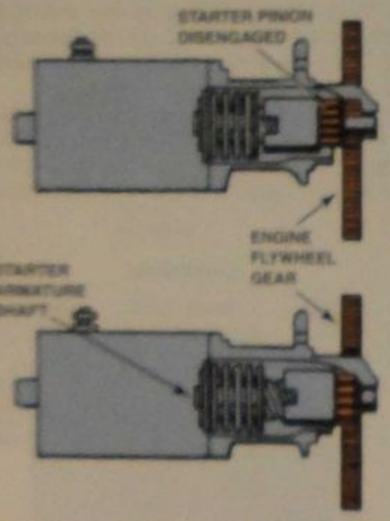


Figure 40–17 The pinion gear meshes with the fly-wheel ring gear.

TECH TIP ✓ **Don't Hit That Starter!**

In the past, it was common to see service technicians hitting a starter in their effort to diagnose a no-crank condition. Often the shock of the blow to the starter aligned or moved the brushes, armature, and bushings. Many times, the starter functioned after being hit—even if only for a short time.

However, most of today's starters use **permanent-magnet fields**, and the magnets can be easily broken if hit. A magnet that is broken becomes two weaker magnets. Some early PM starters used magnets that were glued or bonded to the field housing. If struck with a heavy tool, the magnets could be broken, with parts of the magnet falling onto the armature and into the bearing pockets, making the starter impossible to repair or rebuild. See Figure 40–19.

GEAR-REDUCTION STARTERS

Gear-reduction starters are used by many automotive manufacturers. The purpose of the gear reduction (typically 2:1 to 4:1) is to increase the speed of the armature of the starter and provide the torque multiplication necessary to crank an engine. See Figure 40–20. As a series-wound motor increases in rotational speed, the starter produces less power, and less current is drawn from the battery because the armature generates greater CEMF as the starter speed increases. However, a starter motor's maximum torque occurs at zero RPM and torque decreases with increasing RPM. A smaller starter using a gear-reduction design can produce the necessary cranking power with reduced starter amperage requirements. Lower current requirements mean that smaller battery cables can be used. Permanent-magnet starters use a planetary gear set (a type of gear reduction) to provide the necessary torque for starting.

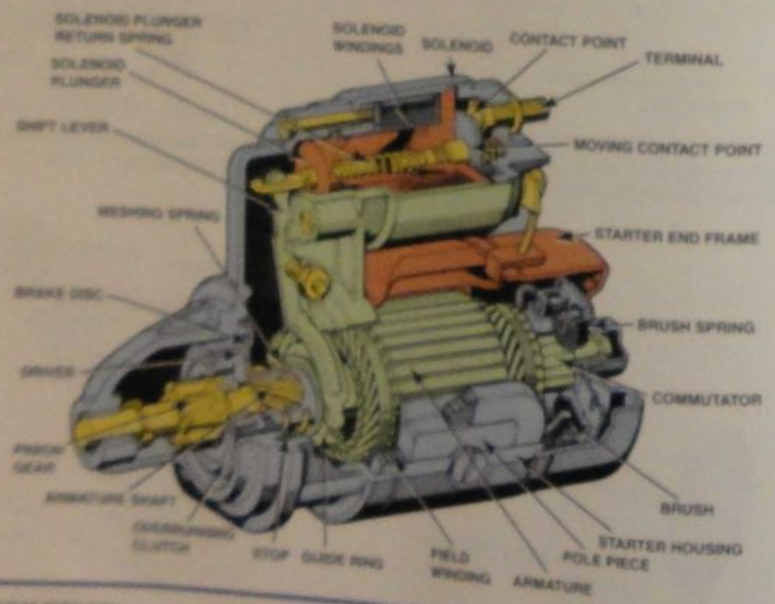


Figure 40–18 A cutaway of a typical starter motor.



Figure 40–19 This starter permanent-magnet field housing was ruined when someone used a hammer on the field housing in an attempt to "fix" a starter that would not work. A starter replacement is the only solution in this case.



Figure 40–20 Many gear-reduction starters use a planetary gear-reduction assembly similar to that used in an automatic transmission.

STARTER DRIVES

A **starter drive** includes a small pinion gear that meshes with and rotates the larger gear on the flywheel for starting. The pinion gear must engage with the engine gear slightly *before* the starter motor rotates, to prevent serious damage to either the starter gear or the engine, but the pinion gear must be disengaged after the engine starts. The ends of the starter pinion gear are tapered to help the teeth mesh more easily without damaging the flywheel ring gear teeth. See Figure 40–21. The ratio of the number of teeth on the engine gear to the number on the starter pinion is between 15:1 and 20:1. A typical small starter pinion gear has 9 teeth that turn a engine gear with 166 teeth. This provides an 18:1 gear reduction; thus, the starter motor is rotating approximately 18 times faster than the engine. Normal cranking speed for the engine is 200 RPM. This means that the starter motor speed is 18 times faster, or 3600 starter RPM (200 × 18 = 3600). If the engine started and was accelerated to 2000 RPM (normal cold engine speed), the starter would be destroyed by the high speed (36,000 RPM) if not disengaged from the engine. See Figure 40–22.

Older-model starters often used a Bendix drive mechanism, which used inertia to engage the starter pinion with the engine flywheel gear. Inertia is the tendency of a stationary object to remain stationary, because of its weight, unless forced to move. On these older-model starters, the small starter pinion gear was attached to a shaft with threads, and the weight of this gear caused it to be spun along the threaded shaft and mesh with the flywheel whenever the starter motor spun. If the engine speed was greater than the starter speed, the pinion gear was forced back along the threaded shaft and out of mesh with the flywheel gear.

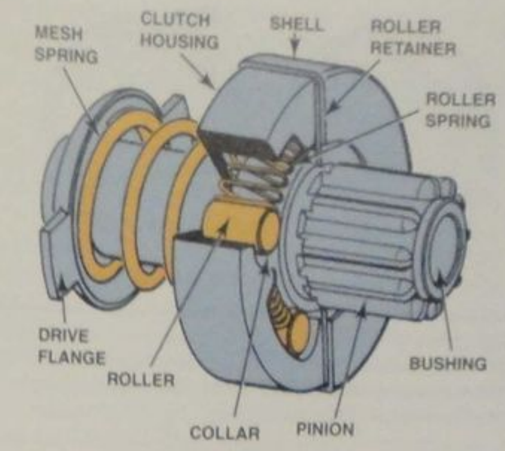


Figure 40–21 A cutaway of a typical starter drive.

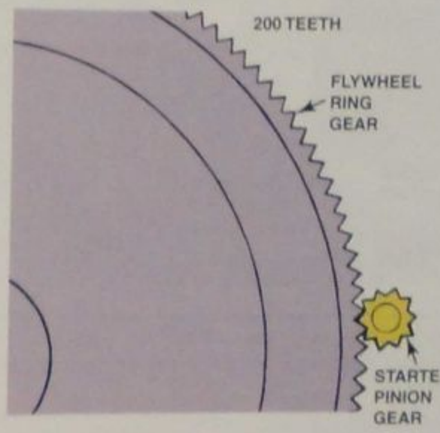


Figure 40–22 The ring gear to pinion gear ratio is usually 15:1 to 20:1.

All starter drive mechanisms use a type of one-way clutch that allows the starter to rotate the engine, but that turns freely if the engine speed is greater than the starter motor speed. This clutch is called an **overrunning clutch** and it protects the starter motor from damage if the ignition switch is held in the start position after the engine starts. The overrunning clutch, which is built in as a part of the starter drive unit, uses steel balls or rollers installed in tapered notches. See Figure 40–23. This taper forces the balls or rollers tightly into the notch, when rotating in the direction necessary, to start the engine. Whenever the engine rotates faster than the starter pinion, the balls or rollers are forced out of the narrow tapered notch, allowing the pinion gear to turn freely (overruns).

The spring between the drive tang or pulley and the overrunning clutch and pinion is called a **mesh spring** and it helps to cushion and control the engagement of the starter drive pinion with the

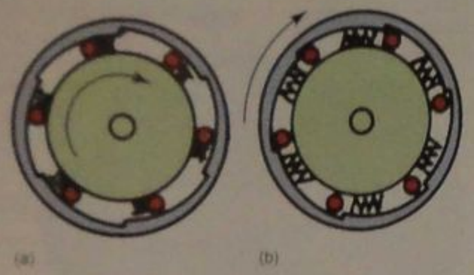


Figure 40–23 Operation of the overrunning clutch. (a) Starter motor is driving the starter pinion and cranking the engine. The rollers are wedged against spring force into their slots. (b) The engine has started and is rotating faster than the starter armature. Spring force pushes the rollers so they can rotate freely.



Figure 40–24 Cutaway of a solenoid-activated starter showing the solenoid, shift lever, and starter drive assembly that includes the starter pinion and overrunning clutch with a mesh spring in one unit.

engine flywheel gear. This spring is also called a **compression spring** because the starter solenoid or starter yoke compresses the spring and the spring tension causes the starter pinion to engage the engine flywheel. See Figure 40–24.

STARTER DRIVE OPERATION

The starter drive (pinion gear) must be moved into mesh with the engine ring gear before the starter motor starts to spin. Most automotive starters use a solenoid or the magnetic pull of the shunt coil in the starter to engage the starter pinion.

A starter drive is generally a dependable unit and does not require replacement unless it is defective or worn. The major wear occurs in the overrunning clutch section of the starter drive unit. The steel balls or rollers wear and often do not wedge tightly into the tapered notches as is necessary for engine cranking. A worn starter drive can cause the starter motor to operate freely and not rotate the engine. Therefore, the starter makes a "whining" noise. The whine indicates that the starter motor is operating and that the starter drive is not rotating the engine flywheel. The entire starter drive is replaced as a unit. The overrunning clutch section of the starter drive cannot be serviced or repaired separately because the drive is a sealed unit. Starter drives are most likely to fail intermittently at first and then more frequently, until replacement becomes necessary to start the engine. Intermittent starter drive failure (starter whine) is often most noticeable during cold weather.

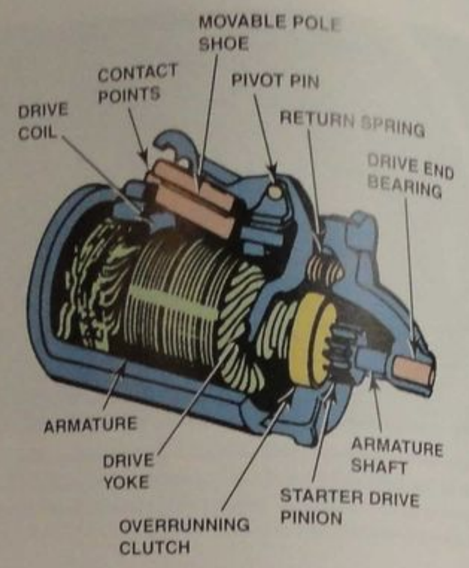


Figure 40–25 A Ford movable-pole-shoe starter.

POSITIVE-ENGAGEMENT STARTERS

Positive-engagement starters, used on some old Ford engines, utilize the shunt coil winding of the starter to engage the starter drive. The high starting current is controlled by an ignition switch–operated starter solenoid, usually mounted near the positive post of the battery. When this control circuit is closed, current flows through a hollow coil (called a **drive coil**) that attracts a **movable pole shoe.** See Figure 40–25. The movable metal pole shoe is attached to and engages the starter drive with a lever (called the **plunger lever**).

As soon as the starter drive has engaged the engine flywheel, a tang on the movable pole shoe "opens" a set of contact points. The contact points provide the ground return path for the drive coil operation. After these grounding contacts are opened, all of the starter current can flow through the remaining three field coils and through the brushes to the armature, causing the starter to operate.

The movable pole shoe is held down (which keeps the starter drive engaged) by a smaller coil on the inside of the main drive coil. This coil is called the **holding coil** and it is strong enough to hold the starter drive engaged while permitting the flow of the maximum possible current to operate the starter. If the grounding contact points are severely pitted, the starter may not operate the starter drive or the starter motor because of the resulting poor ground for the drive coil. If the contact points are bent or damaged enough to prevent them from opening, the starter will "clunk" the starter drive into engagement but will not allow the starter motor to operate.

SOLENOID-OPERATED STARTERS

A **starter solenoid** is an **electromagnetic switch** containing two separate but connected electromagnetic windings. This switch is used to engage the starter drive and to control the current from the battery to the starter motor. See Figure 40–26.

The two internal windings contain approximately the same number of turns but are made from a different gauge wire. Together both windings produce a strong magnetic field that pulls a metal plunger into the solenoid. The plunger is attached to the

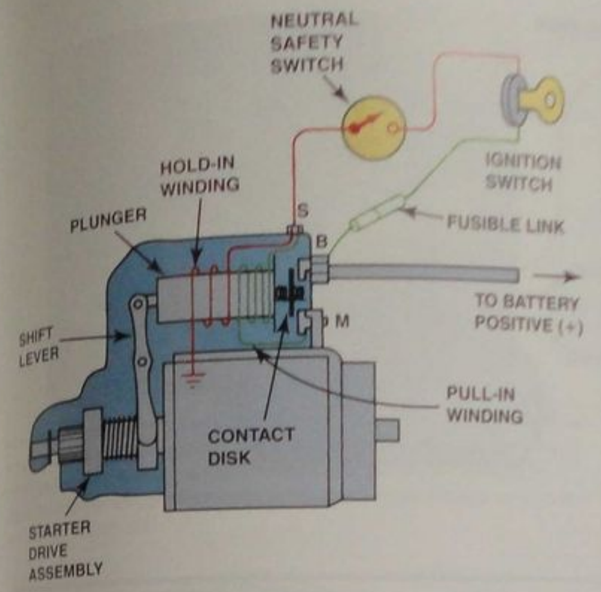


Figure 40–26 Wiring diagram of a typical starter solenoid. Notice that both the pull-in winding and the hold-in winding are energized when the ignition switch is first turned to the "start" position. As soon as the solenoid contact disk makes electrical contact with both the B and M terminals, the battery current is conducted to the starter motor and electrically neutralizes the pull-in winding.

starter drive through a **shift fork lever.** When the ignition switch is turned to the start position, the motion of the plunger into the solenoid causes the starter drive to move into mesh with the flywheel ring gear. The heavier-gauge winding (called the **pull-in winding**) is needed to draw the plunger into the solenoid. The lighter-gauge winding (called the **hold-in winding**) produces enough magnetic force to keep the plunger in position. The main purpose of using two separate windings is to permit as much current as possible to operate the starter and yet provide the strong magnetic field required to move the starter drive into engagement. The instant the plunger is drawn into the solenoid enough to engage the starter drive, the plunger makes contact with a metal disk that connects the battery terminal post of the solenoid to the motor terminal. This permits full battery current to flow through the solenoid to operate the starter motor. The contact disk also electrically bypasses the pull-in winding. The solenoid *has* to work to supply current to the starter. Therefore, if the starter motor operates at all, the solenoid is working, even though it may have high external resistance that could cause slow starter motor operation.

STARTING SYSTEM TROUBLESHOOTING

The proper operation of the starting system depends on a good battery, good cables and connections, and a good starter motor. Because a starting problem can be caused by a defective component anywhere in the starting circuit, it is important to check for the proper operation of each part of the circuit to diagnose and repair the problem quickly.

VOLTAGE-DROP TESTING

Voltage drop is the drop in voltage that occurs when current is flowing through a resistance. For example, a voltage drop is the difference between voltage at the source and the voltage at the electrical device to which it is flowing. The higher the voltage drop, the greater the resistance in the circuit. Even though **voltage-drop testing** can be performed on any electrical circuit, the most common areas of testing include the cranking circuit and the charging circuit wiring and connections.

A high-voltage drop (high resistance) in the cranking circuit wiring can cause slow engine cranking with less than normal starter amperage drain as a result of the excessive circuit resistance. If the voltage drop is high enough, such as could be caused by dirty battery terminals, the starter may not operate. A typical symptom of high resistance in the cranking circuit is a "clicking" of the starter solenoid.

Voltage-drop testing of the wire involves connecting any voltmeter (on the low scale) to the suspected high-resistance cable ends and cranking the engine. See Figures 40–27 through 40–29.

NOTE: Before a difference in voltage (voltage drop) can be measured between the ends of a battery cable, current must be flowing through the cable. *Resistance is not effective unless current is flowing.* If the engine is not being cranked, current is not flowing through the battery cables and the voltage drop cannot be measured.

Crank the engine with a voltmeter connected to the battery and record the reading. Crank the engine with the voltmeter connected across the starter and record the reading. If the difference in the two readings exceeds 0.5 volt, perform the following steps to determine the exact location of the voltage drop.

Step #1 Connect the positive voltmeter test lead to the most-positive end of the cable being tested. The most-positive end of a cable is the end closest to the positive terminal of the battery.

Step #2 Connect the negative voltmeter test lead to the other end of the cable being tested. With no current flowing through the cable, the voltmeter should read zero because both ends of the cable have the same voltage.

Step #3 Crank the engine. The voltmeter should read less than 0.2 volt.

TECH TIP ✓ **Voltage Drop Is Resistance**

Many technicians have asked, "Why measure voltage drop when the resistance can be easily measured using an ohmmeter?" Think of a battery cable with all the strands of the cable broken, except for one strand. If an ohmmeter were used to measure the resistance of the cable, the reading would be very low, probably less than 1 ohm. However, the cable is not capable of conducting the amount of current necessary to crank the engine. In less severe cases, several strands can be broken and can affect the operation of the starter motor. While the resistance of the battery cable will not indicate any increased resistance, the restriction to current flow will cause heat and a decrease in the voltage available at the starter. Since resistance is not effective until current flows, measuring the voltage drop (differences in voltage between two points) is the most accurate method of determining the true resistance in a circuit.

How much is too much? According to Bosch Corporation, all electrical circuits should have a maximum of 3% loss of the voltage of the circuit to resistance. Therefore, in a 12-volt circuit, the maximum loss of voltage in cables and connections should be 0.36 volt (12 × 0.03 = 0.36 volt. The remaining 97% of the circuit voltage (11.64 volts) is available to operate the electrical device (load). Just remember:

Low-voltage drop = Low resistance

High-voltage drop = High resistance

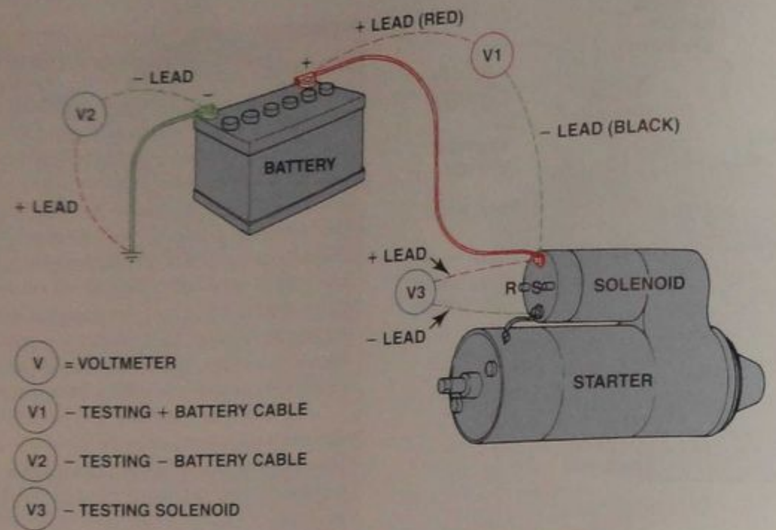


Figure 40–27 Voltmeter hookups for voltage-drop testing of a GM-type cranking circuit.

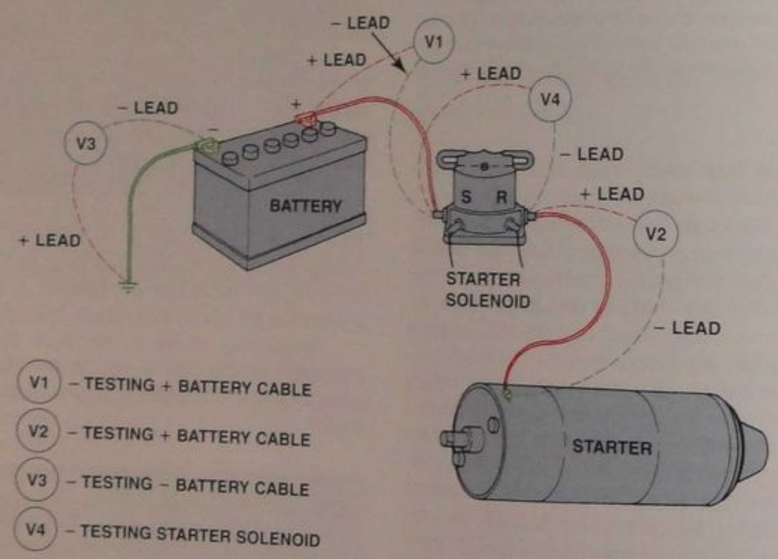


Figure 40–28 Voltmeter hookups for voltage-drop testing of a Ford-type cranking circuit.

Step #4 Evaluate the results. If the voltmeter reads zero, the cable being tested has no resistance and is good. If the voltmeter reads higher than 0.2 volt, the cable has excessive resistance and should be replaced. However, before replacing the cable, make certain that the connections at both ends of the cable being tested are clean and tight.

TECH TIP ✔ **Heat Equals Resistance**

If a cable or connection is hot to the touch, there is electrical resistance in the cable or connection. The resistance changes electrical energy into heat energy. Therefore, if a voltmeter is not available, carefully touch the battery cables and connections while cranking the engine. If any cable or connection is hot to the touch, it should be cleaned or replaced.

REAL WORLD FIX **Battery Cable Heat and Counter EMF**

When there is excessive current flow through the cable, battery cables can overheat. The amount of current (in amperes) is determined by the power required to operate the starter motor. A typical problem involved a vehicle driven to Florida from Michigan. The battery cables overheated when the driver tried to start the vehicle. At a service center, some technicians believed that the cause of the overheated cables was an oversized battery, which is often used in vehicles from northern climates. Although it is true that a smaller battery can be used in warmer climates, a large battery does absolutely no harm and, in fact, generally lasts longer than a smaller battery. The cause of the problem was discovered (by testing) to be a defective starter motor that rotated too slowly. The too-slow rotation of the starter meant that the starter was not producing the normal amount of counter EMF or CEMF. The overall result was a tremendous increase in current being drawn from the battery, and it was this extra current flow that heated the battery cables.



Figure 40–29 To test the voltage drop of the battery cable connection, place one voltmeter lead on the battery terminal and the other voltmeter lead on the cable end and crank the engine. The voltmeter will read the difference in voltage between the two leads which should not exceed 0.2 volt (200 mV).

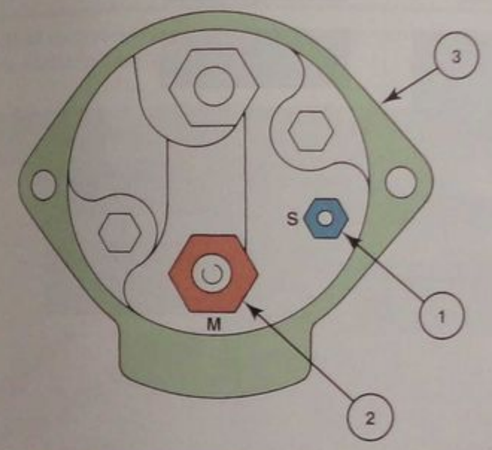


Figure 40–30 GM solenoid ohmmeter check. The reading between 1 and 3 (S terminal and ground) should be 0.4 to 0.6 ohm (hold-in winding). The reading between 1 and 2 (S terminal and M terminal) should be 0.2 to 0.4 ohm (pull-in winding).

CONTROL CIRCUIT TESTING

The control circuit for the starting circuit includes the battery, ignition switch, neutral or clutch safety switch, and starter solenoid. Whenever the ignition switch is rotated to the start position, current flows through the ignition switch and the neutral safety switch and activates the solenoid. High current then flows directly from the battery through the solenoid and to the starter motor. Therefore, an open or break anywhere in the control circuit will prevent the operation of the starter motor. If a starter is inoperative, first check for voltage at the *S* (start) terminal of the starter solenoid. See Figure 40–30. Some newer models with antitheft controls use a relay to open this control circuit to prevent starter operation. See Figure 40–31 for a starter system diagnostic chart.

SPECIFICATIONS FOR A STARTER AMPERAGE TEST

Before performing a starter amperage test, be certain that the battery is sufficiently charged (75% or more) and capable of supplying adequate starting current.

A starter amperage test should be performed whenever the starter fails to operate normally (is slow in cranking) or as part of a routine electrical system inspection. See Figure 40–32. Some service information specifies normal starter amperage for starter motors being tested on the vehicle; however, most service information only gives the specifications for bench testing a starter without a load applied. These specifications are helpful in making certain that a repaired starter meets exact specifications, but they do not apply to starter testing on the vehicle. If exact specifications are not available, the following can be used as general specifications for testing a starter on the vehicle:

- Four-cylinder engines: 150 to 185 amperes MAX
- Six-cylinder engines: 160 to 200 amperes MAX
- Eight-cylinder engines: 185 to 250 amperes MAX

Excessive current draw may indicate one or more of the following:

1. Binding of starter armature as a result of worn bushings
2. Oil too thick (viscosity too high) for weather conditions
3. Shorted or grounded starter windings or cables
4. Tight or seized engine
5. High resistance in the starter motor (usually caused by excessively worn brushes)

REAL WORLD FIX **The Starter That Croaked and the Jumping Battery Cables**

Once upon a time a vehicle would not start (crank). A technician at first hoped that the problem was a simple case of loose or corroded battery terminal connections; but after the technician cleaned the cables, the starter still made no noise when the ignition switch was turned to the *start* position. The technician opened the vehicle door and observed the dome (interior) light. The light was bright, indicating that the battery voltage was relatively high and that the battery should be adequately charged to crank the engine. However, when the technician turned the ignition switch to the start position, the dome light went out completely! This indicated that the battery voltage went down considerably.

NOTE: It is normal for the dome light to dim during cranking as a result of the lowered battery voltage during cranking. However, the voltage should not drop below 9.6 volts, which normally will still provide adequate voltage to light the dome light dimly.

The technician then arranged the two battery cables so that they were parallel for a short distance and repeated the test. As soon as the ignition switch was turned to the start position, the battery cables jumped toward each other. The technician knew that the engine was seized or the starter had a shorted or grounded field coil or armature. This provided a direct path to ground for the starter current, which resulted in a substantially greater amount of current (in amperes) leaving the battery than would normally occur with a good starter. This amount of current drain lowered the battery voltage so much that the dome light did not light.

Why did the battery cables jump? The battery cables jumped because the high current flow created a strong magnetic field around each cable. Because one cable is positive and the other cable is negative, the magnetic fields were of opposite polarity and were attracted toward each other.

STARTER REMOVAL

After testing has confirmed that a starter motor may need to be replaced, most vehicle manufacturers recommend the following general steps and procedures:

Step #1 Disconnect the negative battery cable.

Step #2 Hoist the vehicle safely.

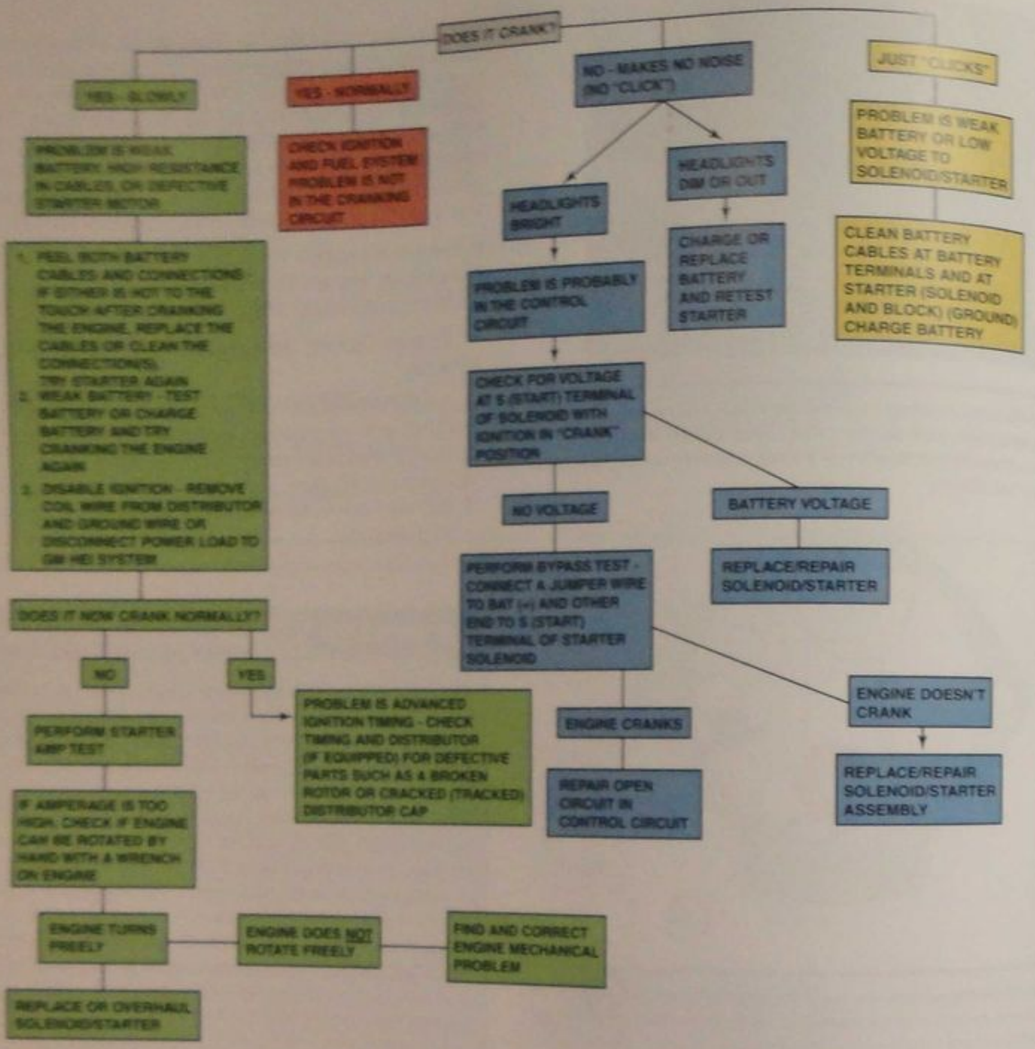


Figure 40–31 Starter trouble diagnostic chart.

NOTE: This step may not be necessary. Check service information for the specified procedure for the vehicle being serviced.

Step #3 Remove the starter retaining bolts and lower the starter to gain access to the wire(s) connection(s) on the starter.

Step #4 Disconnect the wire(s) from the starter and remove the starter.

Step #5 Inspect the flywheel (flex plate) for ring gear damage. Also check that the mounting holes are clean and the mounting flange is clean and smooth. Service as needed.

See Figures 40–33 through 40–36.

STARTER DISASSEMBLY

Most starters are replaced as an assembly and are not disassembled. If the starter is to be inspected or repaired, disassemble the starter using the following steps or the procedure specified in the service information. The steps usually include the following:

Step #1 Remove the solenoid from the starter assembly if equipped.

Step #2 Remove the through bolts and separate the drive-end housing from the field frame.

Step #3 Remove the armature assembly.

Testing Starter Armatures

After the starter drive has been removed from the armature, it can be checked for runout using a dial indicator and V-blocks as shown in Figure 40–39. Because the loops of copper wire are interconnected in the armature of a starter, an armature can be accurately tested only by use of a **growler**. A growler is a 110-volt AC test unit that generates an alternating (60 hertz) magnetic field around an armature. A starter armature is placed into the V-shaped top portion of a laminated soft-iron core surrounded by a coil of copper wire. When the growler is plugged into a 110-volt outlet and switched on, the moving magnetic field creates an alternating current in the windings of the armature.

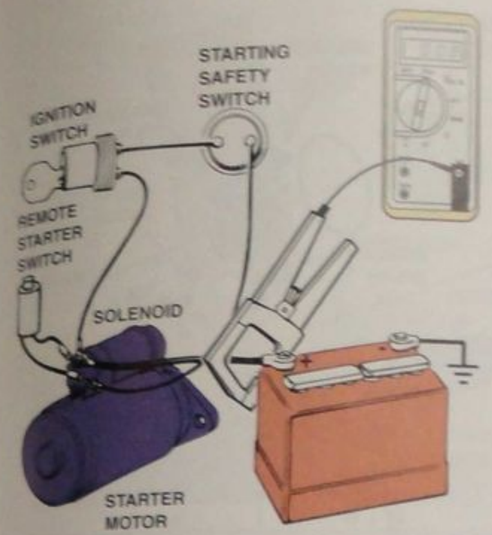


Figure 40–32 Starter current can be measured by using a high-current clamp and a digital voltmeter or a specialized starting and charging tester.



Figure 40–33 Before disassembly of any starter, mark the location of the through bolts on the field housing. This makes reassembly easier.



Figure 40–34 Removing the solenoid from the starter on a GM-type starter assembly.



Figure 40–35 Rotate the solenoid to remove it from the starter housing. *Caution:* The plunger return spring exerts a force on the solenoid and may cause personal injury if not carefully released.



Figure 40–36 The brushes should be replaced if worn to less than 50% of their original length. Replace if less than 1/2-inch long (13 millimeters).

Armature Service

If the armature tests okay, the commutator should be measured and machined on a lathe, if necessary, to be certain that the surface is smooth and round. Some manufacturers recommend that the insulation between the segments of the armature (mica or hard plastic) be **undercut,** as shown in Figure 40–40. Mica is harder than copper and will form raised "bumps" as the copper segments of the commutator wear. Undercutting the mica permits a longer service life for this type of starter armature.

Testing Starter Motor Field Coils

With the armature removed from the starter motor, the field coils should be tested for opens and grounds. A powered test light or an ohmmeter can be used. To test for a grounded field coil, touch one lead of the tester to a field brush (insulated or hot) and the other end to the starter field housing. The ohmmeter should indicate infinity (no continuity), and the test light should *not* light. If there is continuity, replace the field coil housing assembly. The ground brushes should show continuity to the starter housing.

NOTE: Many starters use removable field coils, and these coils must be rewound using the proper equipment and insulating materials. Usually the cost involved in replacing defective field coils exceeds the cost of a replacement starter.

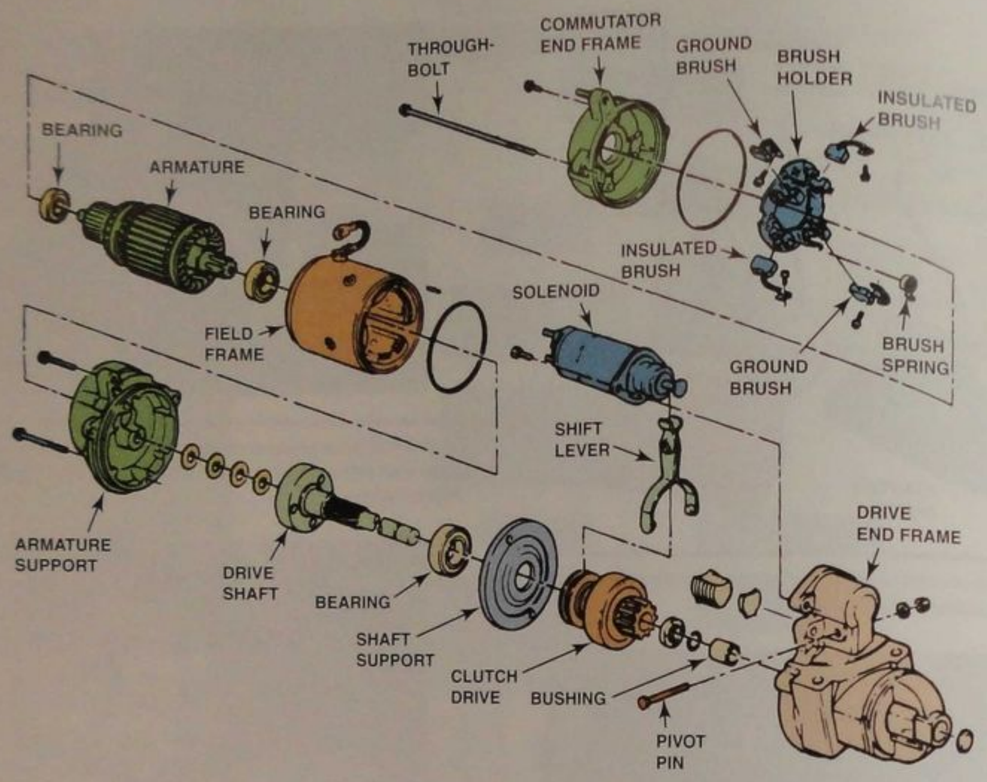


Figure 40–37 An exploded view of a General Motors starter.

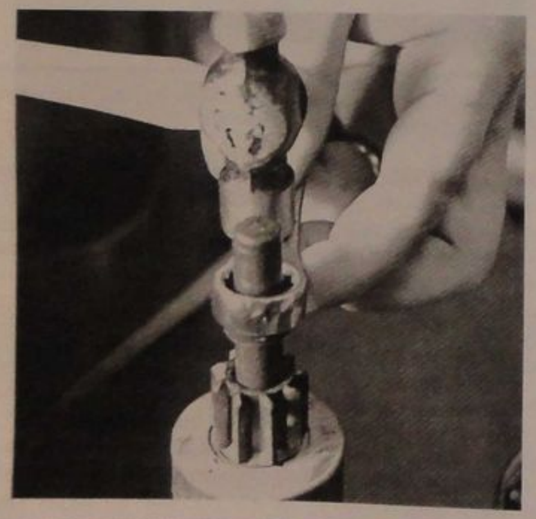


Figure 40–38 To replace the starter drive unit, the retainer and clip must be removed from the armature shaft. A box-end wrench and a hammer can be used to pop the retainer off of the spring clip.

Starter Brush Inspection Starter brushes should be replaced if the brush length is less than one-half of its original length (less than 1/2 inch [13 millimeters]). On some models of starter motors, the field brushes are serviced with the field coil assembly and the ground brushes with the brush holder. Many starters use brushes that are held in with screws and are easily replaced, whereas other starters may require soldering to remove and replace the brushes.

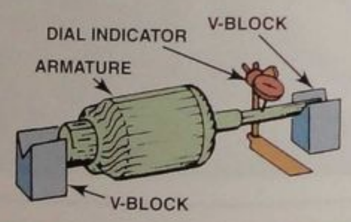


Figure 40–39 Measuring an armature shaft for runout using a dial indicator and V-blocks.

Bench Testing Every starter should be tested before installation in a vehicle. The usual method includes clamping the starter in a vise to prevent rotation during operation and connecting heavy-gauge jumper wires (minimum 4 gauge) to a battery known to be good and to the starter. The starter motor should rotate as fast as specifications indicate and not draw more than the free-spinning amperage permitted. A typical amperage specification for a starter being tested on a **bench** (not installed in a vehicle) usually ranges from 60 to 100 amperes.

STARTER INSTALLATION

After verifying that the starter assembly is functioning correctly, verify that the negative battery cable has been disconnected. Then safely hoist the vehicle if necessary. The following are the usual steps performed to install a starter. Be sure to check service

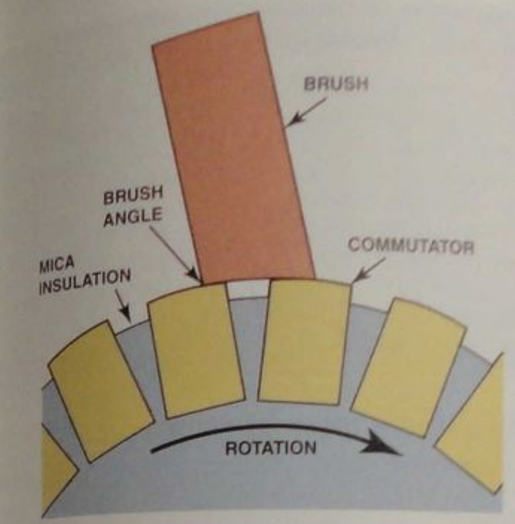


Figure 40–40 Replacement starter brushes should be installed so the beveled edge matches the rotation of the commutator.

information for the exact procedures to follow for the vehicle being serviced.

Step #1 Check service information for the exact wiring connections to the starter and/or solenoid.

Step #2 Verify that all electrical connections on the starter motor and/or solenoid are correct for the vehicle and that they are in good condition.

> **NOTE:** Be sure that the locking nuts for the studs are tight. Often the retaining nut that holds the wire to the stud will be properly tightened, but if the stud itself is loose, cranking problems can occur.

Step #3 Attach the power and control wires.

Step #4 Install the starter, and torque all the fasteners to factory specifications.

> **CAUTION:** Be sure to install all factory heat shields to help ensure proper starter operation under all weather and driving conditions.

Starter Drive-to-Flywheel Clearance For the proper operation of the starter and absence of abnormal starter noise, there must be a slight clearance between the starter pinion and the engine flywheel ring gear. Many GM starters use shims (thin metal strips) between the flywheel and the engine block mounting pad to provide the proper clearance. See Figure 40–41.

> **NOTE:** Some manufacturers use shims under the starter drive-end housing during production. Other manufacturers *grind* the mounting pads at the factory for proper starter pinion gear clearance. If *any* GM starter is replaced, the starter pinion *must* be checked and corrected as necessary to prevent starter damage and excessive noise.

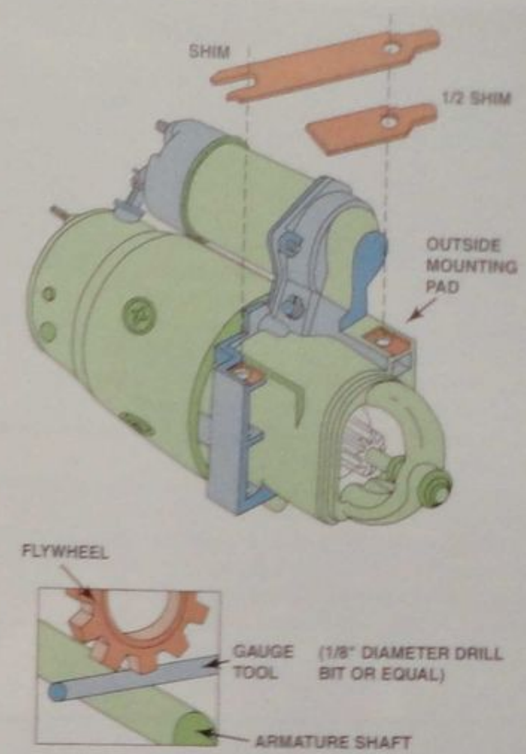


Figure 40–41 A shim (or half shim) may be needed to provide the proper clearance between the flywheel teeth of the engine and the pinion teeth of the starter.

If the clearance is too great, the starter will produce a high-pitched whine *during* cranking. If the *clearance is too small*, the starter will produce a high-pitched whine *after* the engine starts, just as the ignition key is released.

> **NOTE:** The major cause of broken drive-end housings on starters is too small a clearance. If the clearance cannot be measured, it is better to put a shim between the engine block and the starter than to leave one out and risk breaking a drive-end housing.

To be sure that the starter is shimmed correctly, use the following procedure:

Step #1 Place the starter in position and finger tighten the mounting bolts.

Step #2 Use an 1/8 inch diameter drill bit (or gauge tool) and insert between the armature shaft and a tooth of the engine flywheel.

Step #3 If the gauge tool cannot be inserted, use a full-length shim across both mounting holes, which moves the starter away from the flywheel.

Step #4 If the gauge tool is loose between the shaft and the tooth of the engine flywheel, remove a shim or shims.

Step #5 If no shims have been used and the fit of the gauge tool is too loose, add a half shim to the outside pad only. This moves the starter closer to the teeth of the engine flywheel.

TECH TIP ✓ **Ground Wire Current Flow**

Before installing a new or rebuilt starter in a vehicle, be sure that both the positive cable and the negative cable are in good condition. The reason is all electrical power must have a complete path from the power source, through the electrical loads, and back to the power source. This rule is true for all circuits, whether series, parallel, or series-parallel type.

As the current flows through resistances and loads (such as bulbs and coils), its voltage decreases because of the resistance (electrical load) in the circuit. Amperes is the unit of electricity that actually does the work in a circuit. The greater the current flow, the more electrical power available. Because current flow is actually a measure of the number of electrons making the trip through a circuit, this same number of electrons also must return to the power source. The electrical pressure (voltage) on the return (ground) wires is low (almost zero), but the current in amperes must still flow back to the battery.

The battery ground cable must be just as large as the positive cable because just as many amperes return as leave the battery.

Still not convinced? Connect a starting-charging-testing unit to a vehicle. Instead of connecting the ampere probe around the positive cable, connect it around the ground cable (all cables should be within the ampere probe if more than one ground cable is connected to the battery terminal). All ammeter readings should be the same if taken on the positive or negative cables of the battery.

NOTE: Most starting-charging-testing units use an arrow on the ammeter probe to show polarity. Reversing the direction in which the arrow points is often necessary to read the correct polarity (positive or negative) on the tester display.

TECH TIP ✓ **Reuse Drive-End Housing to Be Sure**

Most General Motors starter motors use a pad mount and attach to the engine with bolts through the drive-end (nose) housing. Many times when a starter is replaced on a GM vehicle, the starter makes noise because of improper starter pinion-to-engine flywheel ring gear clearance. Instead of spending a lot of time shimming the new starter, simply remove the drive-end housing from the original starter and install it on the replacement starter. Because the original starter did not produce excessive gear engagement noise, the replacement starter should also be okay. Reuse any shims that were used with the original starter. This method is better than having to remove and reinstall the replacement starter several times until the proper clearance is determined.

STARTING SYSTEM TROUBLESHOOTING GUIDE

The following list will assist technicians in troubleshooting starting systems.

Problem	Possible Causes
1. Starter motor whines.	1. Possible defective starter drive. Worn starter drive engagement yoke. Defective flywheel.
2. Starter rotates slowly.	2. Possible high resistance in the battery cables or connections. Possible defective or discharged battery. Possible worn starter bushings, causing the starter armature to drag on the field coils. Possible worn starter brushes or weak brush springs. Possible defective (open or shorted) field coil.
3. Starter fails to rotate.	3. Possible defective ignition switch or neutral safety switch, or open in the starter motor control circuit. Possible shorted field coils. Possible defective starter armature. Possible open in the power circuit between the battery and the starter. Possible defective starter solenoid.
4. Starter produces grinding noise.	4. Possible defective starter drive unit. Possible defective flywheel. Possible incorrect distance between the starter pinion and the flywheel. Possible cracked or broken starter drive-end housing.

PHOTO SEQUENCE Starter Overhaul Step-by-Step



P40–1 This dirty and greasy starter can be restored to useful service.



P40–2 The connecting wire between the solenoid and the starter is removed.



P40–3 An old starter field housing is being used to support the drive-end housing of the starter as it is being disassembled. This rebuilder is using an electric impact wrench to remove the solenoid fasteners.

PHOTO SEQUENCE Starter Overhaul Step-by-Step—continued



P40–4 A Torx driver is used to remove the solenoid attaching screws.



P40–5 After the retaining screws have been removed, the solenoid can be separated from the starter motor. This rebuilder always replaces the solenoid.



P40–6 The through-bolts are being removed.



P40–7 The brush end plate is removed.



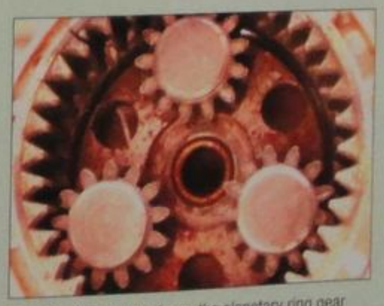
P40–8 The armature assembly is removed from the field frame.



P40–9 Notice that the length of a direct-drive starter armature (top) is the same length as the overall length of a gear-reduction armature except smaller in diameter.



P40–10 A light tap with a hammer dislodges the armature thrust ball (in the palm of the hand) from the center of the gear reduction assembly.



P40–11 This figure shows the planetary ring gear and pinion gears.



P40–12 A close-up of one of the planetary gears, which shows the small needle bearings on the inside.



P40–13 The clip is removed from the shaft so the planetary gear assembly can be separated and removed.



P40–14 The shaft assembly is being separated from the stationary gear assembly.



P40–15 The commutator on the armature is discolored and the brushes may not have been making good contact with the segments.

(continued)

PHOTO SEQUENCE Starter Overhaul Step-by-Step—continued



P40–16 All of the starter components are placed in a tumbler with water-based cleaner. The armature is installed in a lathe and the commutator is resurfaced using emery cloth.



P40–17 The finished commutator looks like new.



P40–18 Starter reassembly begins by installing a new starter drive on the shaft assembly. The stop ring and stop ring retainer are then installed.



P40–19 The gear-reduction assembly is positioned along with the shift fork (drive lever) into the cleaned drive-end housing.



P40–20 After gear retainer has been installed over the gear reduction assembly, the armature is installed.



P40–21 New brushes are being installed into the brush holder assembly.



P40–22 The brush end plate and the through-bolts are installed, being sure that the ground connection for the brushes is clean and tight.



P40–23 This starter was restored to useful service by replacing the solenoid, the brushes, and the starter drive assembly plus a thorough cleaning and attention to detail in the reassembly.

SUMMARY

1. All starter motors use the principle of magnetic interaction between the field coils attached to the housing and the magnetic field of the armature.
2. Proper operation of the starter motor depends on the battery being at least 75% charged and the battery cables being of the correct size (gauge) and having no more than 0.2-volt drop.
3. Voltage-drop testing includes cranking the engine, measuring the drop in voltage from the battery to the starter, and measuring the drop in voltage from the negative terminal of the battery to the engine block.
4. The cranking circuit should be tested for proper amperage draw.
5. An open in the control circuit can prevent starter motor operation.

REVIEW QUESTIONS

1. List the parts of the cranking circuit.
2. Describe the difference between the control circuit and the power circuit sections of a typical cranking circuit.
3. Explain how to perform a voltage-drop test of the cranking circuit.
4. List the steps necessary to overhaul a starter.

CHAPTER QUIZ

1. Starter motors operate on the principle that _____.
   a. The field coils rotate in the opposite direction from the armature
   b. Opposite magnetic poles repel
   c. Like magnetic poles repel
   d. The armature rotates from a strong magnetic field toward a weaker magnetic field
2. Series wound electric motors _____.
   a. Produce electrical power
   b. Produce maximum torque at 0 RPM
   c. Produce maximum torque at high RPM
   d. Use a shunt coil
3. Technician A says that a defective solenoid can cause a starter whine. Technician B says that a defective starter drive can cause a starter whining noise. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. The instant the ignition switch is turned to the start position, _____.
   a. Both the pull-in winding and the hold-in winding are energized
   b. The hold-in winding is energized
   c. The pull-in winding is energized
   d. The starter motor starts to rotate before energizing the starter pinion gear
5. Technician A says that a discharged battery (lower than normal battery voltage) can cause the starter solenoid clicking. Technician B says that a discharged battery or dirty (corroded) battery cables can cause solenoid clicking. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Slow cranking by the starter can be caused by all *except* the following: _____.
   a. A low or discharged battery
   b. Corroded or dirty battery cables
   c. Engine mechanical problems
   d. An open neutral safety switch
7. If the starter "whines" when engaged, a possible cause is _____.
   a. A worn or defective starter drive
   b. A defective solenoid
   c. An "open" pull-in winding
   d. A worn leather armature break
8. If the clearance between the starter pinion and the engine flywheel is too great, _____.
   a. The starter will produce a high-pitched whine during cranking
   b. The starter will produce a high-pitched whine after the engine starts
   c. The starter drive will not rotate at all
   d. The solenoid will not engage the starter drive unit
9. A technician connects one lead of a digital voltmeter to the positive (+) terminal of the battery and the other meter lead to the B terminal of the starter solenoid and then cranks the engine. During cranking, the voltmeter displays a reading of 878 mV. Technician A says that this reading indicates that the positive battery cable has too high resistance. Technician B says that this reading indicates that the starter is defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A vehicle equipped with a V-8 engine does not crank but enough to start and sparks are observed at the negative terminal of the battery during cranking. Technician A says the battery could be discharged or defective. Technician B says that the negative cable is loose at the battery. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 41 Charging System Operation and Diagnosis

OBJECTIVES: After studying Chapter 41, the reader will be able to: Prepare for the ASE charging system diagnosis and service (A6) certification test content area "D". • Discuss the various generator test procedures. • Explain how to disassemble a generator and test its component parts.

KEY TERMS: AC voltage • brushes • charging voltage • delta-connected stator • delta winding • diodes • diode check • diode trio • drive-end (DE) housing • duty cycle • Electrical power management (EPM) • fusible link • generator output test • overrunning alternator dampener (OAD) • overrunning alternator pulley (OAP) • poles • rectifier bridge • rotors • sine wave • slip ring end (SRE) • stators • stator tap • temperature compensation • thermistor • wye-connected stator

All vehicles operate electrical components by taking current from the battery. It is the purpose and function of the charging system to keep the battery fully charged. The Society of Automotive Engineers (SAE) term for the unit that generates electricity is the *generator*. The term *alternator* is also commonly used, especially in service manuals before 1993 when the SAE term was adopted by most vehicle manufacturers.

PRINCIPLES OF GENERATOR OPERATION

All electrical generators use the principle of electromagnetic induction to convert mechanical energy into electrical energy. Electromagnetic induction involves the generation of an electrical current in a conductor when the conductor is moved through a magnetic

field. The amount of current generated can be increased by the following factors:

1. Increasing the *speed* of the conductor through the magnetic field
2. Increasing the *number* of conductors passing through the magnetic field
3. Increasing the *strength* of the magnetic field

ALTERNATING-CURRENT GENERATORS (ALTERNATORS)

An AC generator generates an alternating current when the current changes polarity during the generator's rotation. However, a battery cannot "store" alternating current; therefore, this alternating current is changed to direct current (DC) by diodes inside the generator. Diodes are one-way electrical check valves that permit current to flow in only one direction. Most manufacturers call an AC generator an alternator.

GENERATOR CONSTRUCTION

A generator is constructed of a two-piece cast-aluminum housing. Aluminum is used because of its lightweight, nonmagnetic properties and heat transfer properties needed to help keep the generator cool. A front ball bearing is pressed into the front housing (called the **drive-end [DE] housing**) to provide the support and friction reduction necessary for the belt-driven rotor assembly. The rear housing, or the **slip ring end (SRE),** usually contains a roller-bearing support for the rotor and mounting for the brushes, diodes, and internal voltage regulator (if the generator is so equipped). See Figures 41–1 and 41–2.

TECH TIP ✔ **Generator Horsepower and Engine Operation**

Many technicians are asked how much power certain accessories require. A 100-ampere generator requires about 2 horsepower from the engine. One horsepower is equal to 746 watts. Watts are calculated by multiplying amperes times volts.

$$\text{Power in watts} = 100\,\text{A} \times 14.5\,\text{V} = 1450$$
$$1\,\text{hp} = 746\,\text{W}$$

Therefore, 1450 watts is about 2 horsepower and the generator uses about 2 hp to generate 100 A.

Allowing about 20% for mechanical and electrical losses adds another 0.4 horsepower. Therefore, whenever anybody asks how much power it takes to produce 100 amperes from a generator, the answer is 2.4 horsepower.

Many generators delay the generator output to prevent the engine from stumbling whenever a heavy electrical load is applied. The voltage regulator or vehicle computer is capable of gradually increasing the output of the generator over a period of up to several minutes. Even though 2 horsepower does not sound like much, a sudden demand for 2 horsepower from an idling engine can cause the engine to run rough or stall. The difference in part numbers of various generators is often an indication of the time interval over which the load is applied. Therefore, the use of the wrong replacement generator could cause the engine to stall!

ALTERNATOR OVERRUNNING PULLEY

Purpose and Function Many generators are equipped with an **overrunning alternator pulley (OAP),** also called a *clutch pulley*. The purpose of this pulley is to help eliminate noise and vibration in the accessory drive belt system, especially when the engine is at idle speed. At idle, engine impulses are transmitted to the alternator through the accessory drive belt. The mass of the rotor of the alternator tends to want to keep spinning, but the engine crankshaft speeds up and slows down slightly due to the power impulses. Using a one-way clutch in the alternator pulley allows the belt to apply power to the alternator in only one direction thereby reducing the fluctuations in the belt. See Figure 41–3.



Figure 41–1 A typical generator (alternator) on a Chevrolet V-8 engine.

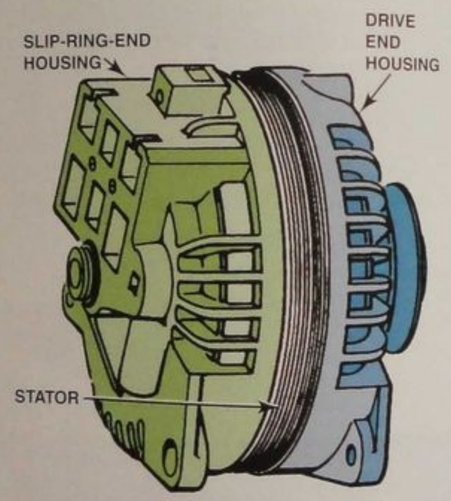


Figure 41–2 The end frame toward the drive belt is called the drive-end housing and the rear section is called the slip-ring-end housing.

A conventional drive pulley attaches to the alternator (rotor) shaft with a nut and lock washer. In the overrunning clutch pulley, the inner race of the clutch acts as the nut and screws onto the shaft. Special tools are required to remove and install this type of pulley.

Another type of alternator pulley uses a dampener spring inside plus a one-way clutch. This unit is called an **overrunning alternator dampener (OAD).** An OAD is larger than an OAP and is used on the Pontiac G8 and other vehicles. See Figure 41–4.

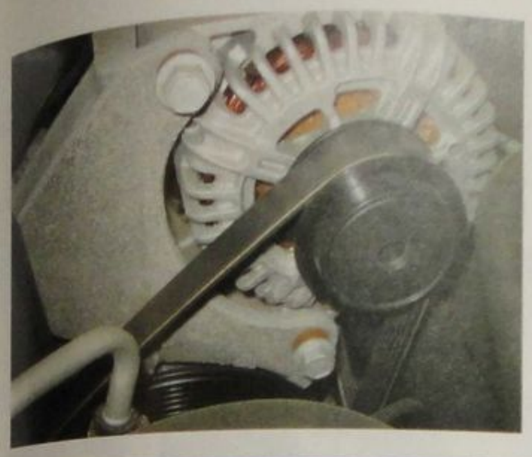


Figure 41–3 An OAP on a generator on a Chevrolet Corvette.

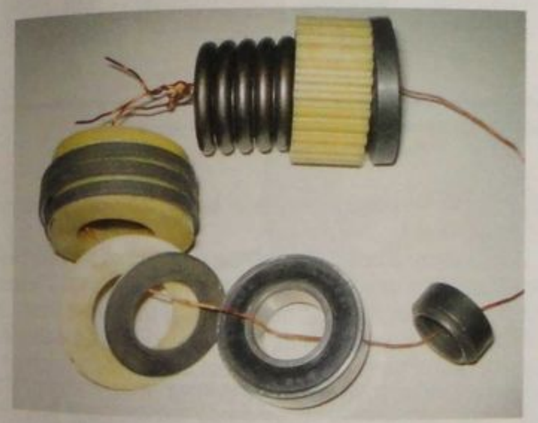


Figure 41–4 An overrunning alternator dampener (OAD) disassembled, showing all of its internal parts.

The use of OAP or OAD pulleys is mostly on vehicles equipped with diesel engines or luxury vehicles where noise and vibration need to be kept at a minimum. Both designs reduce belt noise and improve the life of the accessory drive belt.

Diagnosis and Service Overrunning alternator pulleys and overrunning alternator dampeners can fail. The most common factor is the one-way clutch. If it fails, it can freewheel and not power the alternator or it can lock up and not provide the dampening as designed. If the charging system is not working, the OAP or OAD could be the cause rather than a fault in the alternator itself.

In most cases, the entire alternator assembly will be replaced because each OAP or OAD is unique for each application and they require special tools to remove and replace.

FREQUENTLY ASKED QUESTION ???

Can I Install an OAP or an OAD to My Alternator?

No. An alternator needs to be equipped with the proper shaft to allow the installation of an OAP or OAD. This also means that a conventional pulley cannot be used to replace a defective overrunning alternator pulley or dampener.

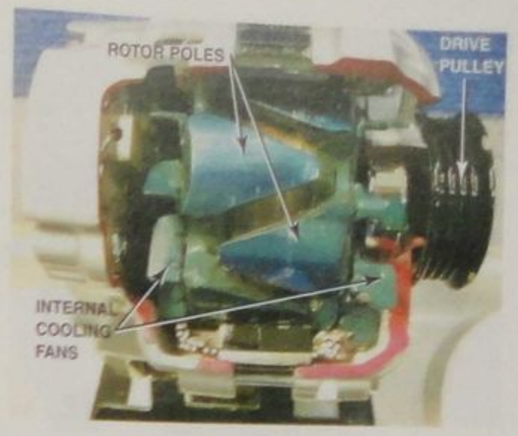


Figure 41–5 A cutaway of a General Motors CS-130D generator showing the rotor and cooling fans that are used to force air through the unit to remove the heat created when it is charging the battery and supplying electrical power for the vehicle.

ROTORS

The **rotor** creates the magnetic field of the generator and produces a current by electromagnetic induction in the stationary stator windings. This differs from a DC generator, where the field current is created in the stationary field windings and the current is generated in the rotating armature. The generator rotor is constructed of many turns of copper wire coated with a varnish insulation wound over an iron core. The iron core is attached to the rotor shaft. At both ends of the rotor windings are heavy-gauge metal plates bent over the windings with triangular fingers called **poles.** These pole fingers do not touch, but rather they alternate or interlace as shown in Figure 41–5. If current flows through the rotor windings, the metal pole pieces at each end of the rotor become electromagnets. Whether a north or a south pole magnet is created depends on the *direction* in which the wire coil is wound. Because the pole pieces are attached to each end of the rotor, one pole piece will be a north pole magnet. The other pole piece is on the opposite end of the rotor and therefore is viewed as being wound in the opposite direction, creating a south pole. Therefore, the rotor fingers are alternating north and south magnetic poles. The magnetic fields are created between the alternating pole piece fingers. These individual magnetic fields produce a current by electromagnetic induction in the stationary stator windings. See Figure 41–6.

The current necessary for the field (rotor) windings is conducted through carbon brushes to the slip rings. The maximum-rated generator output in amperes is largely dependent on the number and gauge of the windings of the rotor. Substituting rotors from one generator into another can greatly affect maximum output either positive or negative, depending on the rotors used. Many commercially rebuilt generators are tested and have a sticker on them indicating their tested output. The original rating stamped on the housing is then ground off.

GENERATOR BRUSHES

The current for the field is controlled by the voltage regulator and is conducted to the slip rings through carbon **brushes.** The brushes conduct only the field current (approximately 2 to 5 amperes), and therefore tend to last longer than the brushes used on a DC generator, where all the current generated in the generator must flow through the brushes.

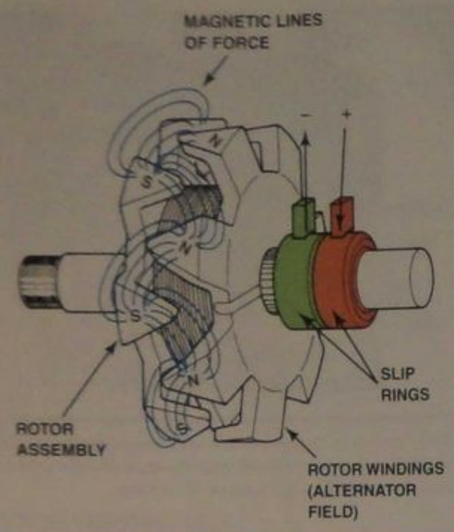


Figure 41–6 Rotor assembly of a typical alternator (AC generator). Current through the slip rings causes the "fingers" of the rotor to become alternating north and south magnetic poles. As the rotor revolves, these magnetic lines of force induce a current in the stator windings.

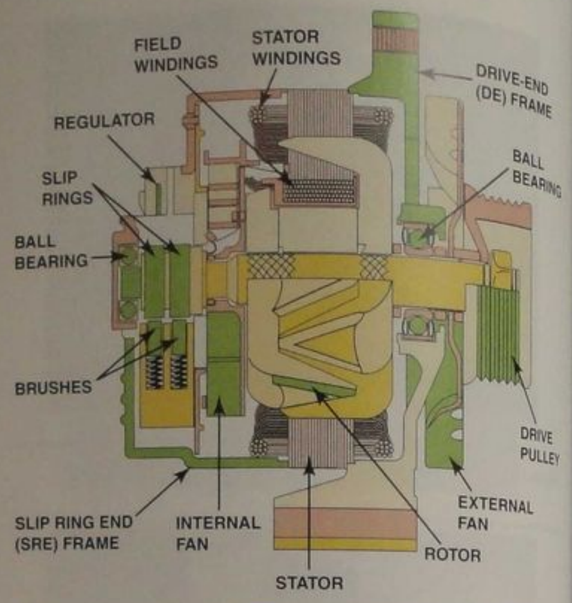


Figure 41–7 A cutaway view of a typical AC generator (alternator).

STATORS

Supported between the two halves of the generator housing are three copper wire windings wound on a laminated metal core. See Figure 41–7. As the rotor revolves, its moving magnetic field induces a current in the windings of the **stator.** See Figure 41–8.

TECH TIP ✔ **The Sniff Test**

Whenever checking for the root cause of a generator failure, one of the first things that a technician should do is to sniff (smell) the generator! If the generator smells like a dead rat (rancid), the stator windings have been overheated by trying to charge a discharged or defective battery. If the battery voltage is continuously low, the voltage regulator will continue supplying full field current to the generator. The voltage regulator is designed to cycle on and off to maintain a narrow charging system voltage range.

If the battery voltage is continually below the cutoff point of the voltage regulator, the generator is continually producing current in the stator windings. This constant charging can often overheat the stator and burn the insulating varnish covering the stator windings. If the generator fails the sniff test, the technician should replace the stator and other generator components that are found to be defective *and* replace or recharge and test the battery.

DIODES

Diodes are constructed of a semiconductor material (usually silicon) and operate as a one-way electrical check valve that permits the current to flow in only one direction. AC generators use six diodes (one positive and one negative diode for each of the three stator windings) to convert alternating current to direct current. The symbol for a diode is shown in Figure 41–9.

HOW A GENERATOR WORKS

A rotor inside a generator is turned by a belt and drive pulley turned by the engine. The magnetic field of the rotor generates a current in the windings of the stator by electromagnetic induction. See Figure 41–10.

Field current flowing through the slip rings to the rotor creates alternating north and south poles on the rotor, with a magnetic field between each finger of the rotor. The induced current in the stator windings is an alternating current because of the alternating magnetic field of the rotor. The induced current starts to increase as the magnetic field starts to induce current in each winding of the stator. The current then peaks when the magnetic field is the strongest and starts to decrease as the magnetic field moves away from the stator winding. Therefore, the current generated is described as being of a **sine wave** pattern. See Figure 41–11. As the rotor continues to rotate, this sine wave current is induced in each of the three windings of the stator.

Because each of the three windings generates a sine wave current, as shown in Figure 41–12, the resulting currents combine to form a three-phase voltage output.

The current induced in the stator windings connects to diodes (one-way electrical check valves) that permit the generator output current to flow in only one direction. All AC generators contain six diodes, one pair of a positive and a negative diode for each of the three stator windings.

WYE-CONNECTED STATORS

The *Y* (pronounced "wye" and generally so written) type or stator pattern is the most commonly used generator stator winding connection. See Figure 41–13. The output current with a **wye-type stator connection** is constant over a broad generator speed range.

Current is induced in each winding by electromagnetic induction from the rotating magnetic fields of the rotor. In a wye-type stator connection, the currents must combine because two windings are always connected in series. See Figure 41–14. The current produced in each winding is added to the other windings' current and then flows through the diodes to the generator output terminal. One-half of the current produced is available at the neutral junction (usually labeled "STA" for stator). The voltage at this center point is used by some generator manufacturers (especially Ford) to control the charge indicator light or is used by the voltage regulator to control the rotor field current.

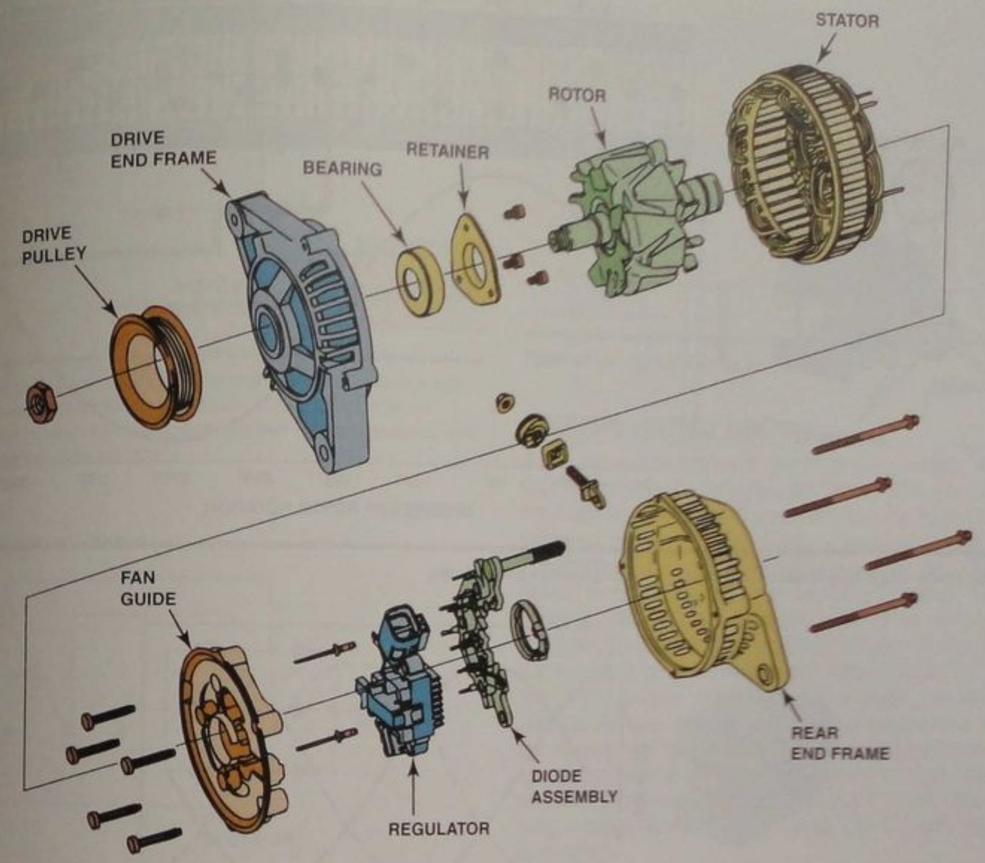


Figure 41–8 An exploded view of a typical generator (alternator) showing all of its internal parts.

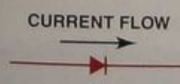


Figure 41–9 A diode symbol.

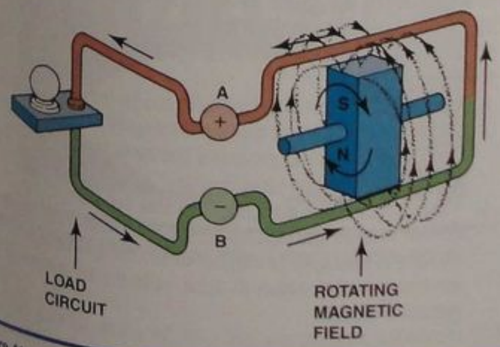


Figure 41–10 Magnetic lines of force cutting across a conductor induce a voltage and current in the conductor.

DELTA-CONNECTED STATORS

The **delta winding** is connected in a triangular shape, as shown in Figure 41–15. (Delta is a Greek letter shaped like a triangle.) Current induced in each winding flows to the diodes in a parallel circuit. More current can flow through two parallel circuits than can flow through a series circuit (as in a wye-type stator connection).

Delta-connected stators are used on generators where high output at high-generator RPM is required. The delta-connected generator can produce 73% more current than the same generator with wye-type stator connections. For example, if a generator with a wye-connected stator can produce 55 A, the *same* generator with delta-connected stator windings can produce 73% more current, or 95 A (55 × 1.73 = 95). The delta-connected generator, however, produces lower current at low speed and must be operated at high speed to produce its maximum output.

GENERATOR OUTPUT FACTORS

The output voltage and current of a generator depend on several factors:

1. **Speed of rotation.** Generator output is increased with generator rotational speed up to the generator's maximum possible ampere output. Generators normally rotate at a speed two to three times faster than engine speed, depending on the relative pulley sizes used for the belt drive.

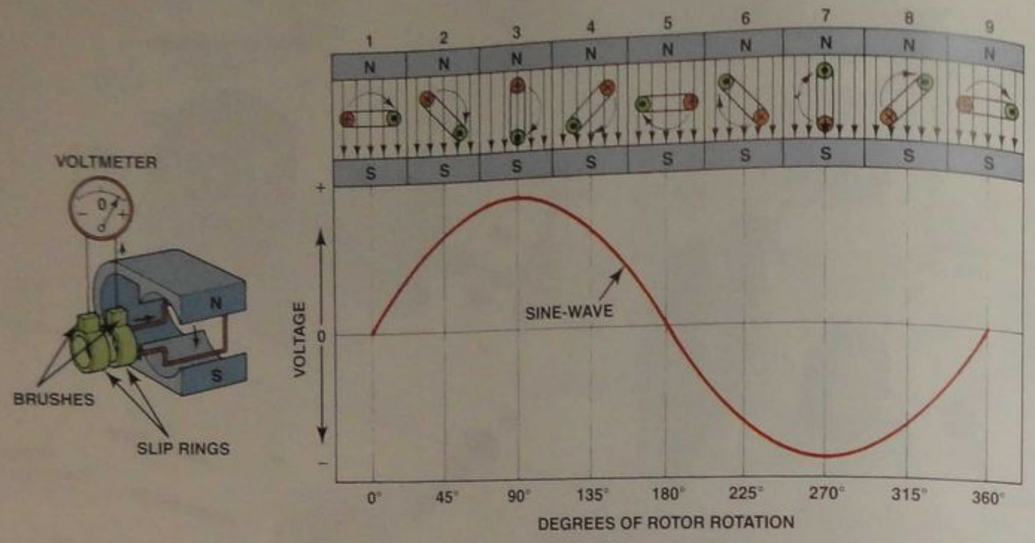


Figure 41–11 Sine wave voltage curve created by one revolution of a winding rotating in a magnetic field.

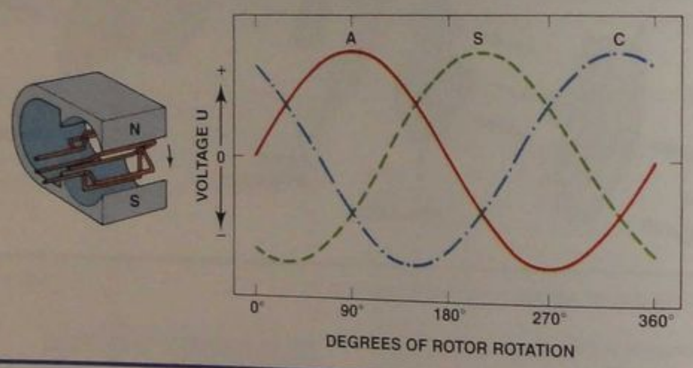


Figure 41–12 When three windings (A, B, and C) are present in a stator, the resulting current generation is represented by the three sine waves. The voltages are 120° out of phase. The connection of the individual phases produces a three-phase alternating voltage.

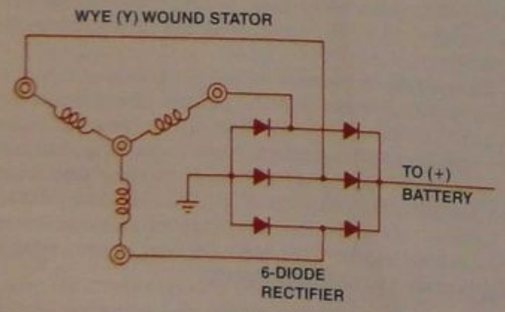


Figure 41–13 Wye-connected stator winding.

2. **Number of conductors.** A high-output generator contains more turns of wire in the stator windings. Stator winding connections (whether wye or delta) also affect the maximum generator output. See Figure 41–16 for an example of a stator that has six rather than three windings, which greatly increases the amperage output of the generator (alternator).

3. **Strength of the magnetic field.** If the magnetic field is strong, a high output is possible because the current generated by electromagnetic induction is dependent on the number of magnetic lines of force that are cut.
   a. The strength of the magnetic field can be increased by increasing the number of turns of conductor wire wound on the rotor. A higher-output generator has more turns of wire than a generator with a low-rated output.
   b. The strength of the magnetic field also depends on the current through the field coil (rotor). Because magnetic field strength is measured in ampere-turns, the greater the amperage or the number of turns, or both, the greater the generator output.

GENERATOR VOLTAGE REGULATION

An automotive generator must be able to produce electrical pressure (voltage) higher than battery voltage to charge the battery. Excessively high voltage can damage the battery, electrical components, and the lights of a vehicle. If no current (zero amperes) was flowing in the field coil of the generator (rotor), generator output would be zero because without field current a magnetic field does not exist.

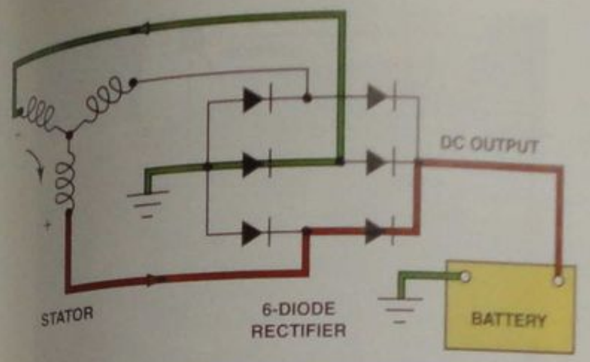


Figure 41–14 As the magnetic field, created in the rotor, cuts across the windings of the stator, a current is induced. Notice that the current path includes passing through one positive (+) diode on the way to the battery and one negative (−) diode as a complete circuit is completed through the rectifier and stator.

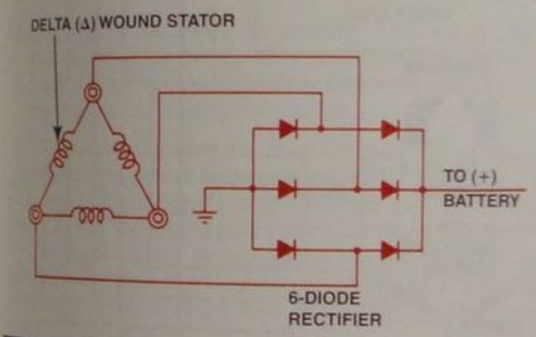


Figure 41–15 Delta-connected stator winding.



Figure 41–16 A stator assembly with six, rather than the normal three, windings.

The field current required by most automotive generators is less than 3 amperes. It is the *control* of the *field* current that controls the output of the generator. Current for the rotor flows from the battery through the brushes to the slip rings. After generator output begins, the voltage regulator controls the current flow through the rotor. See Figure 41–17. The voltage regulator simply opens the field circuit if the voltage reaches a predetermined level then closes the field circuit again as necessary to maintain the correct charging voltage.

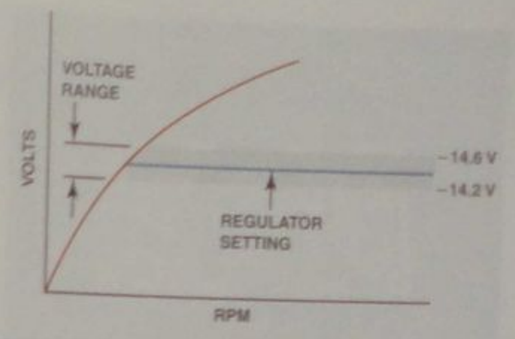


Figure 41–17 Typical voltage regulator voltage range.

CHARGING VOLTAGE CONTROL

If the automotive battery is discharged, its voltage will be lower than the voltage of a fully charged battery. The generator will supply charging current, but it may not reach the maximum **charging voltage.** For example, if a vehicle is jump-started and run at a fast idle (2000 RPM); the charging voltage may be only 12 volts. As the battery becomes charged and the battery voltage increases, the charging voltage will also increase, until the voltage regulator limit is reached; then the voltage regulator will start to control the charging voltage. A good but discharged battery should be able to convert into chemical energy all the current the generator can produce. As long as generator voltage is higher than battery voltage, current will flow from the generator (high pressure, high voltage) to the battery (lower pressure, lower voltage). Therefore, if a voltmeter is connected to a discharged battery with the engine running, it may indicate charging voltage that is lower than normally acceptable.

In other words, the condition and voltage of the battery *do* determine the charging rate of the generator. It is often stated that the battery is the true "voltage regulator" and that the voltage regulator simply acts as the upper-limit voltage control. This is the reason that all charging system testing *must* be performed with a reliable (known to be good) battery, at least 75% charged, to be assured of accurate test results. If a discharged battery is used during charging system testing, tests could mistakenly indicate a defective generator and/or voltage regulator.

Temperature Compensation All voltage regulators (mechanical or electronic) provide a method for increasing the charging voltage slightly at low temperatures and for lowering the charging voltage at high temperatures. A battery requires a higher charging voltage at low temperatures because of the resistance to chemical reaction changes. However, the battery would be overcharged if the charging voltage were not reduced during warm weather. Electronic voltage regulators use a temperature-sensitive resistor in the regulator circuit. This resistor is called a **thermistor** and it provides lower resistance as the temperature increases. A thermistor is used in the electronic circuits of the voltage regulator to control charging voltage over a wide range of under-the-hood temperatures. See Figure 41–18.

NOTE: Voltmeter test results may vary according to temperature. Charging voltage tested at 32°F (0°C) will be higher than for the same vehicle tested at 80°F (27°C) because of the **temperature compensation** factors built into voltage regulators.



Figure 41–18 A typical electronic voltage regulator showing the connections and the circuits involved.

DIODE TRIO GENERATORS

Some generators (alternators) use a diode trio to provide current to the rotor (field) and to turn off the charge indicator light on the dash on non-computer-controlled charging systems. A diode trio consists of three diodes connected in parallel with the three anode ends connected to the three stator winding connectors at the rectifier bridge. The single output terminal of the diode trio is applied to the ignition feed terminal. When the ignition is on, 12 volts is applied through the charge light bulb and is grounded through the rotor winding. This current is blocked from flowing through the diode trio because the diodes are reversed biased. When the stator and the generator start to generate voltage, the 12-volt output of the diode trio opposes the 12 volts from the ignition through the charge light causing the charge light to go out.

NOTE: If one of the three diodes is open, only 8 volts will be applied against the 12 volts from the ignition. The result is a dim generator charge indicator light. While this light may be a customer concern, the generator will produce normal output.

ELECTRONIC VOLTAGE REGULATORS

The electronic circuit of the voltage regulator cycles between 10 and 7,000 times per *second* as needed to accurately control the field current through the rotor, and therefore control the generator output. The control of the field current is accomplished by opening and closing the *ground* side of the field circuit through the rotor of the generator. Electronic voltage regulators also use many resistors to help reduce the current through the regulator, and the resulting heat must be dissipated into the air to prevent damage to the diodes and transistors. Whether mounted inside the generator or externally under the hood, electronic voltage regulators are mounted where normal airflow can keep the electronic components cool. The zener diode is a major electronic component that makes voltage regulation possible. A zener diode blocks current flow until a specific voltage is reached, then it permits current to flow. Generator voltage from the stator and diodes is first sent through a thermistor, which changes resistance with temperature, and then to a zener diode. Whenever the upper-limit voltage is reached, the zener diode conducts current to a transistor, which then opens the field (rotor) circuit. All the current stops flowing

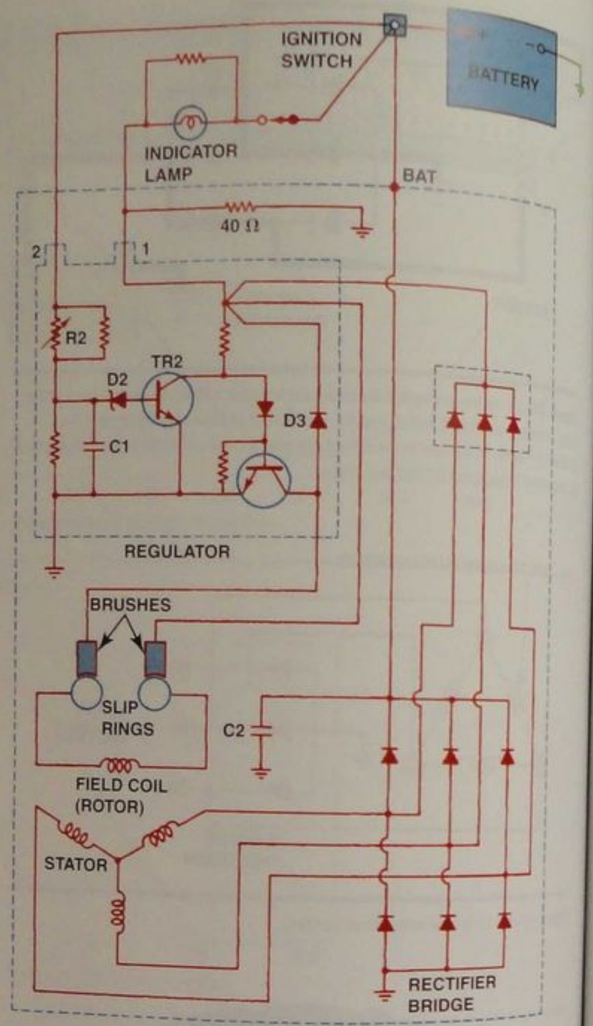


Figure 41–19 Typical General Motors SI-style AC generator with an integral voltage regulator. Voltage present at terminal 2 is used to reverse bias the zener diode (D2) that controls TR2. The hot brush is fed by the ignition current (terminal I) plus current from the diode trio.

through the generator's brushes, slip rings, and rotor, and no magnetic field is formed. Without a magnetic field, a generator does not produce current in the stator windings. When no voltage is applied to the zener diode, current flow stops and the base of the transistor is turned off, closing the field circuit. The magnetic field is thus restored in the rotor. The rotating magnetic fields of the rotor induce a current in the stator, which is again controlled if the output voltage exceeds the designed limit as determined by the zener diode breakdown voltage. Depending on the generator RPM, vehicle electrical load, and state of charge of the battery, this controlled switching on and off can occur between 10 and 7,000 times per second. See Figure 41–19.

Computer-Controlled Generators Computers can interface with the charging system in three ways:

1. The computer can *activate* the charging system by turning on and off the field.
2. The computer can *monitor* the operation of the generator and therefore can increase idle speed to compensate for the additional load if the generator is producing at maximum output.



Figure 41–20 A Hall-effect current sensor attached to the negative battery cable is used as part of the EPM system.

3. The computer can *control* the generator by not only turning the field on and off but can also delay or limit the output of the generator, depending on other loads on the engine, such as power steering or an air-conditioning compressor.

A typical system used on some General Motors vehicles is called **Electrical power management (EPM)** and it uses a Hall-effect sensor attached to the negative battery cable to measure the current leaving and entering the battery. See Figure 41–20.

The engine control module (ECM) controls the alternator by changing the on-time of the current through the rotor. The on-time, called **duty cycle,** is varied from 5% to 95%. See the following chart:

Command Duty Cycle	Alternator Output Voltage
10%	11.0 V
20%	11.6 V
30%	12.1 V
40%	12.7 V
50%	13.3 V
60%	13.8 V
70%	14.4 V
80%	14.9 V
90%	15.5 V

This system has six modes of operation including:

1. **Charge mode.** The charge mode is activated whenever any of the following occurs:
   - Electric cooling fans are on high speed
   - Rear window defogger is on
   - Battery state of charge (SOC) is less than 80%
   - Outside (ambient) temperature is less than 32°F (0°C)
2. **Fuel economy mode.** This mode reduces the load on the engine from the generator (alternator) for maximum fuel economy. This mode is activated whenever the following conditions are met:
   - Ambient temperature is above 32°F (0°C)
   - The state of charge of the battery is 80% or higher
   - The cooling fans and rear defogger are off

The target voltage is 13 volts and will return to the charge mode, if needed.

3. **Voltage reduction mode.** This mode is commanded to reduce the stress on the battery during low-load conditions. This mode is activated whenever the following conditions are met:
   - Ambient temperature is above 32°F (0°C)
   - Low battery discharge rate (less than 7 amperes)
   - Rear defogger is off
   - Cooling fans are on low or off
   - Target voltage is limited to 12.7 volts
4. **Start-up mode.** This mode is selected after engine start and commands a charging voltage of 14.5 volts for 30 seconds. After 30 seconds, the mode is changed depending on conditions.
5. **Battery sulfation mode.** This mode is commanded if the output voltage is less than 13.2 volts for 45 minutes, which can indicate that sulfated plates could be the cause. The target voltage is 13.9 to 15.5 volts for 3 minutes. After 3 minutes, the system returns to another mode based on conditions.
6. **Headlight mode.** This mode is selected whenever the headlights are on and the target voltage is 14.5 volts.

TECH TIP ✓ **The Voltage Display Can Be a Customer Concern**

A customer may complain that the voltmeter reading on the dash fluctuates up and down. This may be normal as the computer-controlled charging system commands various modes of operation based on the operating conditions. Follow the vehicle manufacturer's recommended procedures to verify proper operation.

Beginning in the mid-1980s, General Motors introduced a smaller, yet high-output series of generators. These generators are called the CS (charging system) series. See Figures 41–21 and 41–22. Following *CS* are numbers indicating the *outside diameter* in millimeters of the stator laminations. Typical sizes, designations, and outputs include the following:

CS-121, 5-SI 74 A
CS-130, 9-SI 105 A
CS-144, 17-SI 120 A

These generators feature two cooling fans (one internal) and terminals designed to permit connections to an onboard body computer through terminals L and F.

The reduced-size generators also feature ball bearings in the front and rear and totally soldered internal electrical connections. The voltage is controlled either by the body computer (if the vehicle is so equipped) or by the built-in voltage regulator. The voltage regulator switches the field voltage on and off at a fixed frequency of about 400 times per second. Voltage is controlled by varying the on time and off time of the field current.

CHARGING SYSTEM TESTING AND SERVICE

The charging system can be tested as part of a routine vehicle inspection or to determine the reason for a no-charge or reduced-charging circuit performance.

Charging Voltage Test The first and easiest test to perform to check if the generator is working correctly is to check the charging

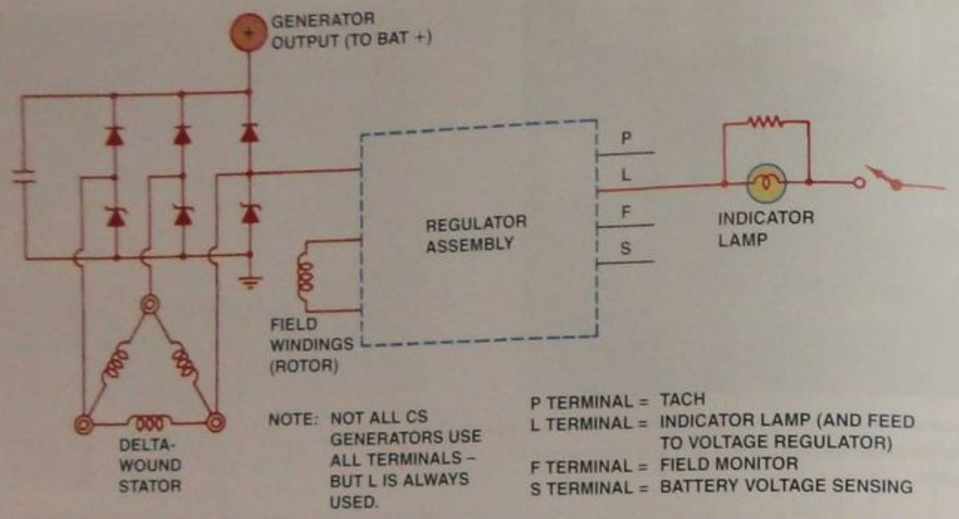


Figure 41–21 General Motors CS generator. Notice the use of zener diodes in the rectifier to help control any high-voltage surges that could affect delicate computer circuits. If a high-voltage surge does occur, the zener diode(s) will be reversed biased and the potentially harmful voltage will be safely conducted to ground. Voltage must be preset at the L terminal to allow the generator to start producing current.



Figure 41–22 The components inside a GM CS generator.

system voltage at the battery. Use a digital multimeter to check using the following steps:

Step #1 Select DC volts.

Step #2 Connect the red meter lead to the positive (+) terminal of the battery and the black meter lead to the negative (−) terminal of the battery.

NOTE: The polarity of the meter leads is not really important when using a digital multimeter. If the meter leads are connected backward on the battery, the resulting readout will simply have a negative (−) sign in front of the voltage reading.

Step #3 Start the engine and increase the engine speed to about 2000 RPM (fast idle) and record the charging voltage. See Figures 41–23 and 41–24.

Specifications for charging voltage = 13.5 to 15.0 V
(General Motors vehicles = 14.2 to 15.2 V).

- If the voltage is too high, check that the charging system components such as the generator and voltage regulator (if separate) are properly grounded. If the battery voltage is still higher than specified, then there is likely a fault with the electrical connections at the voltage regulator or generator.
- If the voltage is lower than specifications, there is a fault with the wiring, generator, or regulator (if external). Additional testing is required to help pinpoint the root cause.

TECH TIP ✔ The Hand Cleaner Trick

Lower-than-normal generator output could be the result of a loose or slipping drive belt. All belts (V and serpentine multigroove) use an interference angle between the angle of the Vs of the belt and the angle of the Vs on the pulley. A belt wears this interference angle off the edges. As a result, the belt may start to slip and make a squealing sound even if tensioned properly.

A common trick used to determine if the noise is belt related is to use grit-type hand cleaner or scouring powder. With the engine off, sprinkle some powder onto the pulley side of the belt. Start the engine. The excess powder will fly into the air, so get away from under the hood when the engine starts. If the belts are now quieter, you know that it was the glazed belt that made the noise. Often, the grit from the hand cleaner will remove the glaze from the belt and the noise will not return. However, if the belt is worn or loose, the noise will return and the belt should be replaced. A fast alternative method to see if the noise is from the belt is to spray water from a squirt bottle at the belt with the engine running. If the noise stops, the belt is the cause of the noise. The water quickly evaporates, and therefore, unlike the gritty hand cleaner, water simply finds the problem—it does not provide a short-term fix.

NOTE: Often, the noise sounds exactly like a noisy bearing. Therefore, before removing and replacing parts, try the hand cleaner trick.

Magnetized Rear Bearing Test All 12-volt automotive generator systems use the voltage regulator to control the current through the rotor of the generator. The rotor creates a magnetic field whenever there is a complete circuit through the brushes and

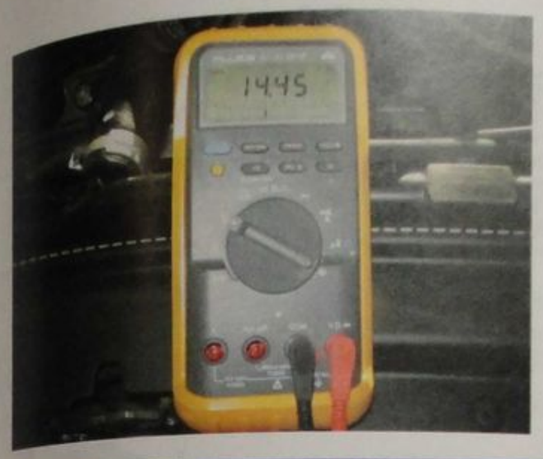


Figure 41–23 The digital multimeter should be set to read DC volts, with the red lead connected to the positive (+) battery terminal and the black meter lead connected to the negative (−) battery terminal.

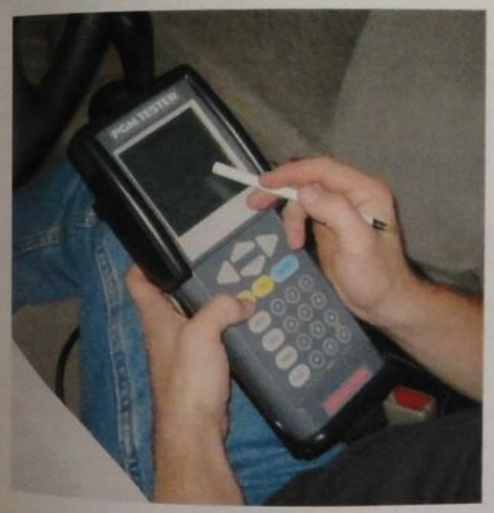


Figure 41–24 A scan tool can be used to diagnose charging system problems.

slip rings of the rotor. If there is no current through the rotor, there is no generator output. Whenever the rotor is energized, the entire rotor shaft and the generator bearings become magnetized. Technicians often use this information to help diagnose a no-charging problem. With the engine running, use a screwdriver or other metallic object to test for magnetism at the rear bearing of the generator. See Figure 41–25.

NOTE: The front bearing is also magnetized, but testing for magnetism of the front bearing with the engine running can be dangerous.

If the rear bearing *is* magnetized, then the following facts are known:

1. The voltage regulator is working.
2. The generator brushes are working.
3. The rotor in the generator is producing a magnetic field.



Figure 41–25 If the rear bearing is magnetized, the voltage regulator, generator brushes, and rotor are functioning.

If the rear bearing is *not* magnetized, then one or more of the following problems exist:

1. The voltage regulator is not working.
2. The generator brushes are worn or stuck, and they are not making good electrical contact with the rotor slip rings.
3. The generator rotor could be defective.

If the rotor is not producing a magnetic field, no automotive generator can produce charging current. It is this rotating magnetic field created in the rotor that induces current in the stator windings. Therefore, by checking for a magnetized rear bearing, the technician can better determine where the charging system problem is located. If, for example, the rear bearing is magnetized, yet the "charge" ("GEN") light is on and the generator is not charging, the problem has to be inside the generator (diodes, stator, etc.).

TECH TIP ✔ The Lighter Plug Trick

Battery voltage measurements can be read through the lighter socket. See Figure 41–26. Simply construct a test tool using a lighter plug at one end of a length of two-conductor wire and the other end connected to a double banana plug. The double banana plug will fit most meters in the common (COM) terminal and the volt terminal of the meter.

TECH TIP ✔ Use a Test Light to Check for a Defective Fusible Link

Most AC generators (alternators) use a **fusible link** between the output terminal located on the slip-ring-end frame and the positive (+) terminal of the battery. If this fusible link is defective (blown), then the charging system will not operate at all. Many AC generators have been replaced repeatedly because of a blown fusible link that was not discovered until later. A quick and easy test to check if the fusible link is okay is to touch a test light to the output terminal. With the other end of the test light attached to a good ground, the fusible link is okay if the light lights. This test confirms that the circuit between the AC generator and the battery has continuity. See Figure 41–27.



Figure 41–26 Charging system voltage can be easily checked at the lighter plug by connecting a lighter plug to the voltmeter through a double banana plug.

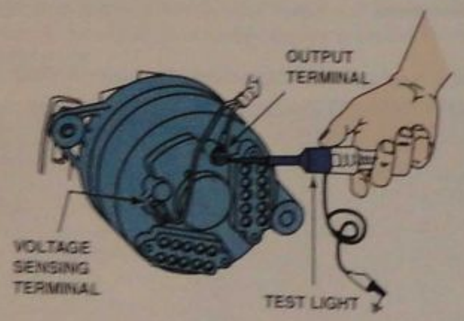


Figure 41–27 Before replacing a generator (alternator), the wise technician checks that battery voltage is present at the output and battery voltage sense terminals.

AC Voltage Check A good generator should produce very little AC voltage. It is the purpose of the diodes in the generator to rectify AC voltage into DC voltage. The procedure to check for AC voltage includes the following steps:

Step #1 Set the digital meter to read AC volts.

Step #2 Start the engine and operate it at 2000 RPM (fast idle).

Step #3 Connect the voltmeter leads to the positive and negative battery terminals.

Step #4 Turn on the headlights to provide an electrical load on the generator.

NOTE: A higher, more accurate reading can be obtained by touching the meter lead to the output terminals of the generator. See Figure 41–28.

The results should be interpreted as follow: If the diodes are good, the voltmeter should read less than 0.4 volt AC. If the reading is over 0.5 volt AC, the rectifier diodes are defective.

NOTE: This test will not test for a defective diode trio.

MEASURING THE AC RIPPLE FROM THE ALTERNATOR TELLS A LOT ABOUT ITS CONDITION. IF THE AC RIPPLE IS ABOVE 500 MILLIVOLTS, OR .5 VOLTS, LOOK FOR A PROBLEM IN THE DIODES OR STATOR. IF THE RIPPLE IS BELOW 500 MILLIVOLTS, CHECK THE ALTERNATOR OUTPUT TO DETERMINE ITS CONDITION.

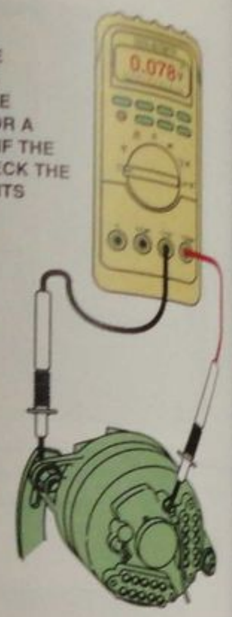


Figure 41–28 AC ripple at the output terminal of the generator is more accurate than testing at the battery due to the resistance of the wiring between the generator and the battery. The reading shown on the meter is only 78 mV (0.078 V), far below what the reading would be if a diode were defective.

TECH TIP ✓ **The Mini Clamp-On DMM Test**

The generator output can be easily measured using a digital mini clamp-on-type digital multimeter. A typical clamp-on meter is capable of reading as low as 10 mA (0.01 A) to 200 A or more. See Figure 41–29. To set up for the test, clamp the meter around the generator output wire and select DC amperes and the correct scale. Start the engine and turn on all lights and accessories and then observe the meter display. The results should be within 10% of the specified generator rating. An AC/DC current clamp adapter can also be used along with a conventional digital multimeter set on the DC millivolt scale. To check for AC current ripple, switch the meter to read AC amperes and record the reading. A reading of greater than 10 amperes AC indicates defective generator diodes.



Figures 41–29 A mini clamp-on digital multimeter can be used to measure generator output. This meter was set on the 200-A DC scale. With the engine running and all lights and accessories on, the generator was able to produce almost exactly its specified rating of 100 A.

Charging System Voltage-Drop Testing For the proper operation of any charging system, there must be good electrical connections between the battery positive terminal and the generator output terminal. The generator must also be properly grounded to the engine block.

Many vehicle manufacturers run the lead from the output terminal of the generator to other connectors or junction blocks that are electrically connected to the positive terminal of the battery. If there is high resistance (a high voltage drop) in these connections or in the wiring itself, the battery will not be properly charged.

Whenever there is a suspected charging system problem (with or without a charge indicator light on), simply follow these steps to measure the voltage drop of the insulated (power side) charging circuit:

Step #1 Start the engine and run it at a fast idle (about 2000 engine RPM).

Step #2 Turn on the headlights to ensure an electrical load on the charging system.

Step #3 Using any voltmeter, connect the positive test lead (usually red) to the output terminal of the generator. Attach the negative test lead (usually black) to the positive post of the battery.

The results should be interpreted as follows:

1. If there is less than a 0.4-volt reading, then all wiring and connections are satisfactory.
2. If the voltmeter reads higher than 0.4 volt, there is excessive resistance (voltage drop) between the generator output terminal and the positive terminal of the battery.
3. If the voltmeter reads battery voltage (or close to battery voltage), there is an open circuit between the battery and the generator output terminal.

To determine whether the generator is correctly grounded, maintain the engine speed at 2000 RPM with the headlights on. Connect the positive voltmeter lead to the case of the generator and the negative voltmeter lead to the negative terminal of the battery. The voltmeter should read less than 0.2 volt if the generator is properly grounded. If the reading is over 0.2 volt, connect one end of an auxiliary ground wire to the case of the generator and the other end to a good engine ground. See Figure 41–30.

TECH TIP ✓ **"2 to 4"**

Most voltage-drop specifications range between 0.2 and 0.4 volt. Generally, if the voltage loss (voltage drop) in a circuit exceeds 0.5 volt (1/2 volt), the wiring in that circuit should be repaired or replaced. During automotive testing, it is sometimes difficult to remember the exact specification for each test; therefore, the technician can simply remember "2 to 4" and that any voltage drop over this amount indicates a problem.

TECH TIP ✓ **Use Jumper Cables as a Diagnostic Tool**

Whenever diagnosing a generator charging problem, try using jumper cables to connect the positive and negative terminals of the generator directly to the positive and negative terminals of the battery. If a definite improvement is noticed, the problem is in the wiring of the vehicle. High resistance, due to corroded connections or loose grounds, can cause low generator output, repeated regulator failures, slow cranking, and discharged batteries. A voltage-drop test of the charging system also can be used to locate excessive resistance (high-voltage drop) in the charging circuit, but using jumper wires (cables) is often faster and easier.

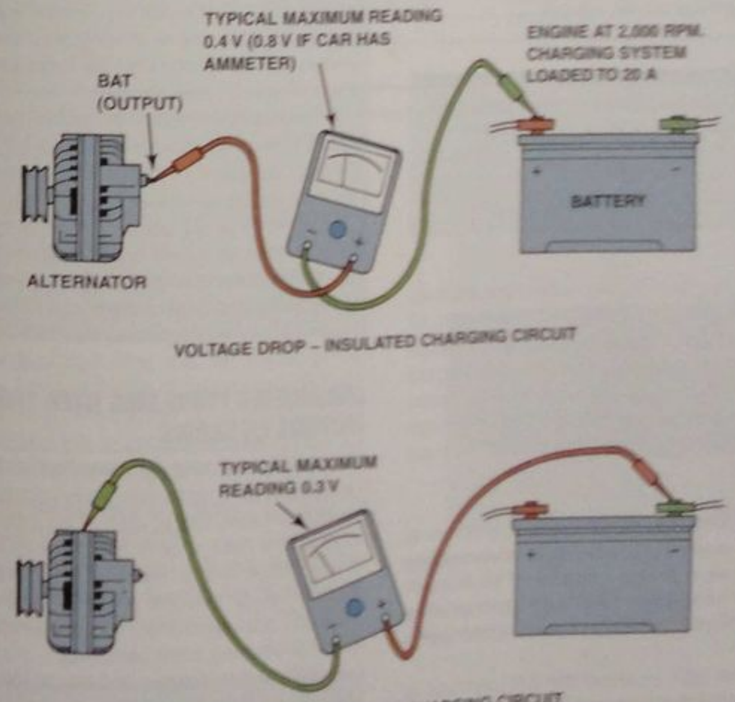


Figure 41–30 Voltmeter hookup to test the voltage drop of the charging circuit.

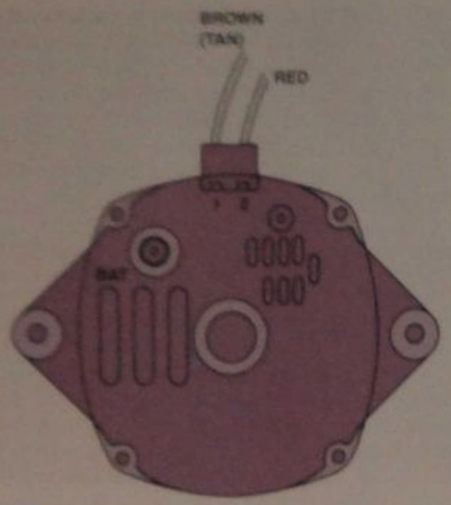


Figure 41–31 Typical GM SI generator. Note the location and wire color used for terminal #1 and #2.

GENERAL MOTORS SI TEST LIGHT TEST

All General Motors SI (System Integration [internal voltage regulator]) series Delcotron generators (alternators) can be easily tested using a standard 6- to 12-volt test light. See Figure 41–31.

Normal Operation The following steps outline the procedure for testing an SI series generator for normal operation:

Step #1 With the ignition on (engine off), a test light should be bright if touched to the "BAT" terminal and #2 terminal.

NOTE: Terminal #2 is the battery-sensing terminal. On many GM applications, a jumper wire simply connects the BAT terminal to terminal #2. The test lights should be dim when touched to terminal #1. Terminal #1 is the wire from the dashboard warning light. The test light should be dim because of the voltage drop across the dashboard light bulb.

Step #2 With the engine running, touching any of the three terminals should produce a bright test light. The BAT terminal and terminal #2 should both cause a bright light because both are battery voltage sources. Terminal #1 should also light the test light brightly because when the generator is producing a current, the internal voltage rises and applies an opposing voltage on the dash light bulb, which causes current to stop flowing through the bulb and the charge light to go out.

Problems and Possible Causes If the test light is not on at all on terminal #1 (brown or tan wire), the problem is an open circuit in the wiring between the dash and the generator.

If the test light is bright on terminal #1 with the key turned to on and the engine off, the most likely cause is a defective (open) voltage regulator.

If the test light does not light on either the BAT terminal or #2 terminal, an open circuit exists between the positive post of the battery and the generator. Check the condition of all fusible links.

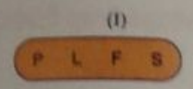


Figure 41–32 Typical GM CS generator wiring plug identification. Note that terminal F is sometimes terminal I on some generators.

GENERAL MOTORS CS SERIES AC GENERATORS

A General Motors CS series generator requires only two wires to operate—the battery (BAT) feed and the wire to the L terminal. The CS series generators are designed to operate as a stand-alone generator or be controlled by a vehicle computer system. See Figure 41–32 for terminal identification.

The P terminal, sometimes called the **stator tap,** is connected directly to the stator that produces about one-half of the system alternating current and is used as a tachometer signal. *P* is used because it is an abbreviation for *pseudo*, meaning "alternating (not straight) output." Terminal S is the sensing terminal for true battery voltage. Terminal F is the computer-sensing terminal. The computer monitors this terminal and sets trouble codes and alerts the driver if there is a charging system malfunction. The letter *I* is sometimes used instead of *F* and this terminal is used as a backup voltage source to the voltage regulator if the L terminal circuit is lost.

REAL WORLD FIX — **The Chevrolet Van Story**

The battery and generator (alternator) had been replaced by another shop, yet the battery would be totally discharged after three days. A check of the charging system showed that the generator was not charging. Before another generator was installed, the technician checked for voltage at both the output terminal of the generator (B terminal) and the L terminal with the ignition switch in the on (run) position. There was no voltage at the L terminal indicating that the problem was in the wiring to the L terminal because without voltage at this terminal, the CS130 will not turn on (charge).

Checking the schematic in the service information showed that the power to the L terminal came from the gauges fuse and then through the charge warning lamp. See Figure 41–33. A visual inspection showed that the fuse was blown. What could have caused the fuse to blow? Further checking of the circuit showed that the gauges fuse also fed the automatic transmission torque converter clutch circuit. A visual inspection discovered a damaged wire under the van most likely due to road debris. Repairing the wire and installing a new fuse solved the charging system problem.

DIAGNOSING PROBLEMS WITH THE GENERAL MOTORS CS SERIES

If the charge indicator light is on in the dash, unplug the connector (which can have up to four wires connected). Start the engine and observe the dash charge light. If the light is still on, there is a short-to-ground in the L wire circuit between the generator and the dash. If the charge light is out, check for voltage at the L terminal. If there is voltage available at the L terminal (remember, the connector is still unplugged from the generator), the problem is in the generator, if charging is not occurring.

If there is no voltage available at the L terminal, apply a voltage through a standard test light to the L terminal of the generator. This supplies the power for the regulator. (This is not full-fielding the generator, but simply supplying power to the internal regulator.) If the generator output is now normal, the problem is in the wiring to

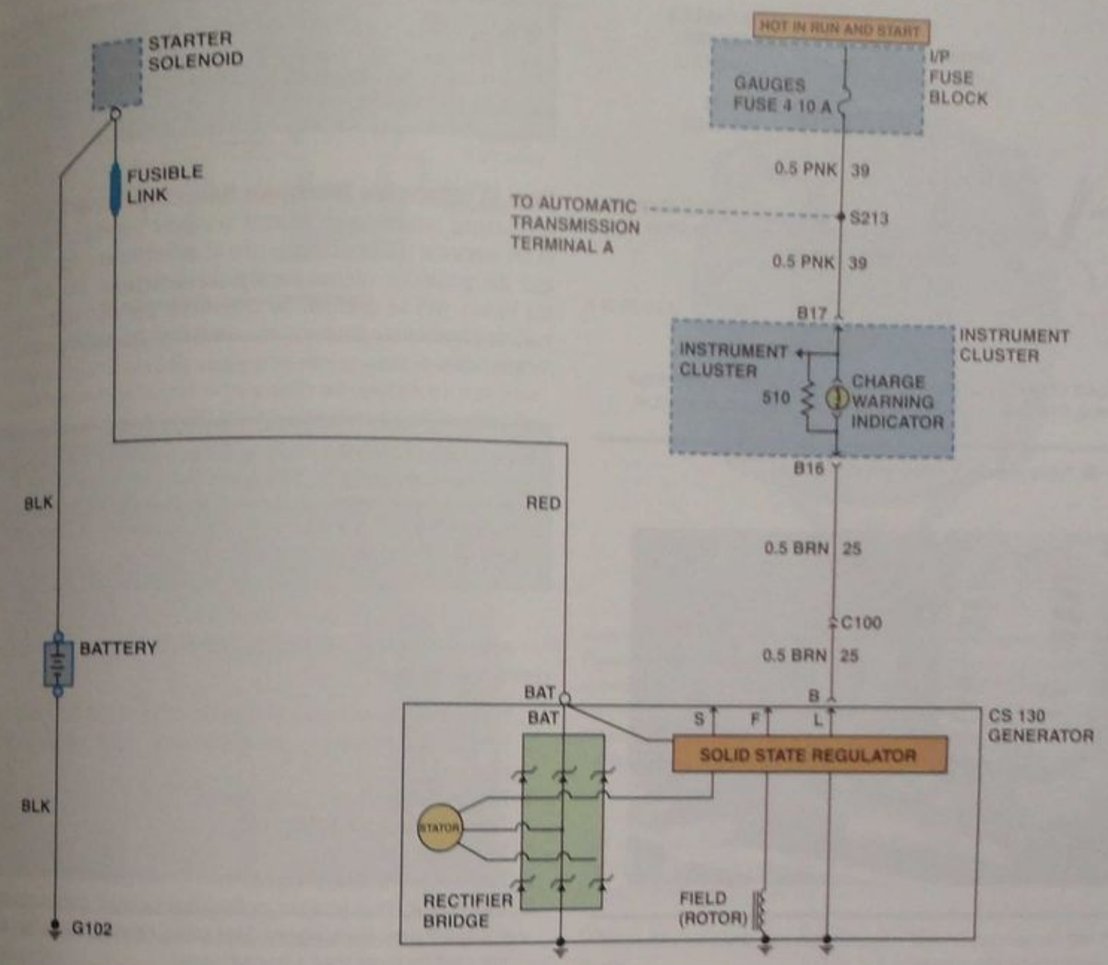


Figure 41–33 A schematic showing a typical wiring for a General Motors CS generator, showing that the L terminal is fed from the gauges fuse. If the fuse was blown, the charger light would never light and the generator (alternator) will not charge.

the L terminal of the generator. Check all fuses, all fusible links, and the charge light indicator bulb.

Generator Output Test A charging circuit may be able to produce correct charging circuit voltage but not be able to produce adequate amperage output. If in doubt about charging system output, first check the condition of the generator drive belt. See Figure 41–34. With the engine off, attempt to rotate the fan of the generator by hand. Replace or tighten the drive belt if the generator fan can be rotated this way. See Figure 41–35 for typical test equipment hookup.

The testing procedure for **generator output** is as follows:

Step #1 Connect the starting and charging test leads according to the test equipment manufacturer's instructions.

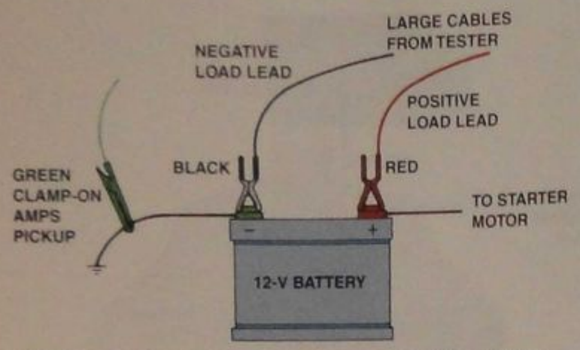
Step #2 Turn the ignition switch on (engine off) and observe the ammeter. This is the ignition circuit current, and it should be about 2 to 8 amperes.

NOTE: Step 2 can be skipped if the ammeter current clamp can be connected around the generator output wire instead of around the battery cable(s). See Figure 41–36.



Figure 41–34 This accessory drive belt should be replaced because it has so many cracks. The usual specification for when a serpentine belt requires replacement is when there are three or more cracks in any one rib in any 3-inch length.

Step #3 Start the engine and operate it at 2000 RPM (fast idle). Turn the load increase control slowly to obtain the highest reading on the ammeter scale. Note the ampere reading.



TEST LEAD CONNECTIONS FOR TESTING THE STARTING SYSTEM, CHARGING SYSTEM, VOLTAGE REGULATOR, AND DIODE STATOR.

Figure 41–35 Typical hookup of a starting and charging tester.



Figure 41–36 The best place to install a charging system tester amp probe is around the generator output terminal wire as shown.

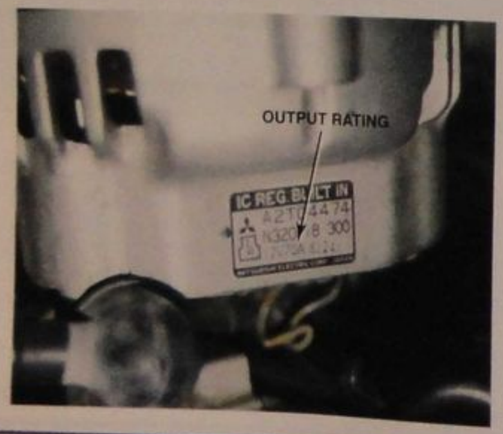


Figure 41–37 The output on this generator is printed on a label.

Step #4 Total the amperes from step 2 and step 3. Results should be within 10% (or 15 amperes) of the rated output. Rated output may be printed on the generator as shown in Figure 41–37.

NOTE: When applying a load to the battery with a carbon pile tester during a generator output test, do not permit the battery voltage to drop below 12 volts. Most generators will produce their maximum output (in amperes) above 13 volts.

How to Determine Minimum Required Generator Output

All charging systems must be able to supply the electrical demands of the electrical system. If lights and accessories are used constantly and the generator cannot supply the necessary ampere output, the battery will be drained. To determine the minimum electrical load requirements, connect an ammeter in series with either battery cable.

NOTE: If using an inductive-pickup ammeter, be certain that the pickup is over *all* the wires leaving the battery terminal. See Figure 41–38. Failure to include the small body ground wire from the negative battery terminal to the body or the small positive wire (if testing from the positive side) will *greatly decrease* the current flow readings.

After connecting an ammeter correctly in the battery circuit, continue as follows:

1. Start the engine and operate to about 2000 RPM (fast idle).
2. Turn the heat selector to air conditioning (if the vehicle is so equipped).
3. Turn the blower motor to high speed.
4. Turn the headlights on bright.
5. Turn on the radio.
6. Turn on the windshield wipers.
7. Turn on any other accessories that may be used continuously (do not operate the horn, power door locks, or other units that are not used for more than a few seconds).

Observe the ammeter. The current indicated is the electrical load that the generator is able to exceed to keep the battery fully charged. The minimum acceptable generator output is 5 amperes greater than the accessory load. A negative (discharge) reading indicates that the generator is not capable of supplying the current (amperes) that may be needed.

TECH TIP ✔ **Bigger Is Not Always Better**

Many technicians are asked to install a higher-output generator to allow the use of emergency equipment or other high-amperage equipment such as a high-wattage sound system.

Although many higher-output units can be physically installed, it is important not to forget to upgrade the wiring and the fusible link(s) in the generator circuit. Failure to upgrade the wiring could lead to overheating. The usual failure locations are at junctions or electrical connectors.

GENERATOR DISASSEMBLY

If testing has confirmed that there are generator problems, remove the generator from the vehicle *after* disconnecting the *negative* battery cable. This will prevent the occurrence of damaging short circuits. Mark the case with a scratch or with chalk to ensure proper reassembly of the generator case. See Figure 41–39.

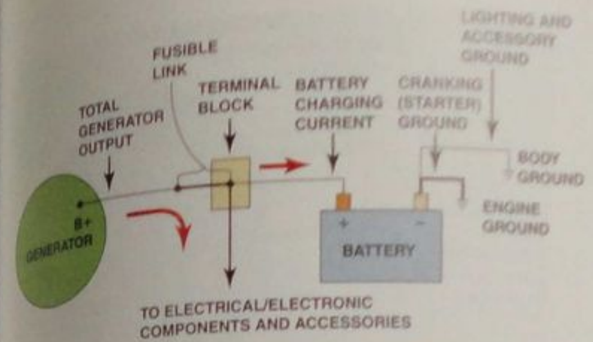


Figure 41–38 A diagram showing the location of the charging system wiring of a typical vehicle. The best location to use to check for the generator (alternator) output is at the output wire from the B+ (BAT) terminal. Notice that the generator supplies all electrical needs of the vehicle first, then charges the battery if needed.

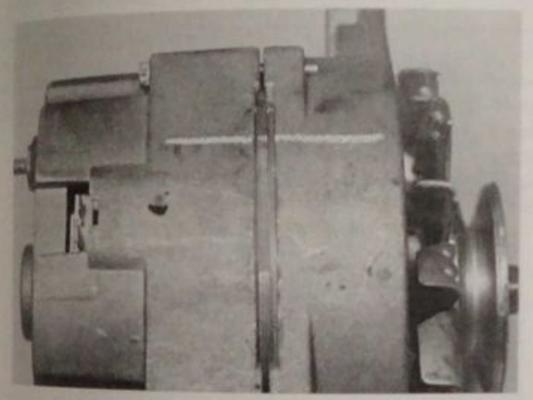


Figure 41–39 Always mark the case of the generator before disassembly to be assured of correct reassembly.

NOTE: Most generators of a particular manufacturer can be used on a variety of vehicles, which may require wiring connections placed in various locations. For example, a Chevrolet and an Oldsmobile generator may be identical except for the position of the rear section containing the electrical connections. The four through bolts that hold the two halves together are equally spaced; therefore, the rear generator housing *can* be installed in any one of four clock positions to match the wiring needs of various models. See Figure 41–40.

After the through-bolts have been removed, carefully separate the two halves; the stator windings stay with the rear case. The rotor can be inspected and tested while attached to the front housing.

Testing the Rotor The slip rings on the rotor should be smooth and round (within 0.002 inch of being perfectly round). If grooved, the slip rings can be machined to provide a suitable surface for the brushes. Do not machine beyond the minimum slip ring dimension as specified by the manufacturer.

If the slip rings are discolored or dirty, they can be cleaned with 400-grit or fine emery (polishing) cloth. The rotor must be turned while being cleaned to prevent flat spots on the slip rings.

The field coil continuity in the rotor can be checked by touching one test lead of a 110-volt (15-watt bulb) tester on each slip ring.

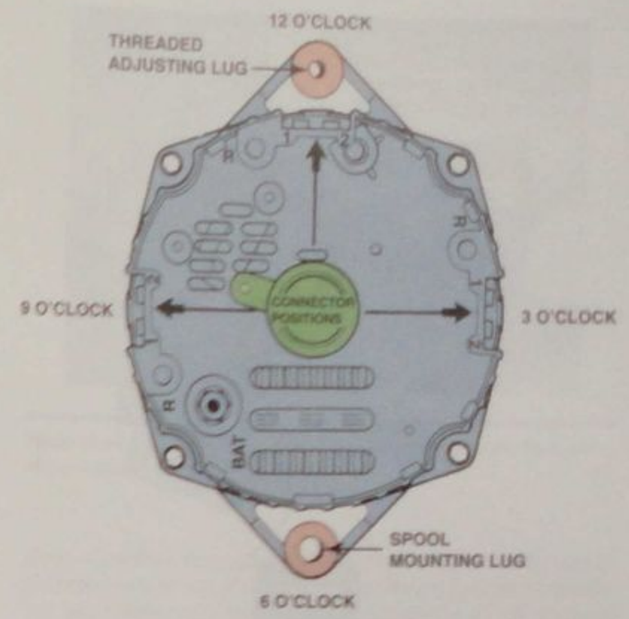


Figure 41–40 Explanation of clock positions. Because the four through-bolts are equally spaced, it is possible for a generator to be installed in one of four different clock positions. The connector position is determined by viewing the generator from the diode end with the threaded adjusting lug in the up or 12 o'clock position. Select the 3 o'clock, 6 o'clock, 9 o'clock, or 12 o'clock position to match the unit being replaced.

The test light should light. A more accurate method is to measure the resistance between the slip rings using an ohmmeter. Typical resistance values include the following:

GM:	2.2 to 3.5 ohms
Ford:	3.0 to 5.5 ohms
Chrysler:	3.0 to 6.0 ohms

The resistance values listed here are typical only; exact specifications for the generator being tested should be consulted before condemning a rotor. Ohmmeters can also vary in accuracy. See Figure 41–41.

1. If the resistance is below specification, the rotor is shorted.
2. If the resistance is above specification, the rotor connections are corroded or open.

Rotor inspection specifications often include an acceptable amperage current. With an ammeter connected in series with the battery, connect one test lead directly to the positive post of the battery and one slip ring. Connect the other test lead between the negative post of the battery and the other slip ring. Current will flow through the field windings of the rotor and create a magnetic field. Compare the ammeter reading with the manufacturer's specifications (usually between 1.8 and 4.5 amperes). If the current draw is above specification, the rotor is shorted. If the current draw is below specification, the rotor has high resistance, corroded connections, or an open rotor winding.

If the rotor is found to be open, shorted (copper to copper), or grounded (copper to steel), the rotor must be replaced or repaired at a specialized shop. Loose connections at the rotor slip rings may be repaired by resoldering.

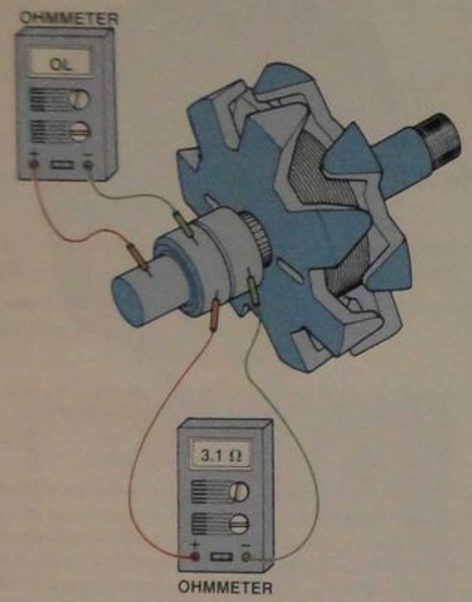


Figure 41–41 Testing a generator rotor using an ohmmeter.

NOTE: The cost of a replacement rotor may exceed the cost of an entire rebuilt generator. Be certain, however, that the rebuilt generator is rated at the same output as the original or higher.

Testing the Stator The stator must be disconnected from the diodes (rectifiers) before testing. Because all three windings of the stator are electrically connected (either wye or delta), a powered (110- or 12-volt) test light or an ohmmeter can be used to check a stator. There should be low resistance at all three stator leads (continuity), and the test light *should* light. There should *not* be continuity (in other words, there should be infinity ohms, or the test light should *not* light) when the stator is tested between any stator lead and the metal stator core. If there is continuity, the stator is *grounded* (short to ground) and must be repaired or replaced. See Figure 41–42. Because the resistance is very low for a normal stator, it is generally *not* possible to test for a *shorted* (copper to copper) stator. A shorted stator will, however, greatly reduce generator output.

If all generator components test okay and the output is still low, substitute a known good stator and retest. If the stator is black or smells burned, check the vehicle for a discharged or defective battery. If battery voltage never reaches the voltage regulator cutoff point, the generator will be continuously producing current in the stator windings. This continuous charging often overheats the stator.

An ohmmeter cannot detect an open stator if the stator is delta wound. The ohmmeter will still indicate low resistance because all three windings are electrically connected. See Figure 41–43.

Testing the Diode Trio Many generators are equipped with a diode trio. A diode is an electrical one-way check valve that permits current to flow in only one direction. Because *trio* means "three," a **diode trio** is three diodes connected together. See Figure 41–44. The diode trio is connected to all three stator windings. The current generated in the stator flows through the diode trio to the internal voltage regulator. The diode trio is designed to supply current for the field (rotor) and turns off the charge indicator light whenever the generator voltage equals or exceeds the battery voltage. If one of the three diodes in the diode trio is defective (usually open), the generator may produce close-to-normal output; however, the charge indicator light will be on dimly.

A diode trio should be tested with a digital multimeter. The meter should be set to the diode-check position. The multimeter should indicate 0.5 to 0.7 volt one way and OL (overlimit) after reversing the test leads and touching all three connectors of the diode trio.

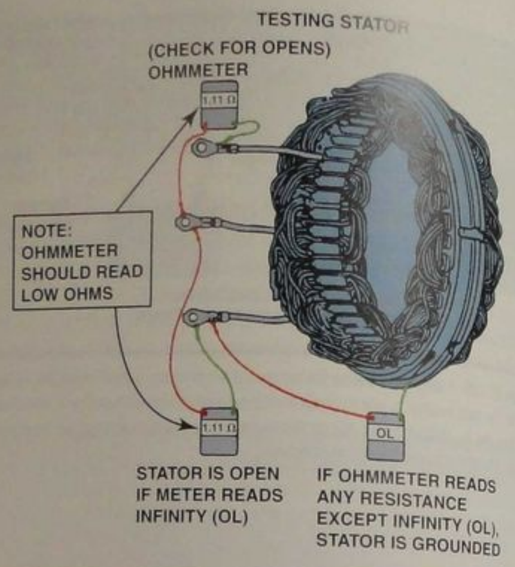


Figure 41–42 If the ohmmeter reads infinity between any two of the three stator windings, the stator is open and, therefore, defective. The ohmmeter should read infinity between any stator lead and the steel laminations. If the reading is less than infinity, the stator is grounded. Stator windings can be tested if shorted because the normal resistance is very low.

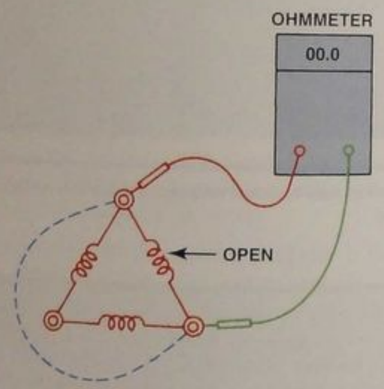


Figure 41–43 An open in a delta-wound stator cannot be detected using an ohmmeter.

Testing the Rectifier Bridge (Diodes) Generators are equipped with six diodes to convert the alternating current (AC) generated in the stator windings into direct current (DC) for use by the vehicle's battery and electrical components. The six diodes include three positive diodes and three negative diodes (one positive and one negative for each winding of the stator). These diodes can be individual diodes or grouped into a positive and a negative rectifier that each contain three diodes. All six diodes can be combined into one replaceable unit called a **rectifier bridge.** The rectifier(s) (diodes) should be tested using a multimeter that is set to **"diode check"** or "ohms."

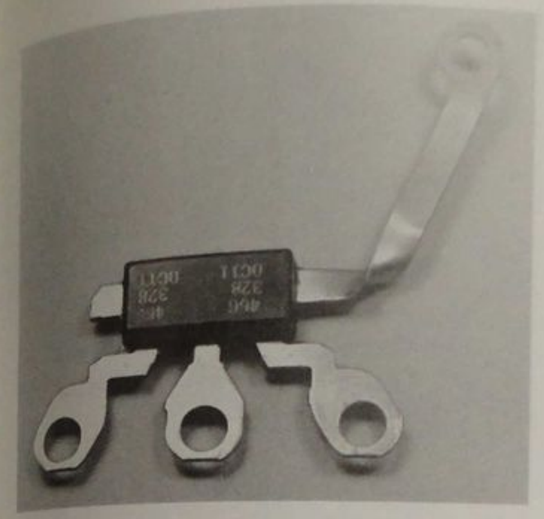


Figure 41–44 Typical diode trio. If one leg of a diode trio is open, the generator may produce close to normal output, but the charge indicator light on the dash will be on dimly. The plus signs indicate the anodes, and the minus sign indicates the cathode terminal of the diodes.

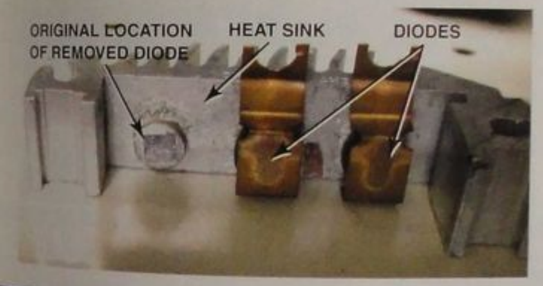


Figure 41–45 A GM rectifier bridge that has been disassembled to show the individual diodes.

Because a diode (rectifier) should allow current to flow in only one direction, each diode should be tested to determine if the diode allows current flow in one direction and blocks current flow in the opposite direction. To test many generator diodes, it may be necessary to unsolder the stator connections. Accurate testing is not possible unless the diodes are separated electrically from other generator components. See Figure 41–45. Connect the leads to the leads of the diode (pigtail and housing of the rectifier bridge). Read the meter. Reverse the test leads. A good diode should have high resistance (OL) one way (reverse bias) and low-voltage drop (0.5 to 0.7 volt) the other way (forward bias).

An ohmmeter also can be used. If the ohmmeter reads low ohms (low-voltage drop) in both directions, the diode is shorted. If the ohmmeter reads high ohms (OL) in both directions, the diode is open. Open or shorted diodes must be replaced. Most generators group or combine all positive and all negative diodes in the one replaceable rectifier component. General Motors Delcotron generators use a replaceable rectifier bridge containing all six diodes in one unit combined with a finned heat sink.

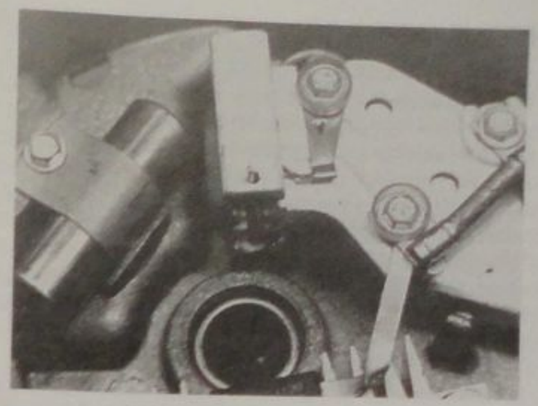


Figure 41–46 A brush holder assembly shown assembled in the generator. The brush retainer is actually a straightened-out paper clip.

Brush Holder Replacement Generator carbon brushes often last for many years and require no scheduled maintenance. The life of the generator brushes is extended because they conduct only the field (rotor) current, which is normally only 2 to 5 amperes. The generator brushes should be inspected whenever the generator is disassembled and should be replaced when worn to less than 1/2 inch in length. Generator brushes are spring loaded, and if the springs are corroded or damaged, the brushes will not be able to keep constant contact with the slip rings of the rotor. If the brushes do not contact the slip rings, field current cannot create the magnetic field in the rotor that is necessary for current generation. Brushes are commonly purchased assembled together in a brush holder. After the brushes are installed (usually retained by two or three screws) and the rotor is installed in the generator housing, a brush retainer pin can be pulled out through an access hole in the rear of the generator, allowing the brushes to be pressed against the slip rings by the brush springs. See Figure 41–46.

Bearing Service and Replacement The bearing of a generator must be able to support the rotor and reduce friction. A generator must be able to rotate at up to 15,000 RPM and withstand the forces created by the drive belt. The front bearing usually is a ball bearing type and the rear is a smaller roller bearing. The front bearing is located under a retainer and pressed into the front generator case. The pulley must be removed before the rotor can be separated from the case. Some generator press-fit pulleys must be removed using a puller, whereas Ford and General Motors generators use a nut to hold the drive pulley to the rotor. The front pulley can be removed from most GM generators by using a 15/16-inch wrench while holding the rotor shaft to keep it from rotating using a 5/16-inch hex (Allen) wrench.

The old or defective bearing sometimes can be pushed out of the front housing and the replacement pushed in by applying pressure with a socket or pipe against the outer edge of the bearing (outer race). Replacement bearings are usually prelubricated and sealed. Adding additional grease could cause overheating of the bearing by reducing heat transfer from the bearing surfaces to the generator housing. Many generator front bearings must be removed from the rotor using a special puller.

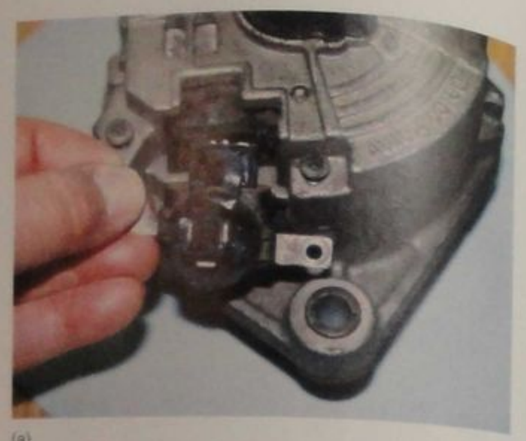
GENERATOR ASSEMBLY

After testing or servicing, the generator rectifier(s), regulator, stator, and brush holder must be reassembled. If the brushes are internally mounted, insert a wire through the holes in the brush holder and in the generator rear frame to retain the brushes for reassembly. Install the rotor and front-end frame in proper alignment with the mark made on the outside of the generator housing. Install the through bolts. Before removing the wire pin holding the brushes, spin the generator pulley. If the generator is noisy or not rotating freely, the generator can easily be disassembled again to check for the cause. After making certain the generator is free to rotate, remove the brush holder pin and spin the generator again by hand. The noise level may be slightly higher with the brushes released onto the slip rings.

Generators should be tested on a bench tester, if available, before they are reinstalled on a vehicle. When installing the generator on the vehicle, be certain that all mounting bolts and nuts are tight. The battery terminal should be covered with a plastic or rubber protective cap to help prevent accidental shorting to ground, which could seriously damage the generator.

REMANUFACTURED GENERATORS

Remanufactured or rebuilt generators are totally disassembled and rebuilt. Even though there are many smaller rebuilders who may not replace all worn parts, the major national remanufacturers *totally* remanufacture the generator. Old generators (called cores) are totally disassembled and cleaned. Both bearings are replaced and all components tested. Rotors are rewound to original specifications if required. The rotor windings are not counted but are rewound on the rotor "spool," using the correct-gauge copper wire, to the *weight* specified by the original manufacturer. New slip rings are replaced as required and soldered to the rotor spool windings and machined. The rotors are also balanced and measured to ensure that the outside diameter of the rotor meets specifications. An undersized rotor will produce less generator output because the field must be close to the stator windings for maximum output. *Individual* diodes (within the rectifiers) are replaced if required. Every generator is then assembled and tested for proper output, boxed, and shipped to a warehouse. Individual parts stores (called jobbers) purchase parts from various regional or local warehouses. See Figure 41–47.



(a)



(b)

Figure 41–47 (a) A generator for a GEO Prism looks like a typical General Motors CS-130 except for this adapter that converted the Toyota wiring harness to the GM generator. (b) After removing the adapter, the original generator connection is visible.

REAL WORLD FIX — **The Two-Minute Generator Repair**

A Chevrolet pickup truck was brought to a dealer for routine service. The owner stated that the battery required a jump-start after a weekend of sitting. The technician tested the battery and charging system voltage using a small handheld digital multimeter. The battery voltage was 12.4 volts (about 75% charged), but the charging voltage was also 12.4 volts at 2000 RPM. Because normal charging voltage should be 13.5 to 15.0 volts, it was obvious that the charging system was not operating correctly.

The technician checked the dash and found that the "charge" light was not on, even though the rear bearing was *not* magnetized, indicating that the voltage regulator was not working. Before removing the generator for service, the technician checked the wiring connection on the generator. When the two-lead regulator connector was removed, the connector was discovered to be rusty. After the contacts were cleaned, the charging system was restored to normal operation. The technician had learned that the simple things should always be checked first before tearing into a big (or expensive) repair.

TECH TIP — **The Weak but Good Generator**

An 80-ampere generator was tested at 2000 engine RPM and found to be producing only 69 amperes. The recommended specification for a generator is that the output should be within 10% of the rated output. Ten percent of 80 amperes is 8 amperes; therefore, the minimum recommended output is 72 amperes (80 − 8 = 72). Because 69 amperes is less than 72 amperes, the generator should be serviced (repaired or replaced). However, because the test result was so close to the specifications, it was decided that a *charging system requirement test* should be performed. This test determines the electrical load of the vehicle that may be required on a continuous basis. The test procedure is simple: Turn on everything electrical, except the horn or other short-term electrical accessories. Add 5 amperes to the reading and the result is the minimum current required of the generator.

The electrical demand test indicated that only 49 amperes was needed. Add 5 amperes (49 + 5 = 54) and you see that a 54-ampere generator is all that is needed. Because the original generator is capable of 69 amperes, it is more than adequate for the vehicle.

REAL WORLD FIX — **The Cold Weather Charge Lamp Problem**

A customer brought his vehicle (Ford) to an independent service facility complaining that occasionally, whenever the temperatures dropped below 10°F (−12°C), his charge indicator lamp stayed on until he had driven for several minutes.

The customer left the vehicle overnight and the technician observed that, indeed, the charge lamp was on after starting the vehicle the next morning. The technician immediately got out of the vehicle, opened the hood, and checked to see if the rear bearing was magnetized—it was not. After a few minutes of operation, the charge lamp went out and the rear generator bearing *was* magnetized. The technician then knew that the problem was sticking generator brushes. The brushes had worn to less than one-half length, and the springs were not strong enough, when cold, to exert sufficient pressure on the rotor slip rings to conduct the current for the field (rotor). After the technician replaced the brushes and cleaned and checked all other generator components, the problem did not recur.

TECH TIP — **Help!**

A technician wanted help in determining what the generator output should be on a Toyota truck. If the generator is protected by a fuse, check the fuse rating. In this case, the fuse was listed as being 80 amperes. The 80% rule states that the maximum current in a circuit should not exceed 80% of the fuse rating. Eighty percent of 80 amperes is 65 amperes. The generator output was measured to be 62 amperes, well within the normal range of within 10% of specifications (10% of 64 is 6.4 amperes).

SUMMARY

1. Charging system testing requires that the battery be at least 75% charged to be assured of accurate test results. The charge indicator light should be on with the ignition switch on but should go out whenever the engine is running. Normal charging voltage (at 2000 engine RPM) is 13.5 to 15.0 volts.
2. If the charging system is not charging properly, the rear bearing of the generator should be checked for magnetism. If the rear bearing is magnetized, the voltage regulator, brushes, and generator rotor are functioning correctly. If the rear bearing is not magnetized, the voltage regulator, generator brushes, or rotor is not functioning. Bypass the voltage regulator by supplying battery voltage to the field. If the rear bearing is now magnetized and the charging system output is normal; the voltage regulator is at fault.
3. To check for excessive resistance in the wiring between the generator and the battery, a voltage-drop test should be performed.
4. Generators do not produce their maximum-rated output unless required by circuit demands. Therefore, to test for maximum generator output, the battery must be loaded to force the generator to produce its maximum output.
5. Each generator should be marked across its case before disassembly to ensure proper clock position during reassembly. After disassembly, all generator internal components should be tested using a continuity light or an ohmmeter. The following components should be tested:
   a. Stator
   b. Rotor
   c. Diodes
   d. Diode trio (if the generator is so equipped)
   e. Bearings
   f. Brushes (should be more than 1/2 inch in length)
6. Electronic voltage regulators can be tested either off the vehicle using a special tester or on the vehicle using the full-field bypass procedure.

PHOTO SEQUENCE Generator (Alternator) Overhaul Step-by-Step



P41–1 Before the generator (alternator) is disassembled, it is spin tested and connected to a scope to check for possible defective components.



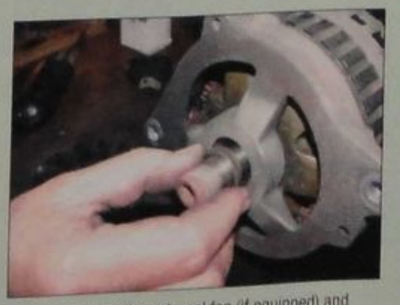
P41–2 The scope pattern shows that the voltage output is far from being a normal pattern. This pattern indicates serious faults in the rectifier diodes.



P41–3 The first step is to remove the drive pulley. This rebuilder is using an electric impact wrench to accomplish the task.



P41–4 Carefully inspect the drive galley for damage or embedded rubber from the drive belt. The slightest fault can cause a vibration, noise, or possible damage to the generator (alternator).



P41–5 Remove the external fan (if equipped) and then the spacers as shown.



P41–6 Next pop off the plastic cover (shield) covering the stator/rectifier connection.

(continued)



P41–7 After the cover has been removed, the stator connections to the rectifier can be seen.



P41–8 Using a diagonal cutter, cut the weld to separate the stator from the rectifier.



P41–9 Before separating the halves of the case, the technician uses a punch to mark both halves.



P41–10 After the case has been marked, the through-bolts are removed.



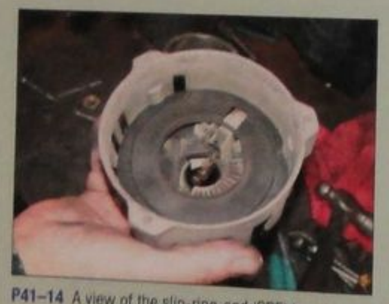
P41–11 The drive-end housing and the stator are being separated from the rear (slip-ring-end) housing.



P41–12 The stator is checked by visual inspection for discoloration or other physical damage, and then checked with an ohmmeter to see if the windings are shorted-to-ground.



P41–13 The front bearing is removed from the drive-end housing using a press.



P41–14 A view of the slip-ring-end (SRE) housing showing the black plastic shield, which helps direct air flow across the rectifier.



P41–15 A punch is used to dislodge the plastic shield retaining clips.



P41–16 After the shield has been removed, the rectifier, regulator, and brush holder assembly can be removed by removing the retaining screws.



P41–17 The rear transfer grease is visible when the rectifier assembly is lifted out of the rear housing.



P41–18 The parts are placed into a tumbler where ceramic stones and a water-based solvent are used to clean the parts.



P41–19 This rebuilder is painting the housing using a high-quality industrial grade spray paint to make the rebuilt generator look like new.



P41–20 The slip rings on the rotor are being machined on a lathe.



P41–21 The rotor is being tested using an ohmmeter. The specifications for the resistance between the slip rings on the CS-130 are 2.2 to 3.5 ohms.



P41–22 The rotor is also tested between the slip ring and the rotor shaft. This reading should be infinity.



P41–23 A new rectifier. This replacement unit is significantly different than the original but is designed to replace the original unit and meets the original factory specifications.



P41–24 Silicone heat transfer compound is applied to the heat sink of the new rectifier.



P41–25 Replacement brushes and springs are assembled into the brush holder.



P41–26 The brushes are pushed into the brush holder and retained by a straight wire, which extends through the rear housing of the generator. This wire is then pulled out when the unit is assembled.



P41–27 Here is what the CS generator looks like after installing the new brush holder assembly, rectifier bridge, and voltage regulator.



P41–28 The injunction between the rectifier bridge and the voltage regulator is soldered.



P41–29 The plastic deflector shield is snapped back into location using a blunt chisel and a hammer. This shield directs the airflow from the fan over the rectifier bridge and voltage regulator.



P41–30 Before the stator windings can be soldered to the rectifier bridge, the varnish insulation is removed from the ends of the leads.

(continued)

PHOTO SEQUENCE Generator (Alternator) Overhaul Step-by-Step—continued



P41–31 After the stator has been inserted into the rear housing the stator leads are soldered to the copper lugs of the rectifier bridge.



P41–32 New bearings are installed. A spacer is placed between the bearing and the slip rings to help prevent the possibility that the bearing could move on the shaft and short against the slip ring.



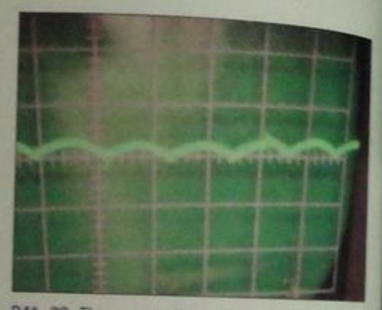
P41–33 The slip-ring-end (SRE) housing is aligned with the marks made during disassembly and is pressed into the drive-end (DE) housing.



P41–34 The retaining bolts, which are threaded into the drive-end housing from the back of the generator are installed.



P41–35 The external fan and drive pulley are installed and the retaining nut is tightened on the rotor shaft.



P41–36 The scope pattern shows that the diodes and stator are functioning correctly and voltage check indicates that the voltage regulator is also functioning correctly.

REVIEW QUESTIONS

1. Describe how a small electronic voltage regulator can control the output of a typical 100-ampere generator.
2. Describe how to test the voltage drop of the charging circuit.
3. Discuss how to measure the amperage output of a generator.
4. Explain how testing can be used to determine whether a diode or stator is defective before removing the generator from the vehicle.

CHAPTER QUIZ

1. Technician A says that the diodes regulate the generator output voltage. Technician B says that the field current can be computer controlled. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. A magnetic field is created in the _____ in a generator (AC generator).
   a. Stator
   b. Diodes
   c. Rotor
   d. Drive-end frame
3. The voltage regulator controls the current _____.
   a. Through the generator brushes
   b. Through the rotor
   c. Through the generator field
   d. All of the above
4. Technician A says that two diodes are required for each stator winding lead. Technician B says that diodes change alternating current into direct current. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. An acceptable charging circuit voltage on a 12-volt system is _____.
   a. 13.5 to 15.0 volts
   b. 12.6 to 15.6 volts
   c. 12 to 14 volts
   d. 14.9 to 16.1 volts
6. Technician A says that the computer controls the generator, by adding resistance to the output. Technician B says that the computer controls the generator output by controlling the field current through the rotor. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Technician A says that a voltage-drop test of the charging circuit should only be performed when current is flowing through the circuit. Technician B says to connect the leads of a voltmeter to the positive and negative terminals of the battery to measure the voltage drop of the charging system. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. When a generator rotor is checked, if an ohmmeter shows zero ohms between the slip rings and the rotor shaft, the rotor is _____.
   a. Okay (normal)
   b. Defective (grounded)
   c. Defective (shorted)
   d. Okay (rotor windings are open)
9. A generator diode is being tested using a digital multimeter set to the diode check position. A good diode will read _____ if the leads are connected one way across the diode and _____ if the leads are reversed.
   a. .300; 300
   b. 0.575; 0.575
   c. OL; OL
   d. 0.651; OL
10. A generator (AC generator) could test as producing lower-than-normal output, yet be okay, if _____.
    a. The battery is weak or defective
    b. The engine speed is not high enough during testing
    c. The drive belt is loose or slipping
    d. All of the above

CHAPTER 42 Lighting and Signaling Circuits

OBJECTIVES: After studying Chapter 42, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "E" (Lighting System Diagnosis and Repair). • Determine which replacement bulb to use on a given vehicle. • Describe how interior and exterior lighting systems work. • Read and interpret a bulb chart. • Discuss troubleshooting procedures for lighting and signaling circuits.

KEY TERMS: adaptive (or advanced) front light system (AFS) • brake lights • candlepower • center high-mounted stop light (CHMSL) • color shift • composite headlight • courtesy lights • daytime running lights (DRLs) • feedback • fiber optics • hazard warning • high-intensity discharge (HID) • hybrid flasher • Kelvin (K) • light-emitting diode (LED) • reference voltage (RF) • rheostat • trade number • U.S. Department of Transportation (DOT) • xenon headlights

The lighting and signaling circuits represent two of the most frequently serviced automotive electrical areas.

LIGHTING

Exterior lighting is controlled by the headlight switch, which is connected directly to the battery on most vehicles. Therefore, if the light switch is left on, it can drain the battery. Most headlight switches contain a built-in circuit breaker. If excessive current flows through the headlight circuit, the circuit breaker will momentarily open the circuit, then close it again. The result is headlights that flicker on and off rapidly.

NOTE: This flickering on and off is misunderstood by many drivers and technicians. Because the flickering is rapid, many people believe that the problem is caused by a loose headlight or by a defective voltage regulator.

This feature allows the headlights to function, as a safety measure, in spite of current overload. The headlight switch controls the following lights on most vehicles:

1. Headlights
2. Taillights
3. Side-marker lights
4. Front parking lights
5. Dash lights
6. Interior (dome) light(s)

NOTE: Because these lights can easily drain the battery if accidentally left on, many newer vehicles control these lights through the vehicle's computer. The computer keeps track of the time the lights are on and can turn them off if the time is excessive. The computer can control either the power side or the ground side of the circuit usually through an electronic control module.

BULB NUMBERS

The number used on automotive bulbs is called the bulb **trade number,** as recorded with the American National Standards Institute (ANSI), and the number is the same regardless of the manufacturer. Amber-color bulbs that use natural amber glass are indicated with an "NA" for *natural amber* at the end of the number (for example, #1157NA). A less expensive amber bulb that uses painted glass is labeled "A" for *amber* (for example, #1157A). See Figure 42–1.

The trade number also identifies the size, shape, number of filaments, and amount of light produced, measured in **candlepower.** For example, the candlepower of a #1156 bulb, commonly used for backup lights, is 32. A #194 bulb, commonly used for dash or side-marker lights, is rated at only 2 candlepower. The amount of light produced by a bulb is determined by the resistance of the filament wire, which also affects the amount of current (in amperes) required by the bulb. See Figures 42–2 and 42–3.

It is important that the correct trade number of bulb always be used for replacement to prevent circuit or component damage. The correct replacement bulb for a vehicle is usually listed in the owner's manual or service manual. See Figure 42–4 and the bulb chart.

Typical Automotive Light Bulbs

Trade Number	Design Volts	Design Amperes	Watts: $P = I \times E$
37	14.0	0.09	1.3
37E	14.0	0.09	1.3
51	7.5	0.22	1.7
53	14.4	0.12	1.7
55	7.0	0.41	2.9
57	14.0	0.24	3.4
57X	14.0	0.24	3.4
63	7.0	0.63	4.4
67	13.5	0.59	8.0
68	13.5	0.59	8.0
70	14.0	0.15	2.1
73	14.0	0.08	1.1
74	14.0	0.10	1.4
81	6.5	1.02	6.6
88	13.0	0.58	7.5
89	13.0	0.58	7.5
90	13.0	0.58	7.5
93	12.8	1.04	13.3
94	12.8	1.04	13.3
158	14.0	0.24	3.4
161	14.0	0.19	2.7
168	14.0	0.35	4.9
192	13.0	0.33	4.3
194	14.0	0.27	3.8
194E-1	14.0	0.27	3.8
194NA	14.0	0.27	3.8
209	6.5	1.78	11.6
211-2	12.8	0.97	12.4
212-2	13.5	0.74	10.0
214-2	13.5	0.52	7.0
561	12.8	0.97	12.4
562	13.5	0.74	10.0
563	13.5	0.52	7.0
631	14.0	0.63	8.8
880	12.8	2.10	27.0
881	12.8	2.10	27.0
906	13.0	0.69	9.0
912	12.8	1.00	12.8
1003	12.8	0.94	12.0
1004	12.8	0.94	12.0
1034	12.8	1.80/0.59	23.0/7.6
1073	12.8	1.80	23.0
1076	12.8	1.80	23.0
1129	6.4	2.63	16.8
1133	6.2	3.91	24.2
1141	12.8	1.44	18.4
1142	12.8	1.44	18.4
1154	6.4	2.63/0.75	16.8/4.5
1156	12.8	2.10	26.9
1157	12.8	2.10/0.59	26.9/7.6
1157A	12.8	2.10/0.59	26.9/7.6
1157NA	12.8	2.10/0.59	26.9/7.6
1176	12.8	1.34/0.59	17.2/7.6
1195	12.5	3.00	37.5
1196	12.5	3.00	37.5
1445	14.4	0.13	1.9
1816	13.0	0.33	4.3
1889	14.0	0.27	3.8
1891	14.0	0.24	3.4
1892	14.4	0.12	1.7
1893	14.0	0.33	4.6
1895	14.0	0.27	3.8
2033	13.5	0.22	3.0
2057	12.8	2.10/0.48	26.9/6.1
2057NA	12.8	2.10/0.48	26.9/6.1
2322-1	12.0	0.16	2.0
2721	12.0	0.10	1.2
2821	12.0	4.00	3.0
2825	12.0	0.42	5.0
3057	12.8	0.16	2.1
3157	12.0	1.10	12.8
3796	12.0	6.00	2.0
3893	12.0	3.00	4.0
3894	12.0	4.00	3.0
3898	12.0	6.00	2.0
3966	12.0	4.00	3.0
5004	12.0	4.00	3.0
5006	6.0	1.20	5.0
5007	12.0	2.40	5.0
5008	12.0	1.20	10.0
6418	12.0	0.42	5.0
6428	12.0	0.25	3.0
6461	12.0	0.83	10.0
7230	12.0	2.40	5.0
7301	12.0	3.75	45.0
7309	12.0	2.92	35.0
7506	12.0	0.60	21.0
7527	12.0	0.69	18.0
7528	12.0	2.40	5.0
7533	12.0	0.80	15.0
9004 H*	12.8	5.00/35.00	65.0/45.0
9005 H*	12.8	5.00	65.0
9006 H*	12.8	4.30	55.0
26736	12.0	0.83	10.0
64150 H1	12.0	4.50	55.0
64151 H3	12.0	4.50	55.0
64152 H1	12.0	8.30	100.0
64153 H3	12.0	8.30	100.0
64173 H2	12.0	4.50	55.0
64174 H2	12.0	8.30	100.0
64185 H4	12.0	2.90	35.0
64193 H4	12.0	5.00	60.0
P25-1	13.5	1.86	25.1
P25-2	13.5	1.86	25.1
R19/5	13.5	0.37	5.1
R19/10	13.5	0.74	10.0
W10/3	13.5	0.25	3.4



Figure 42–1 Bulbs that have the same trade number have the same operating voltage and wattage. The NA means that the bulb uses a natural amber glass ampoule with clear turn signal lenses.

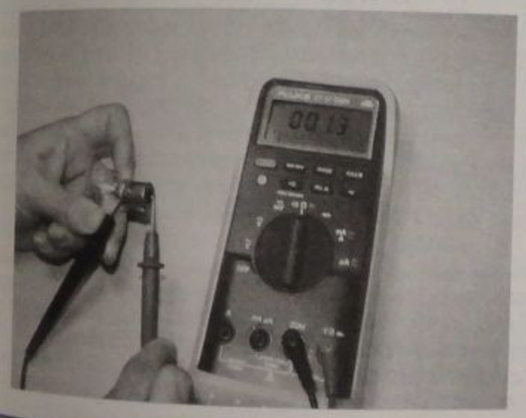


Figure 42–2 This single-filament bulb is being tested with a digital multimeter set to read resistance in ohms. The reading of 1.3 ohms is the resistance of the bulb when cold. As soon as current flows through the filament, the resistance increases about 10 times. It is the initial surge of current flowing through the filament when the bulb is cool that causes many bulbs to fail in cold weather as a result of the reduced resistance. As the temperature increases, the resistance increases.

REAL WORLD FIX

Weird Problem—Easy Solution

A General Motors minivan had the following electrical problems:

- The turn signals flashed rapidly on the left side.
- With the ignition key off, the lights-on warning chime sounded if the brake pedal was depressed.
- When the brake pedal was depressed, the dome light came on.

All of these problems were caused by just one defective 2057 dual-filament bulb, as shown in Figure 42–5. Apparently, the two filaments were electrically connected through the corrosion observed between the terminals of the bulb. This caused the electrical current to feed back from the brake light filament into the taillight circuit, causing all the problems. See Figure 42–6 for another example of a weird bulb problem.



Figure 42–3 Close-up of a dual-filament (double-filament) bulb (#1157) that failed. Notice that one filament (top) broke from its mounting and melted onto the lower filament. This bulb caused the dash lights to come on whenever the brakes were applied.

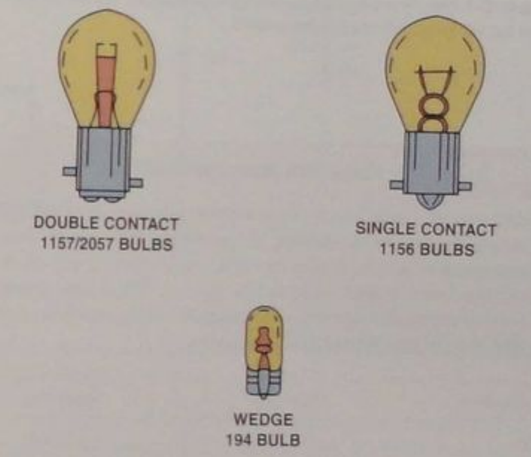


Figure 42–4 Bulbs #1157 or #2057 are typically used for taillight and front parking lights. These bulbs contain both a low-intensity filament for taillights or parking lights and a high-intensity filament for brake lights and turn signals.



Figure 42–5 Corrosion caused the two terminals of this dual-filament bulb to be electrically connected.

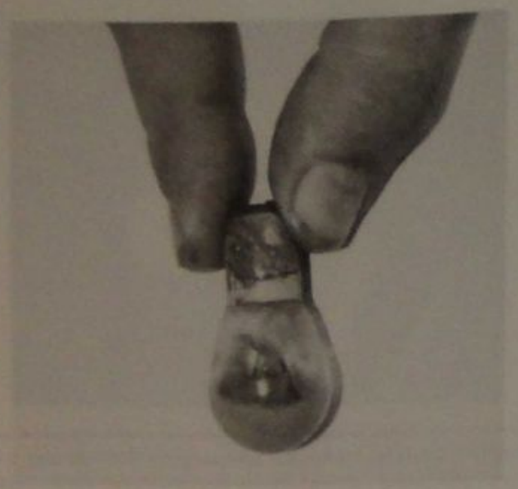


Figure 42–6 Often the best diagnosis is a thorough visual inspection. This bulb was found to be filled with water, which caused weird problems.

TECH TIP ✔ **Heavy-Duty Automotive Bulbs**

Many automotive bulbs have the same operating parameters (same wattage, voltage, amperage, and candlepower) yet have different trade numbers. Some numbers are for standard duty, whereas others have heavier filament wire or additional filament support, which qualifies them for a different trade number. A fleet-duty designation represents some increase in durability, and a heavy-duty designation identifies the most severe service bulb.

Regular	Fleet Duty	Heavy Duty
53	182	1445 or 53X
57	293	1895
67	97	97
68	96	96
69	98	631
90	99	—
93	1093	—
158	193	194
161	184	—
1003	105	—
1004	104	—
1034	198	1157
1034A	—	1157NA/1157A
1073	199	1156
1141	1159	—
1889/1891	1893	1893
4000	—	4040
6014	—	6015

Therefore, if the specification for your vehicle gives a trade number listed under the "regular" heading, you can safely switch to the trade number of bulb listed under the "fleet-duty" or "heavy-duty" heading. For best operation of turn signals and consistent brightness of bulbs, the switch of trade numbers should include all similar bulbs of the type being replaced.

BRAKE LIGHTS

Brake lights use the high-intensity filament of a double-filament bulb. (The lower intensity filament is for the taillights.) The brake light switch is a normally open (N.O.) switch but is closed when the driver depresses the brake pedal. Since 1986, all vehicles sold in the United States have a third brake light commonly referred to as the **center high-mounted stop light (CHMSL).** The brake switch is also used as an input switch (signal) for the following:

1. Cruise control (deactivates when the brake pedal is depressed)
2. Antilock brakes (ABS)
3. Brake shift interlock (prevents shifting from "park" position unless the brake pedal is depressed)

TECH TIP ✔ **No Cruise Control? Check the Third Brake Light**

A common cause of an inoperative cruise control, especially on General Motors vehicles, is a burned out bulb in the third stop light. The cruise control uses the filaments of the third brake bulb (CHMSL) as a ground and shuts off the cruise if the bulbs are burned out (open). See Figure 42–7.

HEADLIGHT SWITCHES

The headlight switch operates the exterior and interior lights of most vehicles. On non-computer-controlled lighting systems, the headlight switch is connected directly to the battery through a fusible link and has continuous power or is "hot" all the time. A circuit breaker is built into most headlight switches to protect the headlight circuit. See Figure 42–8. The interior dash lights can be dimmed manually by rotating the headlight switch knob, which controls a variable resistor (called a **rheostat**) built into the headlight switch.

The headlight switch also contains a built-in circuit breaker that will rapidly turn the headlights on and off in the event of a short circuit. This prevents a total loss of headlights. If the headlights are rapidly flashing on and off, check the entire headlight circuit for possible shorts. The circuit breaker controls only the headlights. The other lights controlled by the headlight switch (taillights, dash lights, and parking lights) are fused separately. Flashing headlights also may be caused by a failure in the built-in circuit breaker, requiring replacement of the switch assembly.

Removing a Headlight Switch Most dash-mounted headlight switches can be removed by first removing the dash panel. However, to get the dash panel off, the headlight switch knob usually has to be removed. Some knobs can be removed by depressing a small clip in a notch in the knob itself. Other headlight switch knobs are removed by depressing a spring-loaded release, which allows for removal of the entire headlight switch knob and shaft, as shown in Figure 42–9.

Headlight switches mounted on the steering column are removed as part of the turn signal and wiper switch assembly. Many can be easily removed, whereas others require the removal of the steering wheel and so forth. In order to be assured of the correct procedure, see the service information for the exact year and model on which you are working.

SEALED-BEAM HEADLIGHTS

Low-beam headlights contain two filaments: one for low beam and the other for high beam. High-beam headlights contain only one filament and have two terminals. Because low-beam headlights also contain a high-beam filament, the entire headlight assembly must be replaced if either filament is defective.

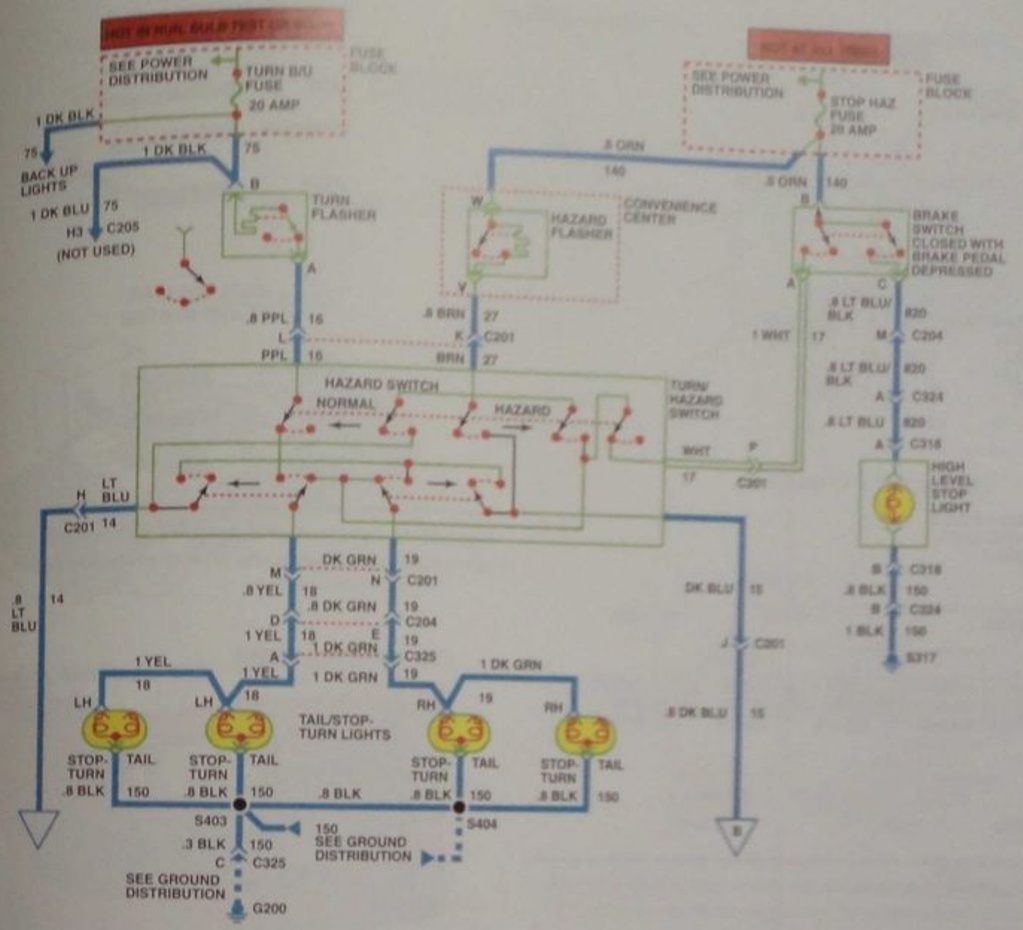


Figure 42–7 Typical brake light and taillight circuit showing the brake switch and all of the related circuit components.

A sealed-beam headlight can be tested with an ohmmeter. A good bulb should indicate low ohms between the ground terminal and both power-side (hot) terminals. If either the high-beam or the low-beam filament is burned out, the ohmmeter will indicate infinity (OL). See Figure 42–10.

HEADLIGHT AIMING

According to U.S. federal law, all headlights, regardless of shape, must be able to be aimed using headlight aiming equipment. See Figures 42–11 through 42–13. Also see the photo sequence on headlight aiming at the end of the chapter.

COMPOSITE HEADLIGHTS

Composite headlights are constructed using a replaceable bulb and a fixed lens cover that is part of the vehicle. See Figure 42–14.

The replaceable bulbs are usually bright halogen bulbs. Halogen bulbs get very hot during operation (between 500° and 1300°F [260° and 700°C]). It is important never to touch the glass of any halogen bulb with bare fingers because the natural oils of the skin on the glass bulb can cause the bulb to break when it heats during normal operation.

HALOGEN SEALED-BEAM HEADLIGHTS

Halogen sealed-beam headlights are brighter and more expensive than normal headlights. Because of their extra brightness, it is common practice to have only two headlights on at any one time, because the candlepower output would exceed the maximum U.S. federal standards if all four halogen headlights were on. Therefore, before trying to repair the problem that only two of the four lamps are on, check the owner's manual or the shop manual for proper operation.

CAUTION: Do not attempt to wire all headlights together. The extra current flow could overheat the wiring from the headlight switch through the dimmer switch and to the headlights. The overloaded circuit could cause a fire.

TECH TIP ✔ **Diagnose Bulb Failure**

Halogen bulbs can fail for various reasons. Some causes for halogen bulb failure and their indications are as follows:

- Gray color—low voltage to bulb (check for corroded socket or connection)
- White (cloudy) color—indication of an air leak
- Broken filament—usually caused by excessive vibration. See Figure 42–15.
- Blistered glass—indication that someone has touched the glass

NOTE: *Never touch the glass ampoule of any halogen bulb.* The oils from your fingers can cause unequal heating of the glass during operation, leading to a shorter-than-normal service life.

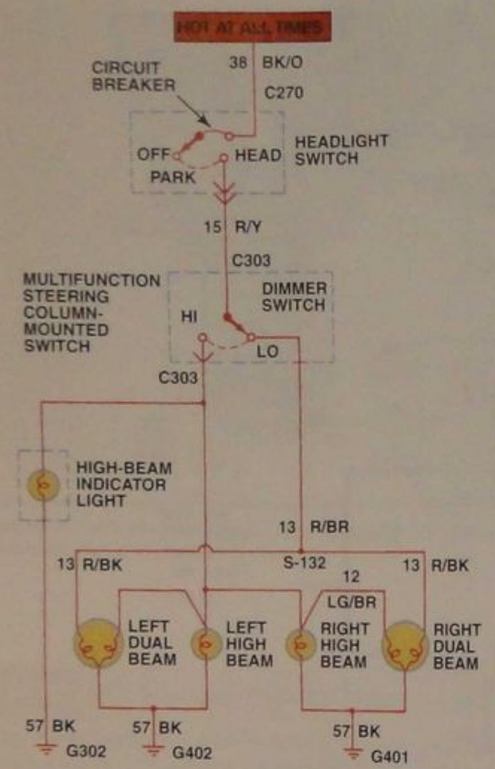


Figure 42–8 Typical headlight circuit diagram. Note that the headlight switch is represented by a dotted outline indicating that other circuits (such as dash lights) also operate from the switch.



Figure 42–9 To remove the headlight switch from a vehicle that uses a knob and shaft, a release button has to be pushed to release the shaft. After the knob and shaft assembly has been removed, then the retaining nut can be removed from the headlight switch so it can be removed from the dash.

HIGH-INTENSITY DISCHARGE HEADLIGHTS

Parts and Operation **High-intensity discharge (HID)** headlights produce a distinctive blue-white light that is crisper, clearer, and brighter than light produced by a halogen headlight.

High-intensity discharge lamps do not use a filament like conventional electrical bulbs, but rather contain two electrodes about 0.2 inch (5 mm) apart. A high-voltage pulse is sent to the bulb, which arcs across the tips of electrodes producing light.

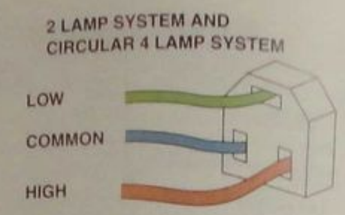


Figure 42–10 Typical headlight socket connections. Some vehicles may be different. The high- and low-beam connections must be determined by visual inspection.

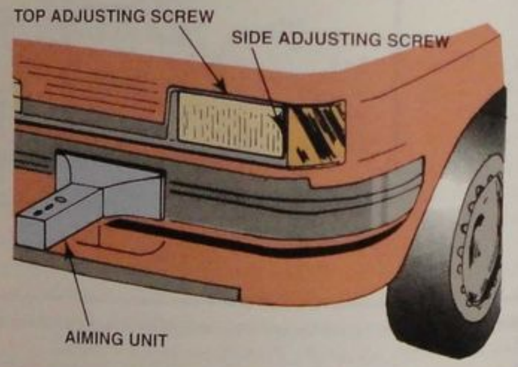


Figure 42–11 All vehicles sold in the United States must have provision for the use of mechanical aiming devices. Even the halogen bulb units with plastic or glass lenses have locating points and adjustment screws.

Unlike a halogen bulb, the HID bulb has no filament. It creates light from an electrical discharge between two electrodes in a gas-filled arc tube. It produces twice the light with less electrical input than conventional halogen bulbs.

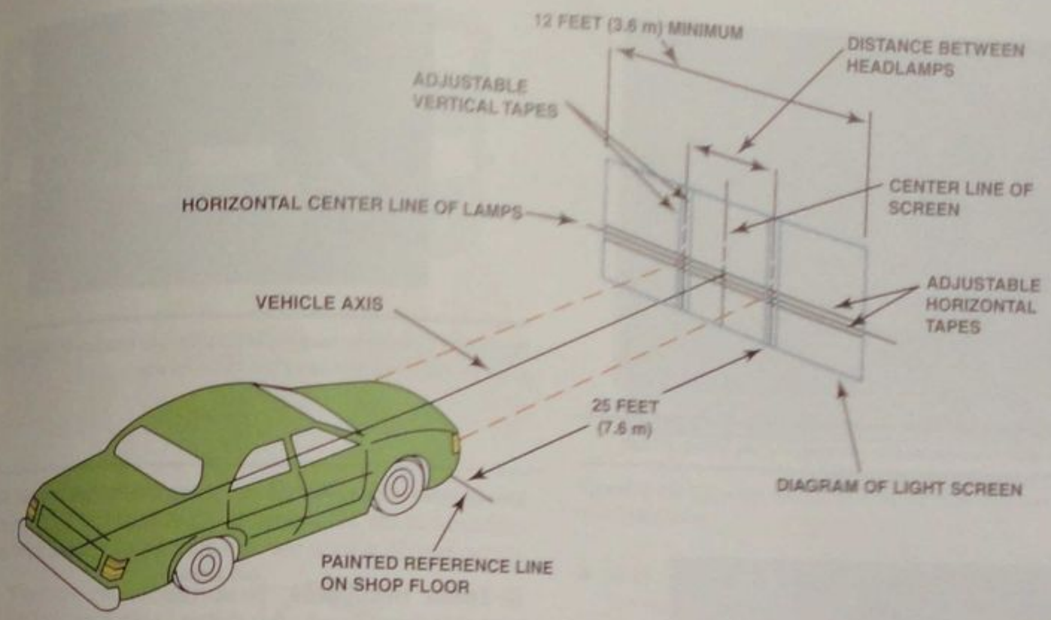
The HID lighting system consists of the discharge arc source, igniter, ballast, and headlight assembly. See Figure 42–16.

The two electrodes are contained in a tiny quartz capsule filled with xenon gas, mercury, and metal halide salts. HID headlights are also called **Xenon headlights.** The lights and support electronics are expensive, but they should last the life of the vehicle unless physically damaged.

HID headlights produce a white light, usually low in red giving the lamp a blue-white color. The color of light is expressed in temperature using the Kelvin scale. **Kelvin (K)** temperature is the Celsius temperature plus 273 degrees. Typical color temperatures include:

- Daylight—5400°K
- HID—4100°K
- Halogen—3200°K
- Incandescent (tungsten)—2800°K

See Figure 42–17.



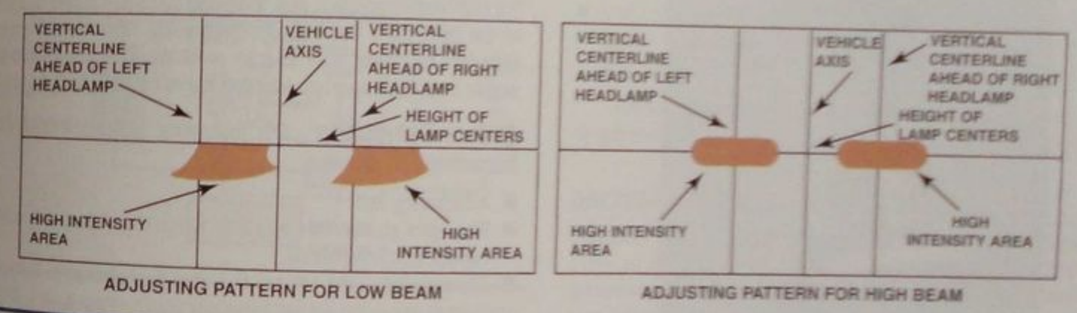


Figure 42–12 Typical headlight-aiming diagram as found in a service manual.

FREQUENTLY ASKED QUESTION ???

What Is the Difference Between the Temperature of the Light and the Brightness of the Light?

The temperature of the light indicates the color of the light. The brightness of the light is measured in lumens. A standard 100-watt incandescent light bulb emits about 1,700 lumens. A typical halogen headlight bulb produces between 1,000 and 2,000 lumens and a typical HID bulb produces about 2,800 lumens.

The HID ballast is powered by 12 volts from the headlight switch on the body control module. The HID headlights operate in three stages or states:

1. Start-up or stroke state
2. Run-up state
3. Steady state

Start-Up or Stroke State When the headlight switch is turned to the on position, the ballast may draw up to 20 amperes at 12 volts. The ballast sends multiple high-voltage pulses to the arc tube to start the arc inside the bulb. The voltage provided by the ballast during the start-up state ranges from −600 volts to +600 volts, which is increased by a transformer to about 25,000 volts. The increased voltage is used to create an arc between the electrodes in the bulb.



Figure 42–13 Many composite headlights have a built-in bubble level to make aiming easy and accurate.

Run-Up State After the arc is established, the ballast provides a higher than steady state voltage to the arc tube to keep the bulb illuminated. On a cold bulb, this state could last as long as 40 seconds. On a hot bulb, the run-up state may last only 15 seconds. The current requirements during the run-up state are about 360 volts from the ballast and a power level of about 75 watts.



Figure 42–14 A typical composite headlamp assembly. The lens, housing, and bulb sockets are usually included as a complete assembly.

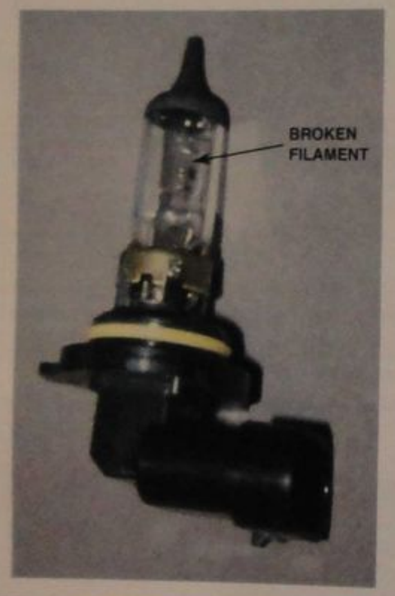


Figure 42–15 Notice the broken filament in this halogen headlight bulb.

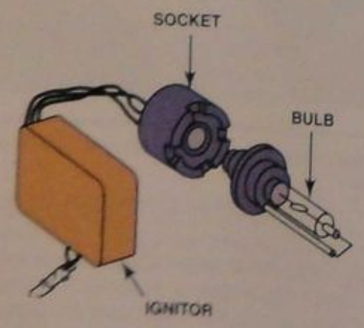


Figure 42–16 The ignitor contains the ballast and transformer needed to provide high-voltage pulses to the arc tube bulb.



Figure 42–17 HID (Xenon) headlights emit a whiter light than halogen headlights and usually look blue compared to the parking light on the side.

Steady State The steady state phase begins when the power requirement of the bulb drops to 35 watts. The ballast provides a minimum of 55 volts to the bulb during steady state operation.

Bi-Xenon Headlights Some vehicles are equipped with bi-xenon headlights, which use a shutter to block some of the light during low-beam operation and then mechanically move to expose more of the light from the bulb for high-beam operation. Because xenon lights are relatively slow to start working, vehicles equipped with bi-xenon headlights use two halogen lights for the "flash-to-pass" feature.

Failure Symptoms The following symptoms may be noticed indicating bulb failure:

- A flickering light
- The lights go out (this is caused when the ballast assembly detects repeated bulb restrikes)
- Color change—the color of the lamp may change to a dim pink glow

Bulb failures are often intermittent and difficult to repeat. However, bulb failure is likely if the symptoms get worse over time. Always follow the vehicle manufacturer's recommended testing and service procedures.

Diagnosis and Service High-intensity discharge headlights will change slightly in color with age. This **color shift** is usually not noticeable unless one headlight arc tube assembly has been replaced due to a collision repair, and then the difference in color may be noticeable. If the arc tube assembly is near the end of its life, it may not light immediately if it is turned off and then back on immediately. This test is called a "hot restrike" and if it fails, a replacement arc tube assembly may be needed or there is another fault, such as a poor electrical connection, that should be checked.

WARNING: Always adhere to all warnings because the high-voltage output of the ballast assembly can cause personal injury or death.

ADAPTIVE FRONT LIGHTING SYSTEM

Parts and Operation A system that mechanically moves the headlights to follow the direction of the front wheels is called **adaptive (or advanced) front light system,** abbreviated **AFS.** The AFS provides a wide range of visibility during cornering. The headlights are usually capable of rotating 15 degrees to the left and 5 degrees to the right (some systems rotate 14 degrees and 9 degrees). See Figure 42–18.

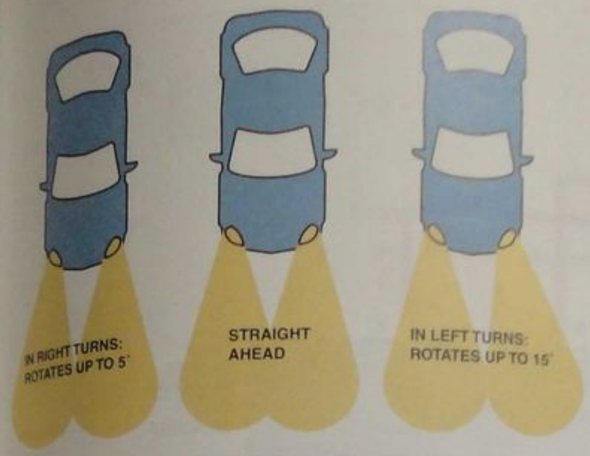


Figure 42–18 Adaptive front lighting systems rotate the low-beam headlight in the direction of travel.

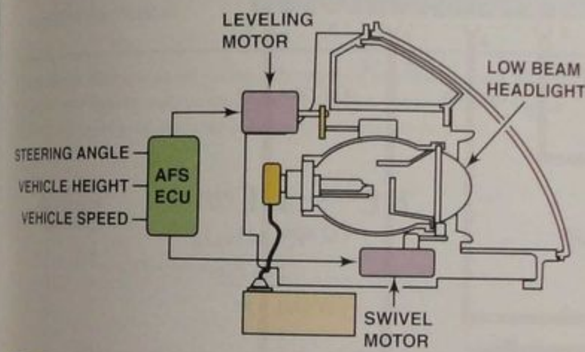


Figure 42–19 A typical adaptive front lighting system uses two motors—one for the up-and-down movement and the other for rotating the low-beam headlight to the left and right.

NOTE: These angles are reversed on vehicles sold in countries that drive on the left side of the road, such as Great Britain, Japan, Australia, New Zealand, and others.

The vehicle has to be moving above a predetermined speed, usually above 20 mph (30 km/h), and the lights stop moving when the speed drops below about 3 mph (5 km/h).

AFS is often used in addition to self-leveling motors so that the headlights remain properly aimed regardless of how the vehicle is loaded. Without self-leveling, headlights would shine higher than normal if the rear of the vehicle is heavily loaded. See Figure 42–19.

In a vehicle that is equipped with an adaptive front lighting system, the lights are moved by the headlight controller outward, and then inward, as well as up and down as a test of the system. This action is very noticeable to the driver and is normal operation of the system.

Diagnosis and Service The first step when diagnosing an AFS system fault is to perform a visual inspection including:

- Start by checking that the AFS system is switched on. Most AFS headlight systems are equipped with a switch that allows the driver to turn the system on and off. See Figure 42–20.
- Check that the system performs a self-test during start-up.



Figure 42–20 Typical dash-mounted switch that allows the driver to disable the adaptive front lighting system.

- Verify that both low-beam and high-beam lights function correctly. The system may be disabled if a fault with one of the headlights is detected.
- Use a scan tool to test for any AFS-related diagnostic trouble codes. Some systems allow the AFS to be checked and operated using a scan tool.

Always follow the recommended testing and service procedures as specified by the vehicle manufacturer in service information.

DAYTIME RUNNING LIGHTS

Daytime running lights (DRLs) involve operating front parking lights or the headlights (usually at reduced current and voltage) whenever the vehicle is running. Canada has required daytime running lights on all new vehicles since 1990. Studies have shown that DRLs have reduced accidents where used.

Daytime running lights primarily use a control module that turns on either the low- or high-beam lamps. The lights on some vehicles come on whenever the engine starts. Some vehicles will turn on the lamps when the engine is running but delay their operation until a signal from the vehicle speed sensor indicates that the vehicle is moving.

To avoid having the lights on during servicing, some systems will turn off the headlights whenever the parking brake is applied. Others will only light the headlights when the vehicle is in a drive gear. See Figure 42–21.

CAUTION: Most factory daytime running lights operate the headlights at reduced intensity. These are *not* designed to be used at night. Normal intensity of the headlights (and operation of the other external lamps) is actuated by turning on the headlights as usual.

DIMMER SWITCHES

The headlight switch controls the power or hot side of the headlight circuit. The current is then sent to the dimmer switch, which allows current to flow to either the high-beam or the low-beam filament of the headlight bulb, as shown in Figure 42–22. An indicator light illuminates on the dash whenever the high beams are selected.

The dimmer switch can be either foot operated on the floor or hand operated on the steering column. The popular steering column switches are actually attached to the *outside* of the steering column on most vehicles and are spring loaded. To replace most of

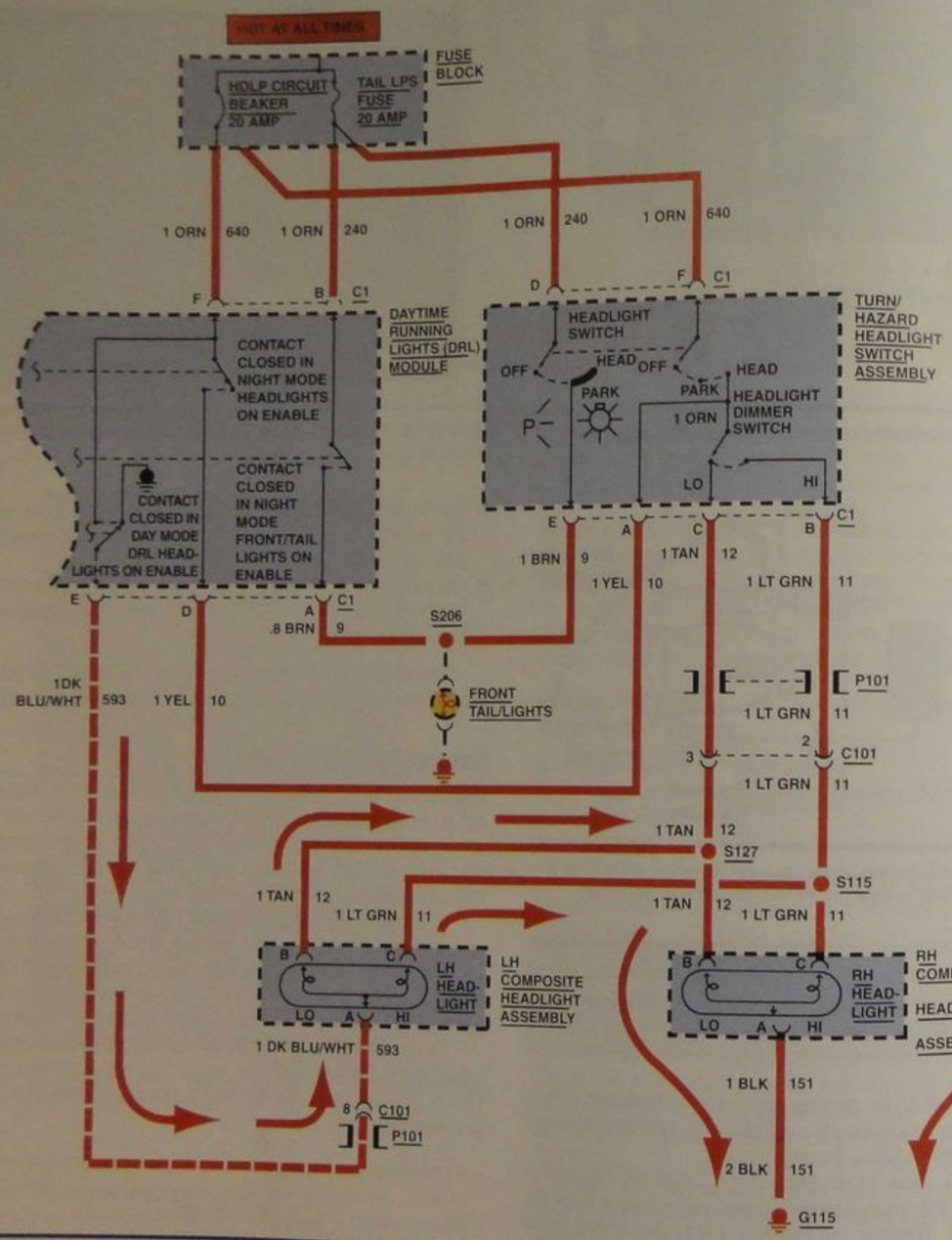


Figure 42–21 Typical daytime running light (DRL) circuit. Follow the arrows from the DRL module through both headlights. Notice that the left and right headlights are connected in series, resulting in increased resistance, less current flow, and dimmer than normal lighting. When the normal headlights are turned on, both headlights receive full battery voltage, with the left headlight grounding through the DRL module.

these types of dimmer switches, the steering column needs to be lowered slightly to gain access to the switch itself, which is also adjustable for proper lever operation.

STOP LAMP AND TURN SIGNALS

When the brakes are applied, the brake switch is closed and the stop lamps light. The brake switch receives current from a fuse that is hot all the time. The turn signal circuit, however, is controlled by a fuse that is ignition switch controlled. See Figure 42–23. When the turn signal switch is moved in either direction, the corresponding turn signal lamps receive current through the flasher unit. The flasher unit causes the current to start and stop as the turn signal lamp flashes on and off with the interrupted current.

In many vehicles, the stop and turn signals are both provided by one filament. When the turn signal switch is closed, the filament receives interrupted current through the flasher unit. When the brakes are applied, the current first flows to the turn signal switch, except for the high-mounted stop, which is fed directly from the brake switch. If neither turn signal is on, then current through the turn signal switch flows to both rear brake lights. If the turn signal switch is operated, current flows through the flasher unit on the side activated and directly to the brake lamp on the opposite side. If the brake pedal is not depressed, then current flows through the flasher and only to one side.

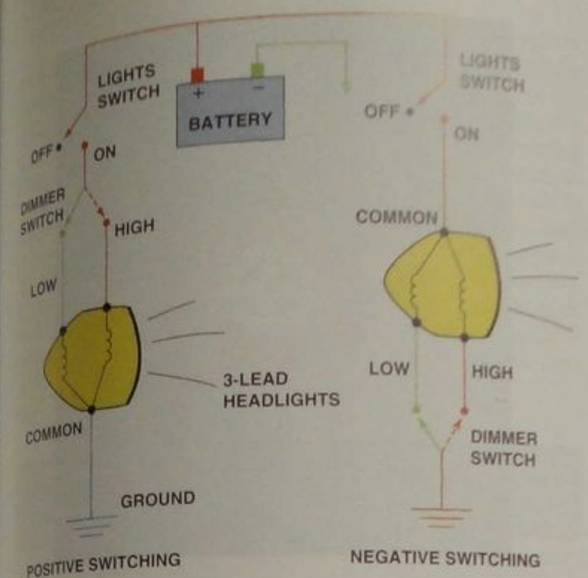


Figure 42–22 Most vehicles use positive switching of the high- and low-beam headlights. Notice that both filaments share the same ground connection. Some vehicles use negative switching and place the dimmer switch between the filaments and the ground.

Figure 42–23 The brake lights are powered directly from the brake switch on a vehicle that uses separate bulbs for brake lights and turn signals.

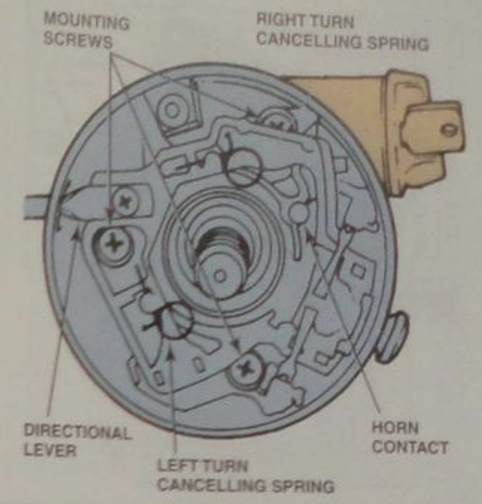


Figure 42–24 The typical turn signal switch includes various springs and cams to control the switch and to cause the switch to cancel after a turn has been completed.

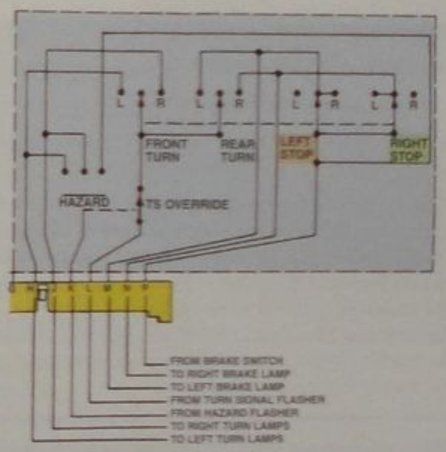


Figure 42–25 When the stop lamps and turn signals share a common bulb filament, stop light current flows through the turn signal switch.

The turn signal switch is mounted within the steering column and operated by a lever. See Figure 42–24. Moving the lever up or down completes the circuit through the flasher unit and to the appropriate turn signal lamp. A turn signal switch includes cams and springs that cancel the signal after the turn has been completed. As the steering wheel is turned in the signaled direction and then returns to its normal position, the cams and springs separate the turn signal switch contacts.

In systems using separate filaments for the stop and turn lamps, the brake and turn signal switches are not connected. If the vehicle uses the same filament for both purposes, then brake switch current is routed through contacts within the turn signal switch. See Figure 42–25. By linking certain contacts, the bulbs can receive either brake switch current or flasher current, depending upon which direction is being signaled.

For example, Figure 42–26 shows current flow through the switch when the brake switch is closed and a right turn is signaled. Steady current through the brake switch is sent to the left brake lamp. Interrupted current from the turn signal is sent to the right turn lamps.

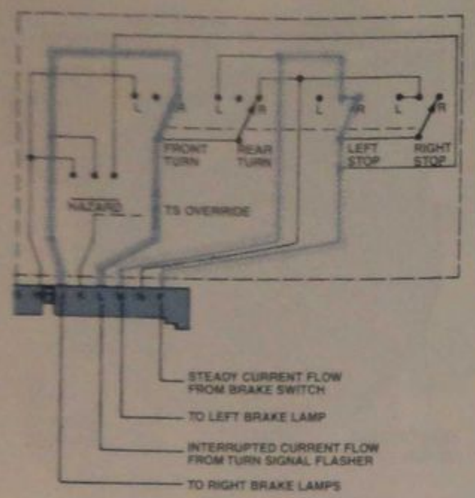


Figure 42–26 When a right turn is signaled, the turn signal switch contacts send flasher current to the right-hand filament and brake switch current to the left-hand filament.

FREQUENTLY ASKED QUESTION ???

Why Are LEDs Used for Brake Lights?

Light-emitting diode (LED) brake lights are frequently used for high-mounted stop lamps (CHMSL) for several reasons including:

1. **Faster illumination.** An LED will light up to 200 milliseconds faster than an incandescent bulb, which requires some time to heat the filament before it is hot enough to create light. This faster illumination can mean the difference in stopping distances at 60 mph (100 km/h) by about 18 feet (6 meters) due to the reduced reaction time for the driver of the vehicle behind.
2. **Longer service life.** LEDs are solid-state devices that do not use a filament to create light. As a result, they are less susceptible to vibration and will often last the life of the vehicle.

NOTE: Aftermarket replacement LED bulbs that are used to replace conventional bulbs may require the use of a different type of flasher unit due to the reduced current draw of the LED bulbs. See Figure 42–27.

NOTE: Some vehicles are equipped with outside mirrors that include an LED arrow that flashes with the turn signal. These LEDs are not serviceable separately, but are serviced with the mirror as an assembly.

FLASHER UNITS

A turn signal flasher unit is a metal or plastic can containing a switch that opens and closes the turn signal circuit. See Figure 42–28. This turn signal flasher unit is usually installed in a metal clip attached to the dash panel to allow the "clicking" noise of the flasher to be heard by the driver. The turn signal flasher is designed to transmit the current to light the front and rear bulbs on only one side at a time. The **U.S. Department of Transportation (DOT)** regulation requires that the driver be alerted when a turn signal bulb is not working. This is achieved by using a series-type flasher unit. The flasher unit requires current flow through two bulbs (one



Figure 42–27 A replacement LED taillight bulb is constructed of many small individual light-emitting diodes.



Figure 42–28 Two styles of two-prong flashers.

in the front and one in the rear) in order to flash. If one bulb burns out, the current flow through only one bulb is not sufficient to make the unit flash; it will be a steady light. These turn signal units are often called DOT flashers. When the turn signal flasher unit is old, the lights will flash more slowly (both sides affected equally). The contact points inside the flasher unit may become corroded and pitted, requiring higher voltage to operate. To restore normal operation, replace the turn signal flasher unit.

Bimetallic Flashers Bimetallic flashers units were the first type used and have generally been replaced with other types that have a longer service life. A bimetallic flasher unit uses strips of two different metals bonded together. Because the two metals expand at different rates, when electrical current flows through the strip, it bends and when current stops, the strip cools and unbends. At the end of the strip is a contact which makes and breaks the electrical turn signal circuit.

If one bulb burns out, either in the front or rear of the vehicle, the flasher will not flash on the side with the bad bulb. Because it requires current to cause the metal strip to bend, not enough current is flowing through one bulb to make the strip bend. As a result, the driver is notified of a burned out bulb on one side and therefore meets the Federal requirement.

Hybrid Flasher (Flasher Relay) A hybrid flasher, also called a **flasher relay,** is a type of flasher unit that contains an electronic timing circuit and a mechanical relay which opens and closes the turn signal circuit. This type of flasher is more expensive than the bimetallic-type flasher but it is longer lasting because the timing and control of the turn signals is performed by two different parts inside one housing. The electronic circuit uses a timer circuit as well as a current sensing circuit. If the current sensing circuit detects a lower than normal current flow through the turn signals, it automatically flashes at a faster rate (twice as fast as normal). This faster flash rate indicates to the driver that a fault has been detected in the turn signal circuit and therefore meets the DOT requirement. If all bulbs are burned out, the flasher will not flash at all.

NOTE: If the turn signals do not operate at all, check the bulbs before replacing the turn signal flasher unit.

Solid State Flashers Solid state flashers use an electronic switching circuit and an electronic timing circuit to operate the turn signals. Because these units do not use a mechanical switch or contacts to open and close the turn signal circuit, these flashers last a long time, but cost more than bimetallic or hybrid units. Similar to hybrid flashers, solid state flashers use a current sensing circuit and will flash rapidly if a bulb is burned out.

Hazard Warning Flasher The **hazard warning** flasher is a device installed in a vehicle lighting system with the primary function of causing the left and right turn signal lamps to flash when the hazard warning switch is activated. Secondary functions may include visible pilot indicators for the hazard system and an audible signal to indicate when the flasher is operating. A typical hazard warning flasher is also called a *parallel* or *variable-load* flasher because there is a resistor in parallel with the contacts to provide a control load, and therefore, a constant flash rate, regardless of the number of bulbs being flashed. See Figure 42–29.

Combination Turn Signal and Hazard Warning Flasher The combination flasher is a device that combines the functions of a turn signal flasher and a hazard warning flasher into one package.

Electronic Flasher Replacement Units Older vehicles (and a few newer ones) use thermal (bimetal) flashers that use heat to switch on and off. Newer vehicles use electronic flashers that use microchips to control the on/off function. Electronic flashers are compatible with older systems, but thermal flashers are not compatible with new systems. Eventually a thermal flasher will burn out (it may be 100,000 miles or more), and will be replaced. Electronic flashers do not burn out, and they provide a crisper and faster "flash" of the turn signals. Another reason to use electronic flashers might be if upgrading to LED taillamps, or lights. These newer LED bulbs only work with electronic flashers.

The easiest way to know which type of flasher can be used is to look at the type of bulb used in the taillamps and turn signals. If it is a "wedge" style (plastic base, flat and rectangular), the vehicle has an electronic flasher. If it is a "twist and turn" bayonet-style bulb, then either type of flasher can be used.



Figure 42–29 A hazard flasher uses a parallel resistor across the contacts to provide a constant flashing rate regardless of the number of bulbs used in the circuit.

FREQUENTLY ASKED QUESTION ???

What Are Puddle Lights?

Puddle lights are lights on the bottom of the outside rear-view mirror that shine downward when the door is opened. They are called puddle lights because they light the area where the driver and passenger are going to step, thereby illuminating any hazards such as water puddles.

LIGHTING SYMPTOM GUIDE

Other common turn signal problems and possible solutions include the following:

Problem	Possible Causes and/or Solutions
1. Slow flashing on both sides equally	1. Replace the worn flasher unit. Check the battery and the charging voltage to be certain that the charging circuit and battery are supplying high-enough voltage for proper operation of the turn signals.
2. Slow or no flashing on one side only	2. Replace the defective bulb, or clean poor connections on the front or rear bulbs on the side that does not work.
3. Turn signals not flashing on either side	3. The most likely cause is a defective flasher unit, in which case replacement will be necessary. However, defective bulbs or connections on *both* sides could also be the cause.

Most turn signal flasher units are mounted in a metal clip that is attached to the dash. The dash panel acts as a sounding board, increasing the sound of the flasher unit. Most four-way hazard flasher units are plugged into the fuse panel. Some two-way turn signal flasher units are also plugged into the fuse panel. How do you know for sure where the flasher unit is located? With both the turn signal and the ignition on, listen and/or feel for the clicking of the flasher unit. Some service manuals also give general locations for the placement of flasher units.

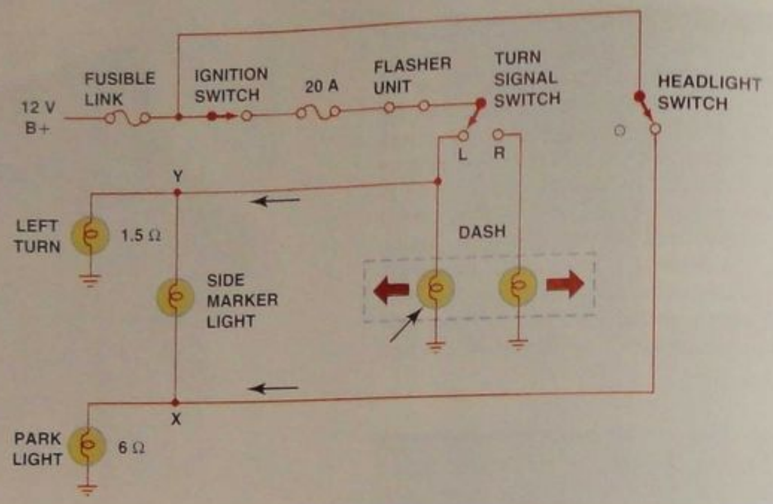


Figure 42–30 The side-marker light goes out whenever there is voltage at both point *X* and *Y*. These opposing voltages stop current flow through the side-market light. The left turn light and left park light are actually the same bulb (usually a #2057) and are shown separately to help explain how the side-marker light works on many vehicles.

FREQUENTLY ASKED QUESTION ???

Why Does the Side-Marker Light Alternately Flash?

A question that service technicians are asked frequently is why the side-marker light alternately goes out when the turn signal is on and is on when the turn signal is off. Some vehicle owners think that there is a fault with their vehicle while actually it is normal operation. The side-marker light goes out whenever the lights are on and the turn signal is flashing because there are 12 volts on both sides of the bulb (see points *X* and *Y* in Figure 42–30). Normally, the side-marker light gets its ground through the turn signal bulb.

COURTESY LIGHTS

Courtesy light is a generic term primarily used for interior lights, including overhead (dome) and under-the-dash (courtesy) lights. These interior lights can be operated by rotating the headlight switch knob fully counterclockwise (left) or by operating switches located in the doorjambs of the vehicle doors. There are two types of circuits commonly used for these interior lights. Most manufacturers, except Ford, use the door switches to ground the courtesy light circuit. See Figure 42–31. Many Ford vehicles use the door switches to open and close the power side of the circuit.

Many newer vehicles operate the interior lights through the vehicle computer or through an electronic module. Because the exact wiring and operation of these units differ, consult the service literature for the exact model on which you are working.

TECH TIP ✔ **Service Information Diagnosis**

The switches in the doorjamb simply signal the computer that a door has been opened. The computer controls the lighting to help prevent accidental battery drain. For example, if the vehicle door has been left open, the computer can open the circuit and prevent a dead battery.

The schematic rarely shows exactly how the circuit works. However, the service information walks you through the diagnosis. With a service manual, or computerized information service, the technician is never lost. Always follow the procedures exactly! Even if the service procedure sounds long and involved, the procedure will lead you to the correct diagnosis.

ILLUMINATED ENTRY

Some vehicles are equipped with illuminated entry, the interior lights are turned on for a given amount of time whenever the outside door handle is operated while the doors are locked. Most vehicles equipped with illuminated entry also light the exterior door keyhole. Some vehicles equipped with body computers use the door handle electrical switch of the illuminated entry circuit to "wake up" the power supply for the body computer.

FIBER OPTICS

Fiber optics is the transmission of light through special plastic (polymethyl methacrylate) that keeps the light rays parallel even if the plastic is tied in a knot. These strands of plastic are commonly used in automotive applications as indicators for the driver that certain lights are functioning. For example, some vehicles are equipped with fender-mounted units that light whenever the lights or turn signals are operating. Plastic fiber-optic strands, which often look like standard electrical wire, transmit the light at the bulb to the indicator on top of the fender so that the driver can determine if a certain light is operating. Fiber-optic strands also can be run like wires to indicate the operation of all lights on the dash or console. Fiber-optic strands are also commonly used to light ashtrays, outside door locks, and other areas where a small amount of light is required. The source of the light can be any normally operating light bulb, which means that one bulb can be used to illuminate many areas. A special bulb clip is usually used to retain the fiber-optic plastic tube near the bulb.



Figure 42–31 A typical courtesy light doorjamb switch. Newer vehicles use the door switch as an input to the vehicle computer and the computer turns on or off the interior lights. By placing the lights under the control of the computer, the vehicle engineers have the opportunity to delay the lights after the door is closed and to shut them off after a period of time to avoid draining the battery.

FEEDBACK

When current that lacks a good ground goes backward along the power side of the circuit in search of a return path (ground) to the battery, this reverse flow is called **feedback** or *reverse-bias* current flow. Feedback can cause other lights or gauges that should not be working, to work.

Feedback Example A customer complained that when the headlights were on, the left turn signal indicator light on the dash remained on. The cause was found to be a poor ground connection for the left front parking light socket. The front parking light bulb is a dual filament: one filament for the parking light (dim) and one filament for the turn signal operation (bright). A corroded socket did not provide a good enough ground to conduct all current required to light the dim filament of the bulb.

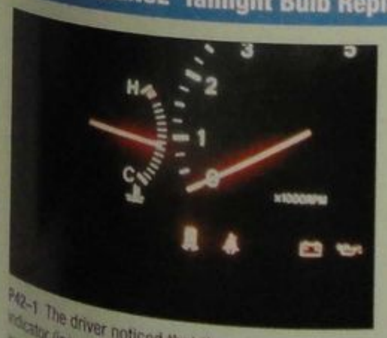
The two filaments of the bulb share the same ground connection and are electrically connected. When all the current could not flow through the bulb's ground in the socket, it caused a feedback or reversed its flow through the other filament, looking for ground. The turn signal filament is electrically connected to the dash indicator light; therefore, the reversed current on its path toward ground could light the turn signal indicator light. Cleaning or replacing the socket usually solves the problem if the ground wire for the socket is making a secure chassis ground connection.

LIGHTING SYSTEM SYMPTOM GUIDE

The following list will assist technicians in troubleshooting *lighting systems.*

Problem	Possible Causes and/or Solutions
1. One headlight dim	1. Check for poor ground connection on body.
2. One headlight out (low or high beam)	2. Possible burned-out headlight filament. Check the headlight with an ohmmeter. There should be a low-ohm reading between the power-side connection and the ground terminal of the bulb.
3. Both high- and low-beam headlights out	3. Check for burned-out bulbs. Check for voltage at the wiring connector to the headlights (possible open circuit to the headlights or open [defective] dimmer switch).
4. All headlights inoperative	4. Possible burned-out filaments in all headlights. Check for excessive charging system voltage. Possible defective dimmer switch. Possible defective headlight switch.
5. Slow turn signal operation	5. Possible defective flasher unit. Possible high resistance in sockets or ground wire connections. Possible incorrect bulb numbers.
6. Turn signals operating on one side only	6. Possible burned-out bulb on affected side. Possible poor ground connection or defective socket on affected side. Possible incorrect bulb number on affected side.
7. Interior light(s) inoperative	7. Possible burned-out bulb(s). Possible open in the power-side circuit (blown fuse). Possible open in doorjamb switch(es).
8. Interior lights on all the time	8. Possible shorted doorjamb switch. Possible headlight switch turned fully counterclockwise.
9. Brake lights inoperative	9. Possible defective brake switch. Possible defective turn signal switch. Possible burned-out brake light bulbs. Possible open circuit or poor ground connection.
10. Hazard warning lights inoperative	10. Possible defective hazard flasher unit. Possible open in hazard circuit.
11. Hazard warning lights blinking too rapidly	11. Possible incorrect flasher unit. Possible shorted wiring to front or rear lights. Possible incorrect bulb numbers.

PHOTO SEQUENCE Taillight Bulb Replacement Step-by-Step



P42–1 The driver noticed that the taillight fault indicator (icon) on the dash was on any time the lights were on.



P42–2 A visual inspection at the rear of the vehicle indicated that the right rear taillight bulb did not light. Removing a few screws from the plastic cover revealed the taillight assembly.



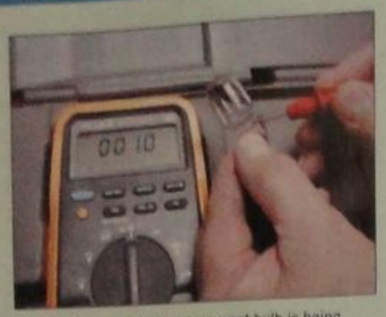
P42–3 The bulb socket is removed from the taillight assembly by gently twisting the base of the bulb counterclockwise.

(continued)

PHOTO SEQUENCE Taillight Bulb Replacement Step-by-Step—continued



P42–4 The bulb is removed from the socket by gently grasping the bulb and pulling the bulb straight out of the socket. Many bulbs required that you rotate the bulb 90° (1/4 turn) to release the retaining bulbs.



P42–5 The new 7443 replacement bulb is being checked with an ohmmeter to be sure that it is okay before it is installed in the vehicle.



P42–6 The replacement bulb in inserted into the taillight socket and the lights are turned on to verify proper operation before putting the components back together.

Optical Headlight Aiming



P42–1 Before checking the vehicle for headlight aim, be sure that all the tires are at the correct inflation pressure, and that the suspension is in good working condition.



P42–2 The headlight aim equipment will have to be adjusted for the slope of the floor in the service bay. Start the process by turning on the laser light generator on the side of the aimer body.



P42–3 Place a yardstick or measuring tape vertically in front of the center of the front wheel, noting the height of the laser beam.



P42–4 Move the yardstick to the center of the rear wheel and measure the height of the laser beam at this point. The height at the front and rear wheels should be the same.



P42–5 If the laser beam height measurements are not the same, the floor slope of the aiming equipment must be adjusted. Turn the floor slope knob until the measurements are equal.



P42–6 Place the aimer in front of the headlight to be checked, at a distance of 10 to 14 inches (25 to 35 cm). Use the aiming pointer to adjust the height of the aimer to the middle of the headlight.



P42–7 Align the aimer horizontally, using the pointer to place the aimer at the center of the headlight.



P42–8 Lateral alignment (aligning the body of the aimer with the body of the vehicle) is done by looking through the upper visor. The line in the upper visor is aligned with symmetrical points on the vehicle body.



P42–9 Turn on the vehicle headlights, being sure to select the correct beam position for the headlight to be aimed.

PHOTO SEQUENCE Optical Headlight Aiming—continued



P42–10 View the light beam through the aimer window. The position of the light pattern will be different for high and low beams.



P42–11 If the first headlight is aimed adequately, move the aimer to the headlight on the opposite side of the vehicle. Follow the previous steps to position the aimer accurately.



P42–12 If adjustment is required, move the headlight adjusting screws using a special tool or a 1/4-in. drive ratchet/socket combination. Watch the light beam through the aimer window to verify the adjustment.

SUMMARY

1. Automotive bulbs are identified by trade numbers.
2. The trade number is the same regardless of manufacturer for the exact same bulb specification.
3. Daytime running lights (DRLs) light the headlights, usually at reduced intensity, whenever the engine is running or the vehicle is moving.
4. High intensity discharge (HID) headlights are brighter and have a blue tint.
5. One defective turn signal bulb causes the turn signal on the affected side to stop blinking (flashing).

REVIEW QUESTIONS

1. Explain why the exact same trade number of bulb should be used as a replacement.
2. Explain why you should not touch a halogen bulb with your fingers.
3. Describe how to diagnose a turn signal operating problem.
4. Discuss how to aim headlights on a vehicle equipped with aerodynamic-style headlights.

CHAPTER QUIZ

1. Technician A says that the bulb trade number is the same for all bulbs of the same size. Technician B says that a dual-filament bulb has different candlepower ratings for each filament. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Two technicians are discussing flasher units. Technician A says that only a DOT-approved flasher unit should be used for turn signals. Technician B says that a parallel (variable-load) flasher will function for turn signal usage, although it will not warn the driver if a bulb burns out. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Interior overhead lights (dome lights) are operated by doorjamb switches that _____.
   a. Complete the power side of the circuit
   b. Complete the ground side of the circuit
   c. Move the bulb(s) into contact with the power and ground
   d. Either a or b depending on application
4. Electrical feedback is usually a result of _____.
   a. Too high a voltage in a circuit
   b. Too much current (in amperes) in a circuit
   c. Lack of a proper ground
   d. Both a and b
5. Which bulb is brightest? (see the bulb table)
   a. #194
   b. #168
   c. #194NA
   d. #1157
6. If a #1157 bulb were to be installed in a left front parking light socket instead of a #2057 bulb, what would be the most likely result?
   a. The left turn signal would flash faster
   b. The left turn signal would flash slower
   c. The left parking light would be slightly brighter
   d. The left parking light would be slightly dimmer
7. A technician replaced a #1157NA with a #1157A bulb. Which is the most likely result?
   a. The bulb is brighter because the #1157A candlepower is higher
   b. The amber color of the bulb is a different shade
   c. The bulb is dimmer because the #1157A candlepower is lower
   d. Both b and c
8. A customer complained that every time he turned on his vehicle's lights, the left-side turn signal indicator light on the dash remained on. The most likely cause is _____.
   a. A poor ground to the parking light (or taillight) bulb on the *left* side
   b. A poor ground to the parking light (or taillight) bulb on the *right* side, causing current to flow to the left-side lights
   c. A defective (open) parking light (or taillight) bulb on the left side
   d. Both a and c
9. A defective taillight or front park light bulb could cause _____.
   a. The turn signal indicator on the dash to light when the lights are turned on
   b. The dash lights to come on when the brake lights are on
   c. The lights-on warning chime to sound if the brake pedal is depressed
   d. All of the above
10. A defective brake switch could prevent proper operation of the _____.
    a. Cruise control
    b. ABS brakes
    c. Shift interlock
    d. All of the above

CHAPTER 43

Driver Information and Navigation Systems

OBJECTIVES: After studying Chapter 43, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "F" (Gauges, Warning Devices, and Driver Information System Diagnosis and Repair). • Be able to identify the meaning of dash warning symbols. • Discuss how a fuel gauge works. • Explain how to use a service manual to troubleshoot a malfunctioning dash instrument. • Describe how a navigation system works. • List the various types of dash instrument displays.

KEY TERMS: analog • backup camera • bulb test • cathode fluorescent lighting (CFL) • cathode ray tube (CRT) • combination valve • electromagnetic • electronically erasable programmable read-only memory (EEPROM) • global positioning system (GPS) • head-up display (HUD) • instrument panel (IP) • lane departure warning system (LDWS) • light-emitting diode (LED) • liquid crystal display (LCD) • nonvolatile random-access memory (NVRAM) • permanent-magnet (PM) generator • phosphor • pressure differential switch • rear park assist (RPA) • stepper motor • telltale lamp • thermoelectric • vacuum tube fluorescent (VTF) • WOW display

DASH WARNING SYMBOLS

All vehicles are equipped with warning lights that are often confusing to drivers. Because many vehicles are sold throughout the world, symbols instead of words are being used as warning lights. See Figure 43–1 for examples and meanings of most symbols. Always check service information for the exact meaning on the vehicle being serviced.

ANALOG DASH INSTRUMENTS

Electromagnetic dash instruments use small electromagnetic coils that are connected to a sending unit for such things as fuel level, water temperature, and oil pressure. The resistance of the sensor varies with what is being measured. See Figure 43–2 for typical electromagnetic fuel gauge operation.

COMPUTER-CONTROLLED INSTRUMENT PANELS

Many instrument panels are operated by electronic control units that communicate with the engine control computer for engine data such as revolutions per minute (RPM) and engine temperature. These electronic instrument panels (IPs) use the voltage change from varying-resistance sensors, such as that of the fuel gauge, to determine fuel level. Therefore, even though the sensor in the fuel tank is the same, the display itself may be computer controlled. Because all sensor inputs are interconnected, the technician should always follow the factory-recommended diagnostic procedures. See Figure 43–3.

STEPPER MOTOR GAUGES

Most analog dash displays use a stepper motor to move the needle. A **stepper motor** is a type of electric motor that is designed to rotate in small steps based on the signal from a computer. This type of gauge is very accurate.

NOTE: Some Chrysler electronic gauge clusters can be checked by depressing the trip reset button and then turning the ignition switch to the on (key on, engine off) position. The dash display needles will be commanded to 1/4, 1/2, 3/4, and full positions before returning to their normal readings. This test allows the service technician to check the operation of each individual gauge, even though replacing the entire instrument panel cluster is usually necessary to repair an inoperative gauge.

TECH TIP ✔ **Find Service Information and Use It**

Today's electronic circuits are often too complex to show on a wiring diagram. Instead, all electronics are simply indicated as a solid box with "electronic module" printed on the diagram. Even if all electronic circuitry was shown on the wiring diagram, it would require the skill of an electronics engineer to determine exactly how the circuit was designed to work. Study Figure 43–4.

Note that the grounding for the "check oil" dash indicator lamp is accomplished through an electronic buffer. The exact conditions, such as amount of time since the ignition was shut off, are unknown to the technician. To correctly diagnose problems with this type of circuit, technicians must read, understand, and follow the written diagnostic procedures specified by the vehicle manufacturer.

HEAD-UP DISPLAY

The **head-up display (HUD)** is a supplemental display that projects the vehicle speed and sometimes other data, such as turn signal information, onto the windshield. The projected image looks as if it is some distance ahead, making it easy for the driver to see without having to refocus on a closer dash display. See Figures 43–5 and 43–6.

The head-up display can also have the brightness controlled on most vehicles that use this type of display. The HUD unit is installed in the instrument panel (IP) and uses a mirror to project vehicle information onto the inside surface of the windshield. See Figure 43–7.

Follow the vehicle manufacturer's recommended diagnostic and testing procedures if any faults are found with the head-up display.

NIGHT VISION

Parts and Operation Night vision systems use a camera that is capable of observing objects in the dark to assist the driver while driving at night. The primary night viewing illumination devices are the headlights. The night vision option uses a head-up display (HUD) to improve the vision of the driver beyond the scope of the headlights. Using a HUD display allows drivers to keep their eyes on the road and hands on the wheel for maximum safety.

Besides the head-up display, the night vision camera uses a special thermal imaging or infrared technology. The camera is mounted behind the grill in the front of the vehicle. See Figure 43–8.

SYMBOLS	DESCRIPTION
OR HOT	ENGINE COOLANT TEMPERATURE TOO HIGH
OR OIL	ENGINE OIL PRESSURE TOO LOW
	CHARGING SYSTEM FAULT DETECTED
OR OR	LOW TIRE PRESSURE DETECTED
OR	WINDSHIELD WASHER FLUID LOW
OR CHECK OR SERVICE ENGINE SOON	MALFUNCTION INDICATOR LIGHT (MIL) ALSO CALLED A CHECK ENGINE LIGHT. LIGHT MEANS THE ENGINE CONTROL COMPUTER HAS DETECTED A FAULT
OR LOW FUEL	LOW FUEL LEVEL
OR DOOR OPEN	DOOR OPEN OR AJAR
OR BRAKE	FAULT DETECTED IN BASE BRAKE SYSTEM
ABS OR ABS OR ABS	FAULT DETECTED IN ANTILOCK BRAKE SYSTEM
	FASTEN SAFETY BELT WARNING LIGHT
	FAULT DETECTED IN THE SUPPLEMENTAL RESTRAINT SYSTEM
	BRAKE LIGHT BULB FAILURE DETECTED
	EXTERIOR LIGHT BULB FAILURE DETECTED
	WORN BRAKE PADS OR LININGS DETECTED

Figure 43–1 Typical dash warning symbols and their meanings.

(continued)

SYMBOLS	DESCRIPTION
 OR TRAC	LOW TRACTION DETECTED TRACTION CONTROL SYSTEM IS FUNCTIONING TO RESTORE TRACTION (USUALLY FLASHES WHEN ACTIVELY WORKING TO RESTORE TRACTION)
	WATER DETECTED IN FUEL. NOTICE TO DRAIN THE WATER FROM THE FUEL FILTER ASSEMBLY ON A VEHICLE EQUIPPED WITH A DIESEL ENGINE
	HEADLIGHTS ON
MAINT REQD	MAINTENANCE REQUIRED. THIS USUALLY MEANS THAT THE ENGINE OIL IS SCHEDULED TO BE CHANGED OR OTHER ROUTINE SERVICE ITEMS REPLACED OR CHECKED
VSC	VEHICLE STABILITY CONTROL SYSTEM EITHER OFF OR WORKING IF FLASHING
TRAC OFF	TRACTION CONTROL SYSTEM HAS BEEN TURNED OFF
CRUISE	INDICATES THAT THE CRUISE CONTROL IS ON AND ABLE TO MAINTAIN VEHICLE SPEED IF SET

Figure 43–1 continued.

The camera creates pictures based on the heat energy emitted by objects rather than from light reflected on an object as in a normal optical camera. The image looks like a black-and-white photo negative when hot objects (higher thermal energy) appear while cool objects appear dark or black. Other parts of the night vision system include:

- **On/Off and Dimming Switch**—This allows the driver to adjust the brightness of the display and to turn it on or off as needed.
- **Up/Down Switch**—The night vision HUD system has an electric tilt adjust motor that allows the driver to adjust the image up or down on the windshield within a certain image.

CAUTION: Becoming accustomed to night vision can be difficult and may take several nights to get used to looking at the head-up display.

Diagnosis and Service The first step when diagnosing a fault with the night vision system is to verify the concern. Check the owner's manual or service information for the proper operation. For example, the Cadillac night vision system requires the following actions to function:

1. The ignition has to be in the on (run) position.
2. The Twilight Sentinel photo cell must indicate that it is dark.
3. The headlights must be on.
4. The switch for the night vision system must be on and the brightness adjusted so the image is properly displayed.

The night vision system uses a camera in the front of the vehicle that is protected from road debris by a grille. However, small stones or other debris can get past the grille and damage the lens of the camera. If the camera is damaged, it must be replaced as an assembly because no separate parts are available. Always follow the vehicle manufacturer's recommended testing and servicing procedures.

DASH INSTRUMENT DIAGNOSIS

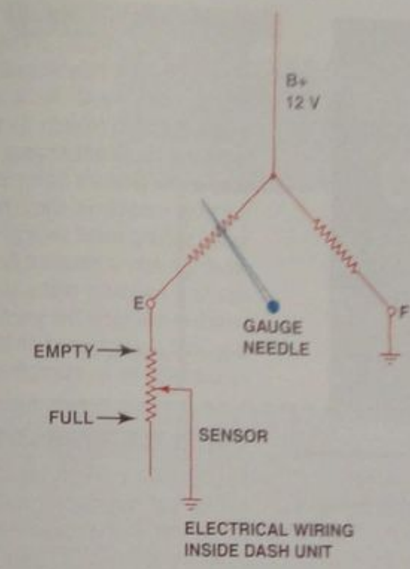
With electromagnetic gauges, if the resistance of the sensor is low, the meter reads low. If the resistance of the sensor is high, the meter reads high.

NOTE: Thermoelectric gauges are opposite from electromagnetic gauges and read low when resistance is high. The following procedures are given for electromagnetic gauges and should be reversed for working on thermoelectric gauges.

When a technician is troubleshooting a fuel gauge, if the power wire is unplugged from the tank unit with the ignition on, the dash unit should move toward full (high resistance). If the power lead is touched to a ground (low resistance), the fuel gauge should register empty. The same operation can be used with oil pressure and water temperature gauges.

TELLTALE LAMPS

Telltale lamps (often called *idiot lights*) warn the driver of system failure. Whenever the ignition is turned on, all warning lamps come on as a bulb check.



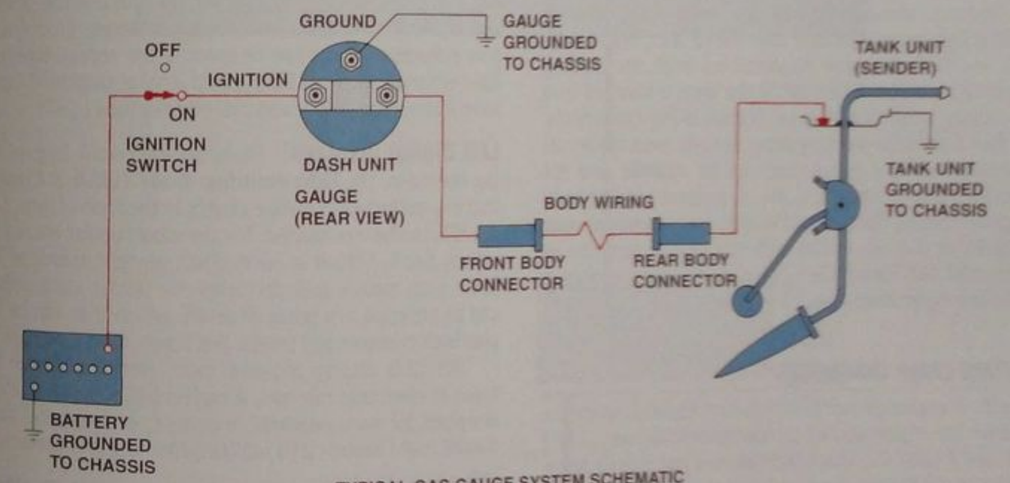


Figure 43–2 Electromagnetic fuel gauge wiring. If the sensor wire is unplugged and grounded, the needle should point to "E" (empty). If the sensor wire is unplugged and held away from ground, the needle should point to "F" (full).

The charging system-warning lamp may be labeled "CHARGE," "GEN," or "ALT" and will light if the charging system fault is detected. See Figure 43–9.

OIL PRESSURE WARNING DEVICES

The oil pressure lamp operates through use of an oil pressure sensor unit, which is screwed into the engine block and which grounds the electrical circuit and lights the dash warning lamp in the event of low oil pressure (3 to 7 PSI [20 to 50 kilopascals, kPa]). See Figure 43–10. Normal oil pressure is generally between 10 and 60 PSI (70 and 400 kPa). See Figure 43–11 on page 484.

TECH TIP ✔ **Oops!**

After replacing valve cover gaskets on a Chevrolet V-8, the technician discovered that the oil pressure-warning lamp was on. After checking the oil level and finding everything else okay, the technician discovered a wire pinched under the valve cover.

The wire went to the oil pressure sending unit. The edge of the valve cover had cut through the insulation and caused the current from the oil lamp to go to ground through the engine. Normally the oil lamp comes on when the sending unit grounds the wire from the lamp.

The technician freed the pinched wire and covered the cut with silicone sealant to prevent corrosion damage.



Figure 43–3 Many vehicles use a computer display for many functions including trip computers, radio, clock, and air conditioning. This vehicle is not moving and yet the engine is running, so the fuel economy is zero.

Oil Pressure Lamp Diagnosis To test the operation of the oil pressure-warning circuit, unplug the wire from the oil pressure-sending unit, usually located near the oil filter, with the ignition switch on. With the wire disconnected from the sending unit, the warning lamp should be off. If the wire is touched to a ground, the warning lamp should be on. If there is *any* doubt of the operation of the oil pressure-warning lamp, always check the actual engine oil pressure using a gauge that can be screwed into the opening that is left after unscrewing the oil pressure-sending unit. For removing the sending unit, special sockets are available at most auto parts stores, or a 1- or 1 1/16-inch six-point socket may be used for most units. See Figure 43–12 on page 483 for the location of typical oil pressure-sending units.

TEMPERATURE LAMP DIAGNOSIS

The "hot" lamp, or engine coolant overheat warning lamp, warns the driver whenever the engine coolant temperature is between 248°F (120°C) and 258°F (126°C). This temperature is just slightly below the boiling point of the coolant in a properly operating cooling system. The temperature sensor on older models was separate from the sensor used by the engine computer. However, most vehicles now use the engine coolant temperature (ECT) sensor for engine temperature gauge operation. To test this sensor, use a scan tool to verify proper engine temperature and follow the vehicle manufacturer's recommended testing procedures. See Figure 43–13 on page 483.

BRAKE WARNING LAMP

All vehicles sold in the United States after 1967 must be equipped with a dual braking system and a dash-mounted warning lamp to signal the driver of a failure in one part of the hydraulic brake system. See Figure 43–14 on page 483.

The switch that operates the warning lamp is called a **pressure differential switch.** This switch is usually the center portion of a multiple-purpose brake part called a **combination valve.** If there is unequal hydraulic pressure in the braking system, the switch usually grounds the 12-volt lead at the switch and the lamp comes on. See Figure 43–15 on page 483.

Unfortunately, the dash warning lamp is often the same lamp as that used to warn the driver that the parking brake is on. The warning lamp is usually operated by using the parking brake lever or brake hydraulic pressure switch to complete the ground for the warning lamp circuit. If the warning lamp is on, first check if the parking brake is fully released. If the parking brake is fully released, the problem could be a defective parking brake switch or a hydraulic brake problem. To test for which system is causing the lamp to remain on, simply unplug the wire from the valve or switch. If the wire on the pressure differential switch is disconnected and the warning lamp remains on, then the problem is due to a defective or misadjusted parking brake switch. If, however, the warning lamp goes out when the wire is removed from the brake switch, then the problem is due to a hydraulic brake fault that caused the pressure differential switch to complete the warning lamp circuit. The red brake warning lamp also can be turned on if the brake fluid is low. See Figure 43–16 on page 483 for an example of a brake fluid level sensor.

DIGITAL ELECTRONIC DASH OPERATION

Mechanical or electromechanical dash instruments use cables, mechanical transducers, and sensors to operate a particular dash instrument. Digital dash instruments use various electric and electronic sensors that activate segments or sections of an electronic display. Most electronic dash clusters use a computer chip and various electronic circuits to operate and control the internal power supply, sensor voltages, and display voltages. Electronic dash display systems may use one or more of the several types of displays: light-emitting diode (LED), liquid crystal display (LCD), vacuum tube fluorescent (VTF), and cathode ray tube (CRT).

LED Digital Displays All diodes emit some form of energy during operation; the **light-emitting diode (LED)** is a semiconductor that is constructed to release energy in the form of light. Many colors of LEDs can be constructed, but the most popular are red, green, and yellow. Red is difficult to see in direct sunlight; therefore, if an LED is used, most vehicle manufacturers use yellow. Light-emitting diodes can be arranged in a group of seven, which then can be used to display both numbers and letters. See Figure 43–17 on page 484.

An LED display requires more electrical power than other types of electronic displays. A typical LED display requires 30 milliamperes for each *segment;* therefore, each number or letter displayed could require 210 milliamperes (0.210 amperes).

Liquid Crystal Displays **Liquid crystal displays (LCDs)** can be arranged into a variety of forms, letters, numbers, and bar graph displays. LCD construction consists of a special fluid sandwiched between two sheets of polarized glass. The special fluid between the glass plates will permit light to pass if a small voltage is applied to the fluid through a conductive film laminated to the glass plates.

The light from a very bright halogen bulb behind the LCD shines through those segments of the LCD that have been polarized to let the light through, which then show numbers or letters. Color filters can be placed in front of the display to change the color of certain segments of the display, such as the maximum engine speed on a digital tachometer. LCDs are used on newer model Chevrolet Corvettes and several other makes and models.

CAUTION: Be careful, when cleaning an LCD, not to push on the glass plate covering the special fluid. If excessive pressure is exerted on the glass, the display may be permanently distorted. If the glass breaks, the fluid will escape and could damage other components in the vehicle as a result of its strong alkaline nature. Use only a soft, damp cloth to clean these displays.

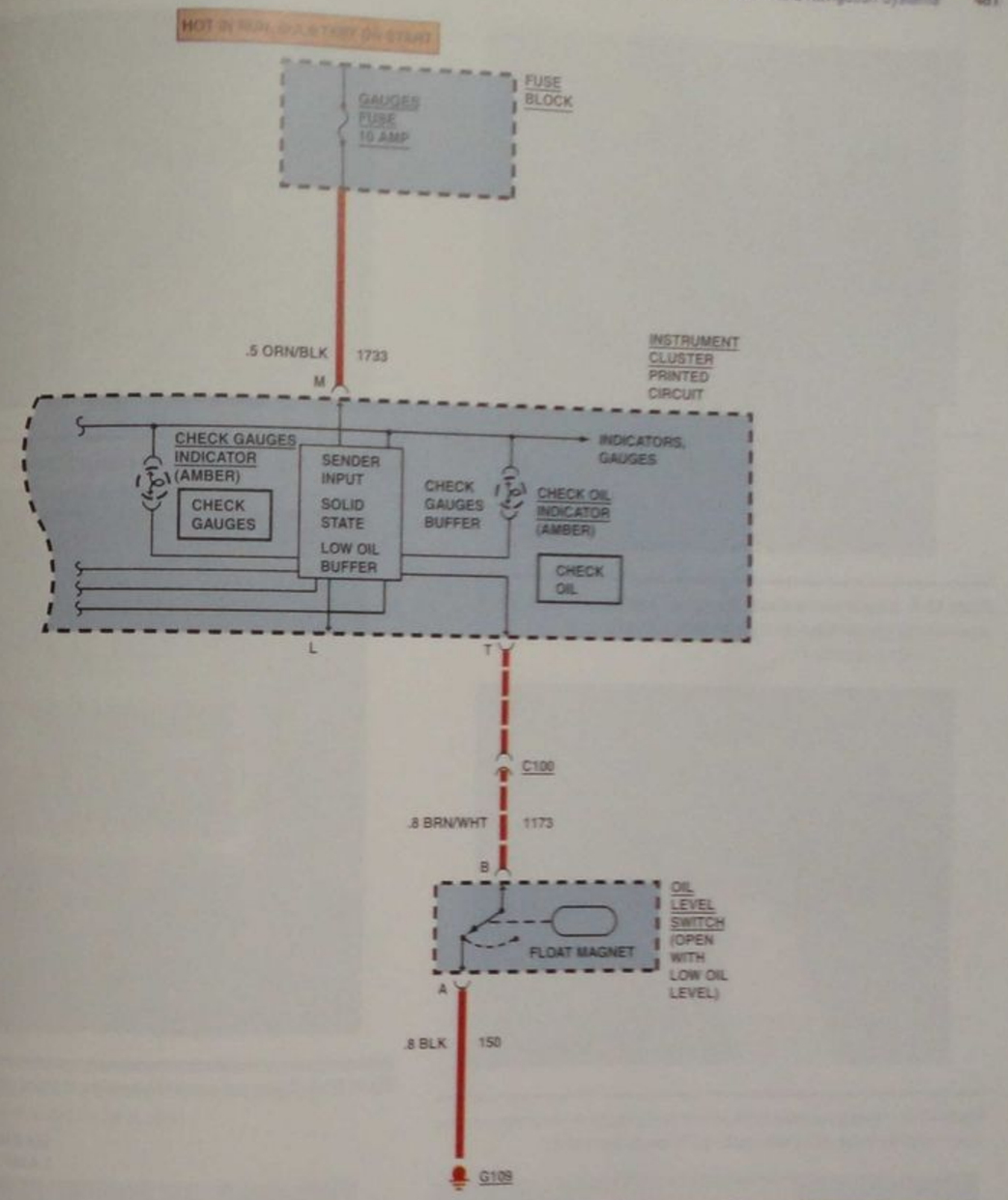


Figure 43–4 The ground for the "check oil" indicator lamp is controlled by the electronic low-oil buffer. Even though this buffer is connected to an oil level sensor, the buffer also takes into consideration the amount of time the engine has been stopped and the temperature of the engine. The only way to properly diagnose a problem with this circuit is to use the procedures specified by the vehicle manufacturer. Besides, only the engineer that designed the circuit knows for sure how it is supposed to work.

The major disadvantage of an LCD digital dash is that the numbers or letters are slow to react or change at low temperatures.

Vacuum Tube Fluorescent Displays The **vacuum tube fluorescent (VTF)** display is a popular automotive and household appliance display because it is very bright and can easily be viewed in strong sunlight. The usual VTF display is green, but white is often used for home appliances. The VTF display generates its bright light in a manner similar to that of a TV screen, where a chemical-coated light-emitting element called a **phosphor** is hit with high-speed electrons. VTF displays are very bright and must be dimmed by use of dense filters or by controlling the voltage applied to the display. A typical VTF dash is dimmed to 75% brightness whenever the parking lights or headlights are turned on. Some displays use a photocell to monitor and adjust the intensity of the display during daylight viewing. Most VTF displays are green for best viewing under most lighting conditions.

Cathode Ray Tube A **cathode ray tube (CRT)** dash display, which is similar to a television tube or LCD display, permits the display of hundreds of controls and diagnostic messages in one convenient location. See Figure 43–18 on page 484.

Using the touch-sensitive cathode ray tube, the driver or technician can select from many different displays, including those of radio,



Figure 43–5 A typical head-up display showing zero miles per hour, which is actually projected on the windshield from the head-up display in the dash.



Figure 43–6 The dash-mounted control for the head-up display on this Cadillac allows the driver to move the image up and down on the windshield for best viewing.

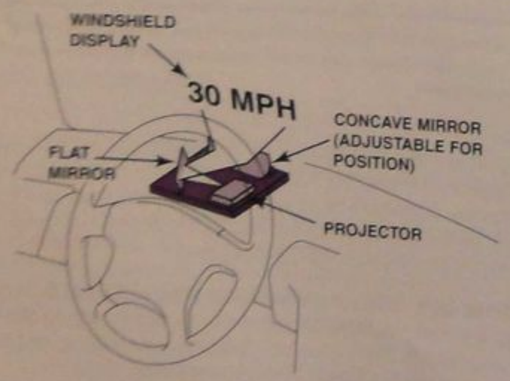


Figure 43–7 A typical head-up display (HUD) unit.



Figure 43–8 A night vision camera in the front of a Cadillac.

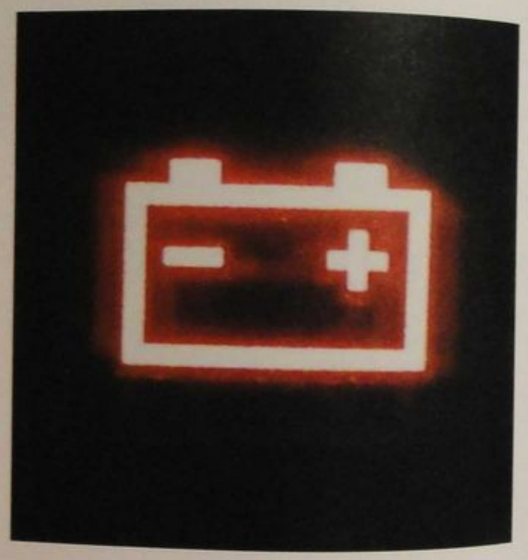


Figure 43–9 This symbol is used to represent a charging circuit problem.

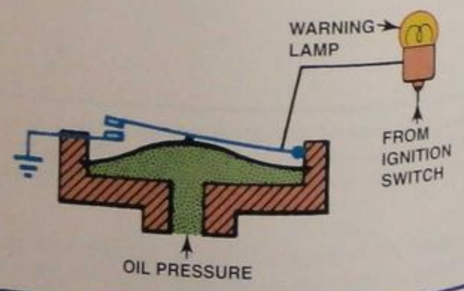


Figure 43–10 This oil pressure grounding switch (sending unit) has a fixed contact connected to ground and a contact that is moved by the pressure-sensitive diaphragm.

climate, trip, and dash instrument information. The driver can readily access all of these functions. Further diagnostic information can be displayed on the CRT if the proper combination of air-conditioning controls is touched. The diagnostic procedures for these displays involve pushing two or more buttons at the same time to access the diagnostic menu. Always follow the factory service manual recommendations.

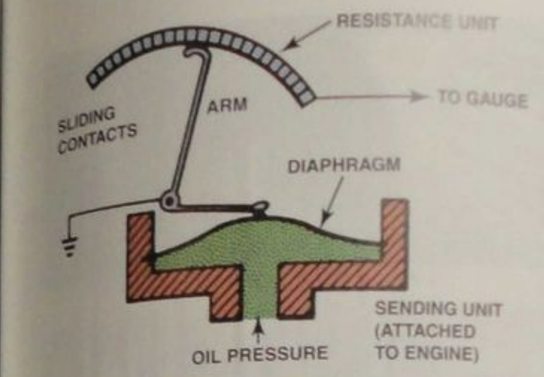


Figure 43–11 A typical oil pressure-sending unit provides a varying amount of resistance as engine oil pressure changes.

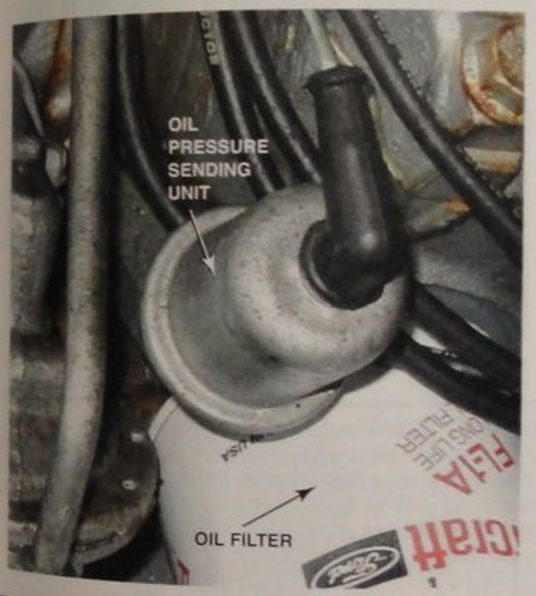


Figure 43–12 A Ford oil pressure-sending unit. Most oil pressure-sending units are located near the oil filter and are threaded into an oil gallery.



Figure 43–13 A GM temperature gauge showing normal operating temperature between 190°F and 215°F, depending on the specific vehicle and engine.

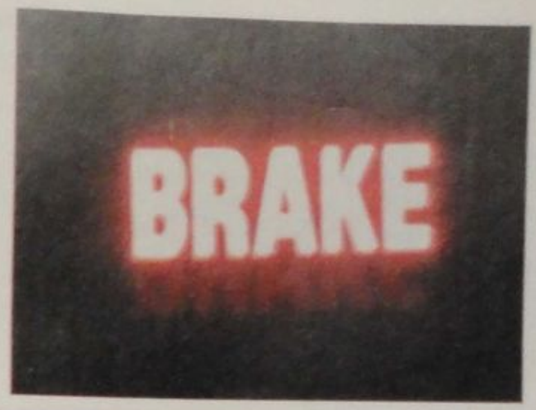


Figure 43–14 Typical red brake warning lamp.

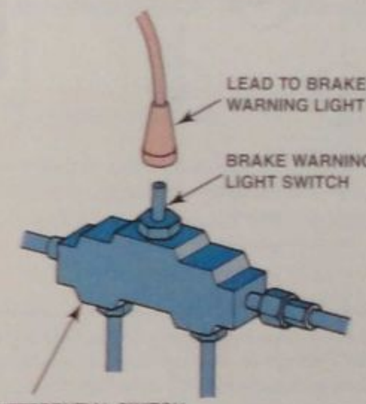


Figure 43–15 Typical brake warning light switch located on or near the master brake cylinder.



Figure 43–16 The red brake warning lamp can be turned on if the brake fluid level is low.

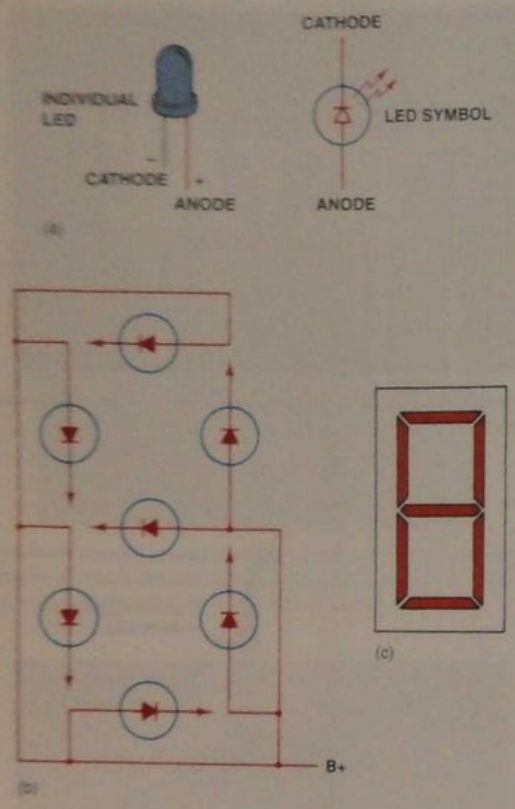


Figure 43–17 (a) Symbol and line drawing of a typical light-emitting diode (LED). (b) Grouped in seven segments, this array is called a seven-segment LED display with a common anode (positive connection). The dash computer toggles the cathode (negative) side of each individual segment to display numbers and letters. (c) When all segments are turned on, the number 8 is displayed.



Figure 43–18 A typical navigation system. This Acura system incorporates some of the climate control functions as well as the trip information on the display. This particular unit uses a DVD unit in the trunk along with a global positioning satellite (GPS) to display a map and your exact location for the entire country.

Cold Cathode Fluorescent Displays Cold **cathode fluorescent lighting (CFL)** models are used by many vehicle manufacturers for backlighting. Current consumption ranges from 3 to 5 mA (0.03 to 0.05 A) with an average life of 40,000 hours. CFL is replacing conventional incandescent light bulbs.

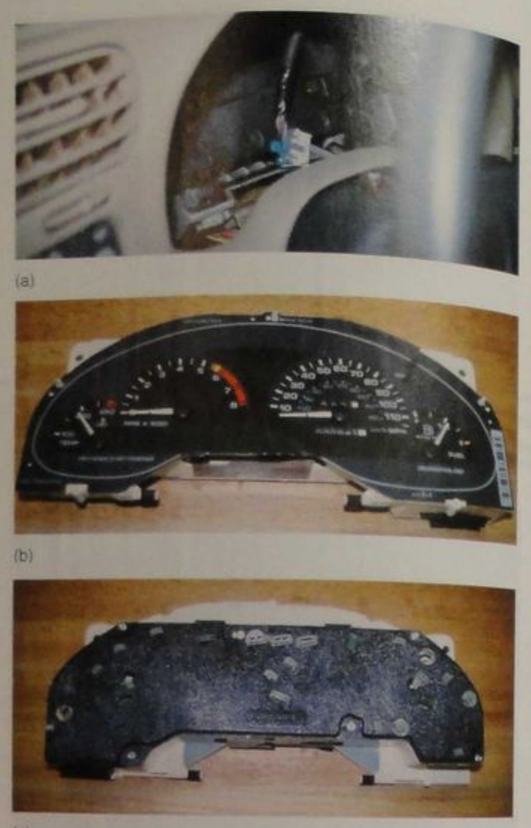


Figure 43–19 (a) View of the vehicle dash with the instrument cluster removed. Sometimes the dash instruments can be serviced by removing the padded dash cover (crash pad) to gain access to the rear of the dash. (b) The front view of the electronic analog dash display. (c) The rear view of the dash display showing that there are a few bulbs that can be serviced, but otherwise the unit is serviced as an assembly.

Electronic Analog Displays Most **analog** dash displays since the early 1990s are electronically or computer controlled. The sensors may be the same, but the sensor information is sent to the body or vehicle computer and then the computer controls current through small electromagnets that move the needle of the gauge. A scan tool often is needed to diagnose the operation of a computer-controlled analog dash instrument display. See Figure 43–19.

Other Electronic Gauge Displays Oil pressure, water temperature, and voltmeter readings are other commonly used electronic dash displays. Oil pressure is monitored by a variable-resistance sending unit threaded into an oil passage, usually near the oil filter. A typical oil pressure-sending unit will have low resistance when the oil pressure is zero and higher resistance when the oil pressure is high.

Water temperature is also sensed by a variable-resistance sending unit, usually located near the engine's thermostat. Similar to the case with oil pressure, the higher the coolant temperature, the greater the number of segments that will be indicated, based on the resistance of the coolant temperature sensor.

NOTE: On older vehicles, the coolant temperature sensor for the dash display was often a separate sensor from the engine coolant temperature (ECT) sensor used by the engine computer.

A voltmeter is often included in a digital display, and each segment of the display represents a particular voltage range. A warning lamp is often part of the electronic circuits in the electronic display to warn the driver of high or low battery voltage.

TECH TIP ✓ **The Bulb Test**

Many ignition switches have six positions. See Figures 43–20 and 43–21.

Notice the **bulb test** position—the position between "on" and "start." When the ignition is turned to "on" (run), some dash warning lamps are illuminated. When the bulb test position is reached, additional dash warning lamps often are lighted. Technicians often use this ignition switch position to check the operation of fuses that protect various circuits. Dash warning lamps are not all powered by the same fuses. If an electrical component or circuit does not work, the power side (fuse) can be quickly checked by observing the operation of the dash lamps that share a common fuse with the problem circuit. Consult a wiring diagram for fuse information on the exact circuit being tested.

The WOW Display When a vehicle equipped with a digital dash is started, all segments of the electronic display are turned on at full brilliance for 1 or 2 seconds. This is commonly called the **WOW display** and is used to show off the brilliance of the display. If numbers are part of the display, the number 8 is displayed, because this number uses all segments of a number display. Technicians can also use the WOW display to determine if all segments of the electronic display are functioning correctly.

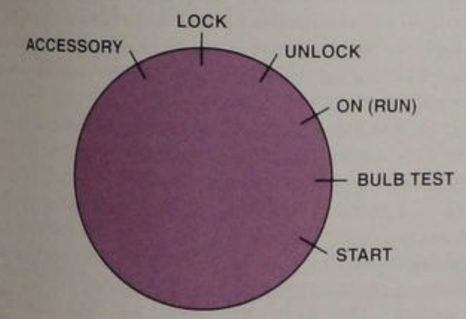


Figure 43–20 Typical ignition switch positions. Notice the bulb check position between ON (RUN) and START.



Figure 43–21 Many newer vehicles place the ignition switch on the dash and incorporate stalk controls. Note the location of the accessory position.

REAL WORLD FIX **The Speedometer Works as If It Is a Tachometer**

The owner of a Lincoln Town Car complained that all of a sudden the speedometer needle went up and down with engine speed rather than vehicle speed. In fact, the speedometer needle went up and down with engine speed even though the gear selector was in "park" and the vehicle was not moving. After hours of troubleshooting, the service technician went back and started checking the basics and discovered that the generator (alternator) had a bad diode. The technician measured over 1 volt AC and over 10 amperes of AC current using a clamp-on AC/DC ammeter. Replacing the generator restored the proper operation of the speedometer.

ELECTRONIC SPEEDOMETERS

Electronic dash displays ordinarily use an electric vehicle speed sensor driven by a small gear on the output shaft of the transmission. These speed sensors contain a permanent magnet and generate a voltage in proportion to the vehicle speed. These speed sensors are commonly called **permanent-magnet (PM) generators.** See Figure 43–22.

TECH TIP ✓ **The Soldering Gun Trick**

Diagnosing problems with digital or electronic dash instruments can be difficult. Replacement parts generally are expensive and usually not returnable if installed in the vehicle. A popular trick that helps isolate the problem is to use a soldering gun near the PM generator.

A PM generator contains a coil of wire. As the magnet inside revolves, a voltage is produced. It is the *frequency* of this voltage that the dash (or engine) computer uses to calculate vehicle speed.

A soldering gun plugged into 110 volts AC will provide a strong *varying* magnetic field around the soldering gun. This magnetic field is constantly changing at the rate of 60 cycles per second. This frequency of the magnetic field induces a voltage in the windings of the PM generator. This induced voltage at 60 hertz (Hz) is converted by the computer circuits to a miles-per-hour (mph) reading on the dash.

To test the electronic speedometer, turn the ignition to "on" (engine off) and hold a soldering gun near the PM generator.

CAUTION: The soldering gun tip can get hot, so hold the soldering gun tip away from wiring or other components that may be damaged by the hot tip.

If the PM generator, wiring, computer, and dash are okay, the speedometer should register a speed, usually 54 mph (87 kilometers per hour [km/h]). If the speedometer does not work when the vehicle is driven, the problem is in the PM generator drive.

If the speedometer does not register a speed when the soldering gun is used, the problem could be caused by:

1. A defective PM generator (check the windings with an ohmmeter)
2. Defective (open or shorted) wiring from the PM generator to the computer
3. Defective computer or dash circuit

The output of a PM generator speed sensor is an AC voltage that varies in frequency and amplitude with increasing vehicle speed. The PM generator speed signal is sent to the instrument cluster electronic circuits. These specialized electronic circuits include a buffer amplifier circuit that converts the variable sine wave voltage from the speed sensor to an on–off signal that can be used by other electronic circuits to indicate a vehicle's speed. The vehicle

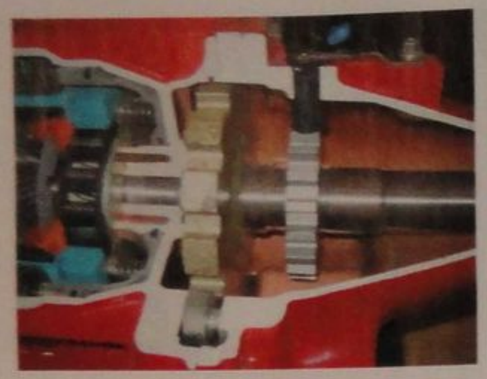


Figure 43–22 A vehicle speed sensor located in the extension housing of the transmission.

speed is then displayed by either an electronic needle-type speedometer or by numbers on a digital display.

TECH TIP ✔ **The Toyota Truck Story**

The owner of a Toyota truck complained that several electrical problems plagued the truck, including the following:

1. The cruise (speed) control would kick out intermittently.
2. The red brake warning lamp would come on, especially during cold weather.

The owner had replaced the parking brake switch, thinking that was the cause of the red brake warning lamp coming on.

An experienced technician checked the wiring diagram on the computer data disc. Checking the warning lamp circuit, the technician noticed that the same wire went to the brake fluid level sensor. The brake fluid was at the minimum level. Filling the master cylinder to the maximum level with clean brake fluid solved both problems. The electronics of the cruise control stopped operation when the red brake warning lamp was on as a safety measure.

ELECTRONIC ODOMETERS

An odometer is a dash display that indicates the total miles traveled by the vehicle. Some dash displays also include a trip odometer that can be reset and used to record total miles traveled on a trip or the distance traveled between fuel stops. Electronic dash displays can use either an electrically driven mechanical odometer or a digital display odometer to indicate miles traveled. A small electric motor called a stepper motor is used to turn the number wheels of a mechanical-style odometer. A pulsed voltage is fed to this stepper motor, which moves in relation to the miles traveled. See Figure 43–23.

Digital odometers use LED, LCD, or VTF displays to indicate miles traveled. Because total miles must be retained when the ignition is turned off or the battery is disconnected, a special electronic chip must be used that will retain the miles traveled.

These special chips are called **nonvolatile random-access memory (NVRAM).** Nonvolatile means that the information stored in the electronic chip is not lost when electrical power is removed. Some vehicles use a chip called **electronically erasable programmable read-only memory (EEPROM).** Most

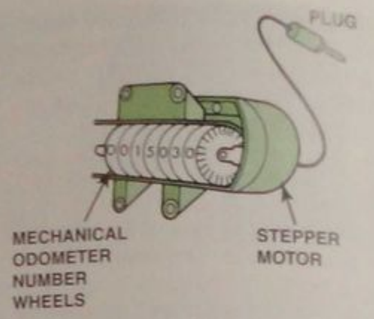


Figure 43–23 Some vehicles that use a PM generator for a vehicle speed sensor use a stepper motor to drive a mechanical odometer. The stepper motor receives a signal (pulses) from the vehicle computer and rotates in "steps" corresponding to the distance traveled.

digital odometers can read up to 999,999.9 miles or kilometers (km), then the display indicates error. If the chip is damaged or exposed to static electricity, it may fail to operate and "error" may appear.

REAL WORLD FIX **Look for Previous Repairs**

A technician was asked to fix the speedometer on a Pontiac Grand Am that showed approximately double the actual speed. Previous repairs had included a new vehicle speed sensor (VSS) and computer. Nothing made any difference. The customer stated that the problem happened all of a sudden. After hours of troubleshooting, the customer just happened to mention that the automatic transaxle had been repaired shortly before the speedometer problem. The root cause of the problem was discovered when the technician learned that a final drive assembly from a 4T60-E transaxle had been installed on the 3T-40 transaxle. The 4T60-E final drive assembly has 13 reluctor teeth whereas the 3T-40 has 7 teeth. This difference in the number of teeth caused the speedometer to read almost double the actual vehicle speed. After the correct part was installed, the speedometer worked correctly. The technician now always asks if there has been any recent work performed on the vehicle before diagnosis is started.

ELECTRONIC SPEEDOMETER AND ODOMETER SERVICE

If the speedometer and odometer fail to operate, the speed sensor should be the first item checked. With the vehicle safely raised off the ground and supported, disconnect the wires from the speed sensor near the output shaft of the transmission. Connect a multimeter set on AC volts to the terminals of the speed sensor and rotate the drive wheels with the transmission in neutral. A good speed sensor should indicate approximately 2 volts AC if the drive wheels are rotated by hand. If the speed sensor is working, check the wiring from the speed sensor to the dash cluster. If the wiring is good, the **instrument panel (IP)** should be sent to a specialty repair facility. Consult your local dealer for the nearest authorized repair facility.

If the speedometer operates correctly but the mechanical odometer does not work, the odometer stepper motor, the number wheel assembly, or the circuit controlling the stepper motor is defective. If the digital odometer does not operate but the speedometer operates correctly, then the dash cluster must be removed and sent to a specialized repair facility. A replacement chip is available only through authorized sources; if the odometer chip is defective, the original number of miles must be programmed into the replacement chip.

NOTE: Some digital odometers only change (update) every 15 miles or whenever the ignition is turned off. Be certain to check for normal operation before attempting to repair the odometer. Digital dash displays that use EEPROM odometer chips are the type most likely to update odometer readings periodically rather than continuously.

REAL WORLD FIX **Electronic Devices Cannot Swim**

The owner of a Dodge minivan complained that after the vehicle was cleaned inside and outside, the temperature gauge, fuel gauge, and speedometer stopped working. The vehicle speed sensor was checked and found to be supplying a square wave signal that changed with vehicle speed. A scan tool indicated a speed, yet the speedometer displayed zero all the time. Finally, the service technician checked the body computer to the right of the accelerator pedal and noticed that it had been wet—from the interior cleaning. Drying the computer did not fix the problem, but a replacement body computer fixed all the problems. The owner discovered that electronic devices do not like water and that computers cannot swim.

ELECTRONIC FUEL-LEVEL GAUGES

Electronic fuel-level gauges ordinarily use the same fuel tank-sending unit as that used on conventional fuel gauges. The tank unit consists of a float attached to a variable resistor. As the fuel level changes, the resistance of the sending unit changes. As the resistance of the tank unit changes, the dash-mounted gauge also changes. The only difference between a digital fuel-level gauge and a conventional needle type is in the display. Digital fuel-level gauges can be either numerical (indicating gallons or liters remaining in the tank) or a bar graph display. A bar graph consists of light segments, often with each segment corresponding to a gallon of fuel. The electronic circuits inside the cluster light the correct number of gallons remaining or the number of segments, depending on the resistance of the tank-sending unit. For example, older General Motors tank units have 90 ohms when the fuel tank is full and zero ohms when the tank is empty. See Figure 43–24. Therefore, every decrease of 6 ohms will decrease the display by a segment if it is a 16-segment bar graph fuel gauge.

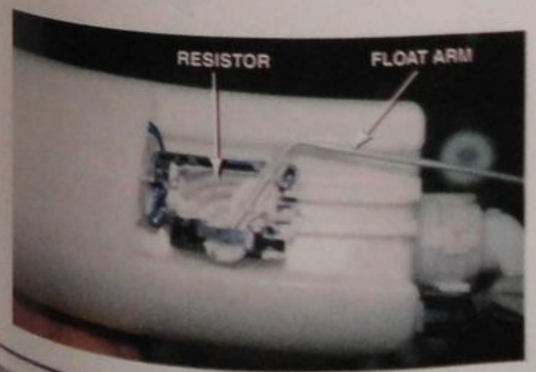


Figure 43–24 A typical fuel pump and fuel-level gauge module. The float moves against a resistor and changes the resistance of the circuit with the fuel level.

NOTE: Many General Motors vehicles built since 1996 use a fuel-level sensing unit that varies between 40 ohms empty and 250 ohms full.

The diagnosis of a problem is the same as that described earlier for conventional fuel gauges. If the tests indicate that the dash unit is defective, usually the *entire* dash gauge assembly must be replaced.

FREQUENTLY ASKED QUESTION ???

Why Does the Oil Pressure Gauge on My Ford Always Read in the Middle?

Some Ford Motor Company vehicles (and perhaps others) use an analog oil pressure display that is set to read in the middle of the scale as long as there is a minimum oil pressure. Think of the gauge as an oil pressure switch (on or off) rather than an analog (variable) display of the actual oil pressure. See Figure 43–25.

The older-style gauge used a variable resistance oil pressure-sending unit. See Figure 43–26.

On newer models, Ford started using an oil pressure switch that electrically grounds the oil pressure gauge through a 20-ohm resistor whenever the oil pressure is above 4.5 to 7.5 PSI. See Figure 43–27.

To determine which type of gauge you have, simply ground the sending unit with the key on (engine off) and observe the gauge. If the gauge reads exactly one-half, then the vehicle has a switch-type oil pressure-sending unit.

NAVIGATION AND GPS

The **global positioning system (GPS)** uses 24 satellites in orbit around the earth to provide signals for navigation devices. The global positioning system (GPS) is funded by and controlled by the United States Department of Defense (DOD). While the system can be used by anyone with a GPS receiver, the system was designed for and is operated by the U.S. military. See Figure 43–28.

Background The current GPS system was developed in the 1980s after a civilian airplane from Korean Airlines, Flight 007 was shot down after it had gone over Soviet territory in 1983. The system was fully operational in 1991. It was decided to allow civilian use of the GPS system that same year but with less accuracy than used by the military.

Until 2000, the nonmilitary use of GPS was purposely degraded by a computer program called selection availability (S/A) built into the satellite transmission signals. After 2000, the S/A was officially turned off, allowing nonmilitary users more accurate position information from the GPS receivers.

Navigation System Parts and Operation Navigation systems use the GPS satellites for basic location information from the satellite. The navigation controller located in the rear of the vehicle uses other sensors, including a digitized map to display the location of the vehicle.

- **GPS Satellite Signals**—These signals from at least three satellites are needed to locate the vehicle.
- **Yaw Sensor**—This sensor is often used inside the navigation unit to detect movement of the vehicle during cornering. This sensor is also called a "g" sensor because it measures force and one g is the force of gravity.



(a)



(b)

Figure 43–25 (a) A Ford dash display with the key on, engine off. (b) As soon as the engine starts, the oil pressure gauge goes immediately to the midpoint on the gauge. This seems strange to some vehicle owners.

- **Vehicle Speed Sensor**—This sensor input is used by the navigation controller to determine the speed and distance the vehicle travels. This information is compiled and compared to the digital map and GPS satellite inputs to locate the vehicle.
- **Audio Output/Input**—Voice-activated factory units use a built-in microphone at the center top of the windshield and the audio speakers speech output.

FREQUENTLY ASKED QUESTION ???

Does the Government Know Where I Am?

No. The navigation system uses signals from the satellites and uses the signals from three or more to determine position. If the vehicle is equipped with OnStar, then the vehicle position can be monitored by the use of the cellular telephone link to OnStar call centers. Unless the vehicle has a cellular phone connection to the outside world, the only people who will know the location of the vehicle are the persons inside the vehicle viewing the navigation screen.

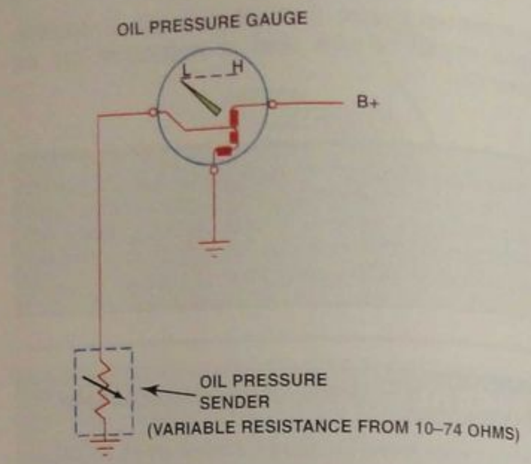


Figure 43–26 A typical magnetic and pressure gauge circuit. Notice that the oil pressure gauge reading depends on the resistance of the sensor. The lower the resistance, the higher the oil pressure on most Ford vehicles.

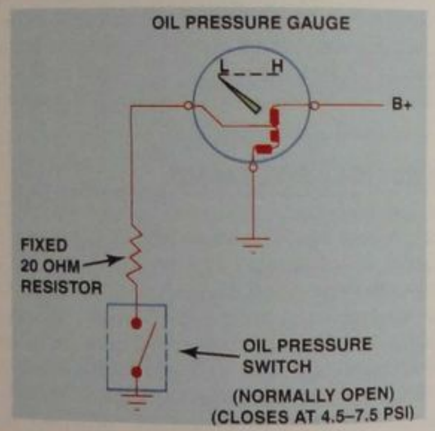


Figure 43–27 Whenever the oil pressure exceeds 4.5 to 7.5 PSI, the oil pressure switch closes and the meter reads in about the middle of its range due to the fixed 20-ohm resistor in the meter circuit.



Figure 43–28 Global positioning systems use 24 satellites in high earth orbit whose signals are picked up by navigation systems. The navigation system computer then calculates the location based on the position of the satellite overhead.



Figure 43–29 The navigation control unit is located in the trunk of this Acura.

Navigation systems include the following components:

1. A screen display
2. A GPS antenna
3. A navigation control unit that usually has a DVD with the map information. See Figure 43–29.

The DVD includes street names and the following:

1. Points of interest (POI). These include automated teller machines (ATMs), restaurants, schools, colleges, museums, shopping, and airports, as well as vehicle dealer locations.
2. Business addresses and telephone numbers as well as hotels and restaurants. If the telephone number is listed in the business telephone book, it can usually be displayed on the navigation screen. If the telephone number of the business is known, the location can be displayed.

NOTE: Private residences or cellular telephone numbers are not included in the data base of telephone numbers stored on the navigation system DVD.

3. Turn-by-turn directions can be provided to addresses that are selected by:
   - Points of interest (POI)
   - Typed in using a keyboard shown on the display

The navigation unit then often allows the user to select the fastest way to the destination, as well as the shortest way, or how to avoid toll roads. See Figure 43–30.

TECH TIP ✓ **Window Tinting Can Hurt GPS Reception**

Most factory-installed navigation systems use a GPS antenna inside the rear back glass or under the rear package shelf. If a metalized window tint is applied to the rear glass, the signal strength from the GPS satellites can be reduced. If the customer concern includes inaccurate or nonfunctioning navigation, check for window tint.

Diagnosis and Service For the correct functioning of the navigation system, three inputs are needed, including:

- Location
- Direction
- Speed

The navigation system uses the GPS satellite and map data to determine a location. Direction and speed are determined by the navigation computer from inputs from the satellite, plus the yaw

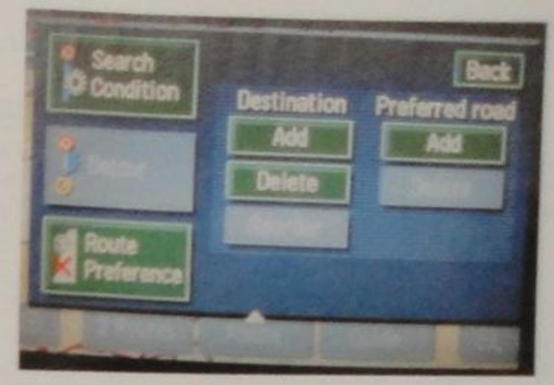


Figure 43–30 A typical navigation display showing various options. Some systems do not allow access to these functions if the vehicle is in gear and/or moving.

sensor and vehicle speed sensor. The following symptoms may occur and be a customer complaint. Knowing how the system malfunctions helps to determine the most likely cause.

- If the vehicle icon jumps down the road, a fault with the vehicle speed (VS) sensor input is usually indicated.
- If the icon rotates on the screen, but the vehicle is not being driven in circles, a fault with the yaw sensor or yaw sensor input to the navigation controller is indicated.
- If the icon goes off course and shows the vehicle on a road that it is not on, a fault with the GPS antenna is indicated.

TECH TIP ✓ **Touch Screen Tip**

Most vehicle navigation systems use a touch screen for use by the driver (or passenger) to input information or other on-screen prompts. Most touch screens use infrared beams projected from the top and bottom plus across the screen to form a grid. The system detects where on the screen a finger is located by the location of the beams that are cut. Do not push harder on the display if the unit does not respond or damage to the display unit may occur. If no response is detected when lightly depressing the screen, rotate the finger to cause the infrared beams to be cut.

Sometimes the navigation system itself will display a warning that views from the satellite are not being received. See Figure 43–31. Always follow the displayed instructions.

FREQUENTLY ASKED QUESTION ???

What Is Navigation-Enhanced Climate Control?

Some vehicles, such as the Acura RL, use data from the navigation system to help control the automatic climate control system. Data about the location of the vehicle includes:

- *Time and Date*—This information allows the automatic climate control system to determine where the sun is located.
- *Direction of Travel*—The navigation system can also help the climate control system determine the direction of travel.

As a result of the input from the navigation system, the automatic climate control system can control cabin temperature in addition to various other sensors in the vehicle. For example, if the vehicle was traveling south in the late afternoon in July, the climate control system could assume that the passenger side of the vehicle would be warmed more by the sun than the driver's side and could increase the airflow to the passenger side to help compensate for the additional solar heating.

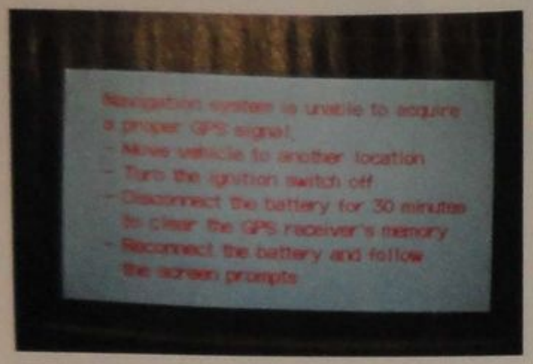


Figure 43–31 A screen display of a navigation system that is unable to acquire usable signals from GPS satellites.



Figure 43–32 The three-button OnStar control on the inside rearview mirror. The left button (telephone handset icon) is pushed if a hands-free cellular call is to be made. The center button is depressed to contact an OnStar advisor and the right emergency button is used to request that help be sent to the vehicle's location.

ONSTAR

Parts and Operation OnStar is a system that includes the following functions:

1. Cellular telephone
2. Global positioning antenna and computer

OnStar is standard or optional on most General Motors vehicles and selected other brands and models, to help the driver in an emergency or to provide other services. The cellular telephone is used to communicate with the driver from advisors at service centers. The advisor at the service center is able to see the location of the vehicle as transmitted from the GPS antenna and computer system in the vehicle on a display. OnStar does not display the location of the vehicle to the driver unless the vehicle is also equipped with a navigation system.

Unlike most navigation systems, the OnStar system requires a monthly fee. OnStar was first introduced in 1996 as an option on some Cadillac models. Early versions used a handheld cellular telephone while later units used a group of three-buttons mounted on the inside rearview mirror and a hands-free cellular telephone. See Figure 43–32.

The first version used analog cellular service while later versions used a dual mode (analog and digital) service until 2007. After 2007, all OnStar systems will use digital cellular service, which means that older systems that were analog only need to be upgraded.

The OnStar system includes the following features which can vary depending on the level of service desired, which will affect the cost per month.

- **Automatic Notification of Airbag Deployment.** If the airbag is deployed, the advisor is notified immediately and attempts to call the vehicle. If there is no reply, or if the occupants report an emergency, the advisor will contact emergency services and give them the location of the vehicle.
- **Emergency Services.** If the red button is pushed, OnStar immediately locates the vehicle and contacts the nearest emergency service agency.
- **Stolen Vehicle Location Assistance.** If a vehicle is reported stolen, a call center advisor can track the vehicle.
- **Remote Door Unlock.** An OnStar advisor can send a cellular telephone message to the vehicle to unlock the vehicle if needed.
- **Roadside Assistance.** When called, an OnStar advisor can locate a towing company or locate a provider who can bring gasoline or change a flat tire.
- **Accident Assistance.** An OnStar advisor is able to help with the best way to handle an accident. The advisor can supply a step-by-step checklist of the things that should be done plus call the insurance company, if desired.
- **Remote Horn and Lights.** The OnStar system is tied into the lights and horn circuits so an advisor can activate them if requested to help the owner locate the vehicle in a parking lot or garage.
- **Vehicle Diagnosis.** Because the OnStar system is tied to the PCM, an OnStar advisor can help with diagnosis if there is a fault detected. The system works as follows:
  - The malfunction indicator light (MIL) (check engine) comes on to warn the driver that a fault has been detected.
  - The driver can depress the OnStar button to talk to an advisor and ask for a diagnosis.
  - The OnStar advisor will send a signal to the vehicle requesting the status from the power train control module (PCM), as well as the controller for the antilock brakes and the airbag module.
  - The vehicle then sends any diagnostic trouble codes to the advisor. The advisor can then inform the driver about the importance of the problem and give advice as to what to do to have the problem resolved.

Diagnosis and Service The OnStar system can fail to meet the needs of the customer if any of the following conditions occur:

1. Lack of cellular telephone service in the area.
2. Poor global positioning system (GPS) signals, which can prevent an OnStar advisor from determining the position of the vehicle.
3. Transport of the vehicle by truck or ferry so that it is out-of-contact with the GPS satellite system in order for an advisor to properly track the vehicle.

If all of the above are okay and the problem still exists, follow service information diagnostic and repair procedures. If a new vehicle communication interface module (VCIM) is installed in the vehicle, the electronic serial number (ESN) must be tied to the vehicle. Follow service information instructions for the exact procedures to follow.

BACKUP CAMERA

Parts and Operation A **backup camera** is used to display the area at the rear of the vehicle in a screen display on the dash when the gear selector is placed in reverse. Backup cameras are also called *reversing cameras* or *rear view cameras*.

Backup cameras are different from normal cameras because the image displayed on the dash is flipped so it is a mirror image of the scene at the rear of the vehicle. This reversing of the image is needed because the driver and the camera are facing in opposite directions. Backup cameras were first used in large vehicles with limited rearward visibility, such as motor homes. Many vehicles equipped with navigation systems today include a backup camera for added safety while backing. See Figure 43–33.



Figure 43–33 A typical view displayed on the navigation screen from the backup camera.



Figure 43–34 A typical fisheye-type backup camera usually located near the center on the rear of the vehicle near the license plate.

The backup camera used contains a wide-angle or fisheye lens to give the largest viewing area. See Figure 43–34. Most backup cameras are pointed downward so that objects on the ground, as well as walls, are displayed.

Diagnosis and Service Faults in the backup camera system can be related to the camera itself, the display, or the connecting wiring. The main input to the display unit comes from the transmission range switch which signals the backup camera when the transmission is shifted into Reverse.

To check the transmission range switch, check the following:

1. Check if the backup (reverse) lights function when the gear selector is placed in Reverse with the ignition key on-engine off (KOEO).
2. Check that the transmission/transaxle is fully engaged in reverse when the selector is placed in reverse.

Most of the other diagnosis involves visual inspection, including:

1. Check the backup camera for damage.
2. Check the screen display for proper operation.
3. Check that the wiring from the rear camera to the body is not cut or damaged.

Always follow the vehicle manufacturer's recommended diagnosis and repair procedures.

BACKUP SENSORS

Components Backup sensors are used to warn the driver if there is an object behind the vehicle while backing. The system used in General Motors vehicles is called **Rear Park Assist (RPA)** and includes the following components:

- Ultrasonic object sensors built into the rear bumper assembly
- A display with three lights usually located inside the vehicle above the rear window and visible to the driver in the rear view mirror
- An electronic control module that uses an input from the transmission range switch and lights the warning lamps needed when the vehicle gear selector is in Reverse

Operation The three-light display includes two amber lights and one red light. The following lights are displayed depending on the distance from the rear bumper:

- One amber lamp will light when the vehicle is in Reverse and traveling at less than 3 mph (5 km/h) and the sensors detect an object 5 feet to 40 inches from the rear bumper. A chime also sounds once when an object is detected to warn the driver to look at the rear-parking assist display. See Figure 43–35.
- Two amber lamps light when the distance between the rear bumper and an object is between 20 and 40 inches (50 and 100 cm) and the chime will sound again.
- Two amber lamps and the red lamp light and the chime sounds continuously when the distance between the rear bumper and the object is between 11 and 20 inches (28 and 50 cm).

If the distance between the rear bumper and the object is less than 11 inches (28 cm), all indicator lamps flash and the chime will sound continuously.

The ultrasonic sensors embedded in the rear bumper "fire" individually every 150 ms (27 times per second). See Figure 43–36.

The sensors fire and then receive a return signal and arm to fire again in sequence from the left sensor to the right sensor.

Each sensor has three wires:

1. An 8-volt supply wire from the RPA module is used to power the sensor



Figure 43–35 A typical backup sensor display located above the rear window inside the vehicle. The warning lights are visible in the inside rearview mirror.



Figure 43–36 The small round buttons in the rear bumper are ultrasonic sensors used to sense distance to an object.

2. A reference low or ground wire
3. A signal line used to send and receive commands to and from the RPA module

Diagnosis The rear parking assist control module is capable of detecting faults and storing diagnostic trouble codes (DTCs). If a fault has been detected by the control module, the red lamp flashes and the system is disabled. Follow service information diagnostic procedures because the rear parking assist module cannot usually be accessed using a scan tool. Most systems use the warning lights to indicate trouble codes.

TECH TIP ✔ **Check for Repainted Bumper**

The ultrasonic sensors embedded in the bumper are sensitive to paint thickness because the paint covers the sensors. If the system does not seem to be responding to objects, and if the bumper has been repainted, measure the paint thickness using a nonferrous paint thickness gauge. The maximum allowable paint thickness is 6 mils (0.006 inch or 0.15 mm).

LANE DEPARTURE WARNING SYSTEM

Parts and Operation The **lane departure warning system (LDWS)** uses cameras to detect if the vehicle is crossing over lane marking lines on the pavement. Some systems use two cameras, one mounted on each outside rearview mirror. Some systems use infrared sensors located under the front bumper to monitor the lane markings on the road surface.

If the cameras detect that the vehicle is starting to cross over a lane dividing line, a warning chime will sound or a vibrating mechanism mounted in the driver's seat cushion is triggered on the side where the departure is being detected. This warning will not occur if the turn signal is on in the same direction as detected.

Diagnosis and Service Before attempting to service or repair a lane departure warning system fault, check service information for an explanation on how the system is supposed to work. If the system is not working as designed, perform a visual inspection of the sensors or cameras, checking for damage from road debris or evidence of body damage, which could affect the sensors. After a visual inspection, follow the vehicle manufacturer's recommended diagnosis procedures to locate and repair the fault in the system.

ELECTRONIC DASH INSTRUMENT DIAGNOSIS AND TROUBLESHOOTING

If one or more electronic dash gauges do not work correctly, first check the WOW display that lights all segments to full brilliance whenever the ignition switch is first switched on. If *all* segments of the display do *not* operate, then the entire electronic cluster must be replaced in most cases. If all segments operate during the WOW display but do not function correctly afterwards, the problem is most often a defective sensor or defective wiring to the sensor.

All dash instruments except the voltmeter use a variable-resistance unit as a sensor for the system being monitored. Most new-vehicle dealers are required to purchase essential test equipment, including a test unit that permits the technician to insert various fixed-resistance values in the suspected circuit. For example, if a 45-ohm resistance is put into the fuel gauge circuit that reads from 0 to 90 ohms, a properly operating dash unit should indicate one-half tank. The same tester can produce a fixed signal to test the operation of the speedometer and tachometer. If this type of special test equipment is not available, the electronic dash instruments can be tested using the following procedure:

1. With the ignition switched off, unplug the wire(s) from the sensor for the function being tested. For example, if the oil pressure gauge is not functioning correctly, unplug the wire connector at the oil pressure-sending unit.
2. With the sensor wire unplugged, turn the ignition switch on and wait until the WOW display stops. The display for the affected unit should show either fully lighted segments or no lighted segments, depending on the make of the vehicle and the type of sensor.
3. Turn the ignition switch off. Connect the sensor wire lead to ground and turn the ignition switch on. After the WOW display, the display should be the opposite (either fully on or fully off) of the results in step 2.

Testing Results If the electronic display does function fully on and fully off with the sensor unplugged and then grounded, the problem is a defective sensor. If the electronic display fails to function fully on and fully off when the sensor wire(s) are opened and grounded, the problem is usually in the wiring from the sensor to the electronic dash or it is a defective electronic cluster.

CAUTION: Whenever working on or *near* any type of electronic dash display, always wear a wire attached to your wrist (wrist strap) connected to a good body ground to prevent damaging the electronic dash with static electricity.

TECH TIP ✔ **Keep Stock Overall Tire Diameter**

Whenever larger (or smaller) wheels or tires are installed, the speedometer and odometer calibration are also thrown off. This can be summarized as follows:

- *Larger-diameter tires.* The speed showing on the speedometer is slower than the actual speed. The odometer reading will show fewer miles than actual.
- *Smaller-diameter tires.* The speed showing on the speedometer is faster than the actual speed. The odometer reading will show more miles than actual.

General Motors trucks can be recalibrated with a recalibration kit (1988–1991) or with a replacement controller assembly called a digital ratio adapter controller (DRAC) located under the dash. It may be possible to recalibrate the speedometer and odometer on earlier models, before 1988, or vehicles that use speedometer cables by replacing the drive gear in the transmission. Check service information for the procedure for the vehicle being serviced.

MAINTENANCE REMINDER LAMPS

Maintenance reminder lamps indicate that the oil should be changed or that other service is required. There are numerous ways to extinguish a maintenance reminder lamp. Some require the use of a special tool. Consult service literature or dealership personnel for the exact procedure for the vehicle being serviced. For example, to reset the oil service reminder light on many General Motors vehicles, you have to perform the following:

Step #1 Turn the ignition key on (engine off).

Step #2 Depress the accelerator pedal three times and hold it down on the fourth.

Step #3 When the reminder light flashes, release the accelerator pedal.

Step #4 Turn the ignition key to the off position.

Step #5 Start the engine and the light should be off.

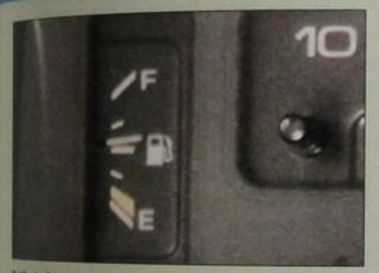
SUMMARY

1. Most digital and analog (needle-type) dash gauges use variable resistance sensors.
2. Dash warning lamps are called telltale lamps.
3. Many electronically operated or computer-operated dash indicators require that a service manual be used to perform accurate diagnosis.
4. Permanent-magnet (PM) generators produce an AC signal and are used for vehicle speed and wheel speed sensors.

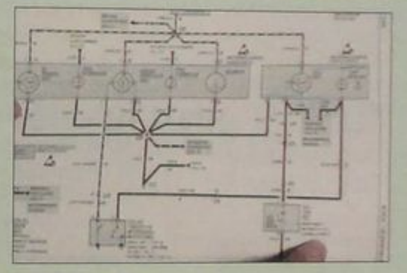
REVIEW QUESTIONS

1. Explain the difference between thermoelectric and electromagnetic dash instruments.
2. Describe LED, LCD, VTF, and CRT dash displays.
3. Discuss how to diagnose a problem with a red brake-warning lamp.
4. Explain how to test the dash unit of a fuel gauge.

PHOTO SEQUENCE Fuel Gauge Diagnosis



P43–1 Observe the fuel gauge. This General Motors vehicle shows an indicated reading of slightly above one-half tank.



P43–2 Consult the factory service manual for the specifications, wire color, and recommended test procedure.



P43–3 A visual inspection indicated that the electrical wiring and connector were not damaged or corroded.



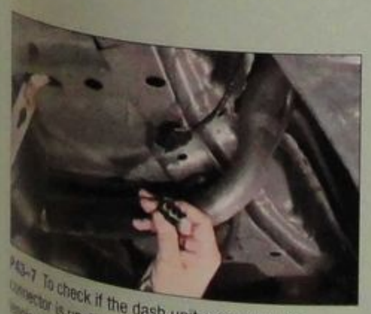
P43–4 To test resistance of the sending unit (tank unit) use a digital multimeter and select ohms (Ω).



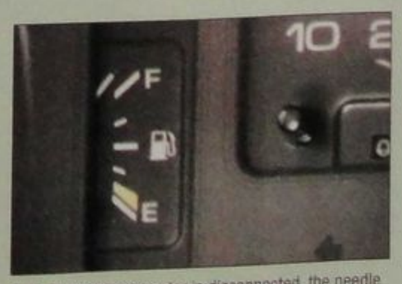
P43–5 Following the schematic in the service manual the sending unit resistance can be measured between the pink and the black wires in the connector.



P43–6 The meter displays 50 ohms or slightly above the middle of the normal resistance value for the vehicle of 0Ω (empty) to 90Ω (full).



P43–7 To check if the dash unit can move, the connector is unplugged with the ignition key on (engine off).



P43–8 As the connector is disconnected, the needle of the dash unit moves toward full.



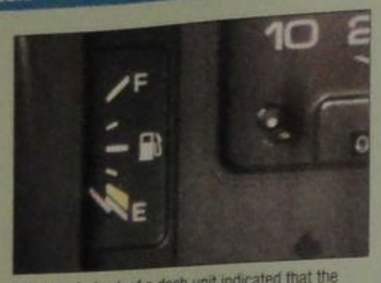
P43–9 After a couple of seconds, the needle disappears above the full reading. The open connector represented infinity ohms and normal maximum reading occurs when the tank unit reads 90 ohms.

(continued)

PHOTO SEQUENCE Fuel Gauge Diagnosis—continued



P43–10 To check if the dash unit is capable of reading empty, a fuse jumper wire is connected between the signal wire at the dash end of the connector and a good chassis ground.



P43–11 A check of a dash unit indicated that the needle does accurately read empty.



P43–12 After testing, reconnect the electrical connectors and verify for proper operation of the fuel-level gauge.

CHAPTER QUIZ

1. Two technicians are discussing a fuel gauge on a General Motors vehicle. Technician A says that if the ground wire connection to the fuel tank-sending unit becomes rusty or corroded, the fuel gauge will read lower than normal. Technician B says that if the power lead to the fuel tank-sending unit is disconnected from the tank unit and grounded (ignition on), the fuel gauge should go to empty. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

2. If an oil pressure warning lamp on a General Motors vehicle is on all the time, yet the engine oil pressure is normal, the problem could be _____.
   a. A defective (shorted) oil pressure-sending unit (sensor)
   b. A defective (open) oil pressure-sending unit (sensor)
   c. An open wire between the sending unit (sensor) and the dash warning lamp
   d. Both b and c

3. When the oil pressure drops to between 3 and 7 PSI, the oil pressure lamp lights by _____.
   a. Opening the circuit
   b. Shorting the circuit
   c. Grounding the circuit
   d. Conducting current to the dash lamp by oil

4. A brake warning lamp on the dash remains on whenever the ignition is on. If the wire to the pressure differential switch (usually a part of a combination valve or built into the master cylinder) is unplugged, the dash lamp goes out. Technician A says that this is an indication of a fault in the hydraulic brake system. Technician B says that the problem is probably due to a stuck parking brake cable switch. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

5. A customer complains that every time the lights are turned on in the vehicle, the dash display dims. What is the most probable explanation?
   a. Normal behavior for LED dash displays
   b. Normal behavior for VTF dash displays
   c. Poor ground in lighting circuit causing a voltage drop to the dash lamps
   d. Feedback problem most likely caused by a short-to-voltage between the headlights and dash display

6. Technician A says that LCDs may be slow to work at low temperatures. Technician B says that an LCD dash display can be damaged if pressure is exerted on the front of the display during cleaning. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. Technician A says that backup sensors use LEDs to detect objects. Technician B says that a backup sensor will not work correctly if the paint is thicker than 0.006 in. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. Technician A says that metal-type tinting can affect the navigation system. Technician B says most navigation systems require a monthly payment for use of the GPS satellite. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. Technician A says that the data displayed on the dash can come from the engine computer. Technician B says that the entire dash assembly may have to be replaced even if just one unit fails. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. How does changing the size of the tires affect the speedometer reading?
    a. A smaller-diameter tire causes the speedometer to read faster than actual speed and more than actual mileage on the odometer.
    b. A smaller-diameter tire causes the speedometer to read slower than the actual speed and less than the actual mileage on the odometer.
    c. A larger-diameter tire causes the speedometer to read faster than the actual speed and more than the actual mileage on the odometer.
    d. A larger-diameter tire causes the speedometer to read slower than the actual speed and more than the actual mileage on the odometer.

CHAPTER 44

Horn, Wiper, and Blower Motor Circuits

OBJECTIVES: After studying Chapter 44, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "G" (Horn and Wiper/Washer Diagnosis and Repair) and content area "H" (Accessories Diagnosis and Repair). • Describe how the horn operates. • List the components of a wiper circuit. • Explain how the blower motor can run at different speeds.

KEY TERMS: horns • pulse wipers • rain sense module (RSM) • rain-sense wipers • series-wound field • shunt field • variable-delay wipers • windshield wipers

Electrical accessories provide comfort and assistance to the driver and passengers. The growing list of electrical accessories makes this an area of much concern to vehicle owners and service technicians.

HORNS

Horns are devices that emit a loud sound and vehicles have one or two horns. See Figure 44–1. When two horns are used, each has a different tone when operated separately, yet the sound combines when both are operated. Automotive horns are usually wired directly to battery voltage from the fuse panel. The majority of automobiles, except for most Fords, utilize a horn *relay*. With a relay, the horn button on the steering wheel or column completes a circuit to ground that closes a relay, and the heavy current flow required by the horn then travels from the relay to the horn. See Figure 44–2. Some older systems do not use a relay, and current is supplied directly to the horn through a switch in the steering column.

A vehicle horn is an actuator that converts an electrical signal to sound. The horn circuit includes an armature and contacts that are attached to a diaphragm. When energized, the armature causes the diaphragm to vibrate at an audible frequency. The sound created by the diaphragm is magnified as it travels through a trumpet attached to the diaphragm chamber. Most horn systems typically use one or two horns, but some have up to four. Those with multiple horns use both high- and low-pitch units to achieve a harmonious tone. Only a high-pitched unit is used in single-horn applications. The horn assembly is marked with an "H" or "L" for pitch identification.

Horns are manufactured in several different tones or frequencies ranging between 1,800 and 3,550 hertz. Vehicle manufacturers can select from various horn tones for a particular vehicle sound.



Figure 44–1 The two horns on this vehicle were finally located under the front bumper. They were not visible until the vehicle was hoisted.

Horn System Diagnosis

There are three types of horn failure:

- No horn operation
- Intermittent operation
- Constant operation

If a horn does not operate at all, check for:

- Burned fuse or fusible link
- Open circuit
- Defective horn
- Faulty relay
- Defective horn switch

If a horn operates intermittently, check for:

- Loose contact at the switch
- Loose, frayed, or broken wires
- Defective relay

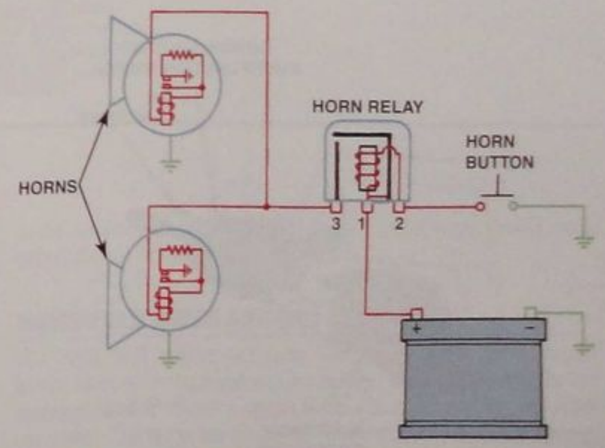


Figure 44–2 A typical horn circuit. Note that the horn button completes the ground circuit for the relay.

A horn that sounds continuously and cannot be shut off is caused by horn switch contacts that are stuck closed, or a short-to-ground on the control circuit. This may be the result of a defective horn switch or a faulty relay. Stuck relay contacts keep the circuit complete so the horn sounds constantly. Disconnect the horn and check continuity through the horn switch and relay to locate the source of the problem.

To help determine the cause of an inoperative horn, use a jumper wire and connect one end to the positive post of the battery and the other end to the wire terminal of the horn itself. If the horn works, the problem is in the circuit supplying current to the horn. If the horn does not work, the horn itself could be defective or the mounting bracket may not be providing a good ground.

If a replacement horn is required, attempt to use a horn of the same tone as the original. The tone is usually indicated by a number or letter stamped on the body of the horn.

Horn Service When a horn malfunctions, circuit tests are made to determine if the horn, relay, switch, or wiring is the source of the failure. Typically, a digital multimeter (DMM) is used to perform voltage drop and continuity checks to isolate the failure.

Switch and Relay A momentary contact switch is used to sound the horn. The horn switch is mounted to the steering wheel in the center of the steering column on some models, and is part of a multifunction switch installed on the steering column on other models. See Figure 44–3. These may require pulling on the stalk or depressing a button on the end of the stalk to sound the horn.

Once a switch has been disconnected from the circuit, it is easily checked with an ohmmeter. There should be continuity through the circuit only when the horn switch is depressed. Horn switch replacement may include removing the steering wheel to gain access to connections and mountings.

On most late-model vehicles, the horn relay is located in a centralized power distribution center along with other relays, circuit breakers, and fuses. The horn relay bolts onto an inner fender or the bulkhead in the engine compartment of older vehicles. Check the relay to determine if the coil is being energized and if current passes through the power circuit when the horn switch is depressed. Use a voltmeter to test input, output, and control voltage.

Circuit Testing Make sure the fuse or fusible link is good before attempting to troubleshoot the circuit. Also, check that the ground

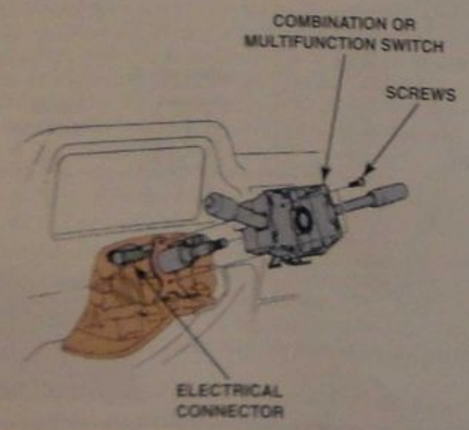


Figure 44–3 The horn switch is part of a combination switch on some vehicles.

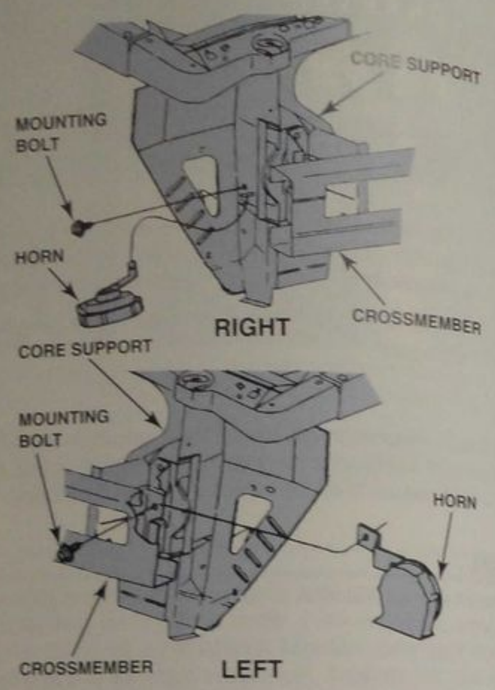


Figure 44–4 Horns typically mount to the radiator core support or bracket at the front of the vehicle.

connections for the horn are clean and tight. Most horns ground to the chassis through the mounting bolts. High ground circuit resistance due to corrosion, road dirt, or loose fasteners may cause no, or intermittent, horn operation.

On a system with a relay, test the power output circuit and the control circuit. Check for voltage available at the horn, voltage available at the relay, and continuity through the switch. When no relay is used, there are two wires leading to the horn switch, and a connection to the steering wheel is made with a double contact slip ring. Test points on this system are similar to those of a system with a relay, but there is no control circuit.

Horn Replacement Horns are generally mounted on the radiator core support by bolts and nuts or sheet metal screws. It may be necessary to remove the grille or other parts to access the horn mounting screws. To replace a horn, simply remove the fasteners and lift the old horn from its mounting bracket. See Figure 44–4. Clean the attachment area on the mounting bracket and chassis before installing the new horn. Some models use a corrosion-resistant mounting screw to ensure a ground connection.

WINDSHIELD WIPER AND WASHER SYSTEM

Windshield wipers are used to keep the viewing area of the windshield clean of rain. Windshield wiper systems and circuits vary greatly between manufacturers as well as between models. Some vehicles combine the windshield wiper and windshield washer functions into a single system. Many mini-vans and sport utility vehicles (SUVs) also have a rear-window wiper and washer system that works independently of the windshield system. In spite of the design differences, all windshield and rear-window wiper and washer systems operate in a similar fashion. Therefore, the same basic electrical tests and troubleshooting procedures apply to any system. Accurate test specifications and circuit diagrams are

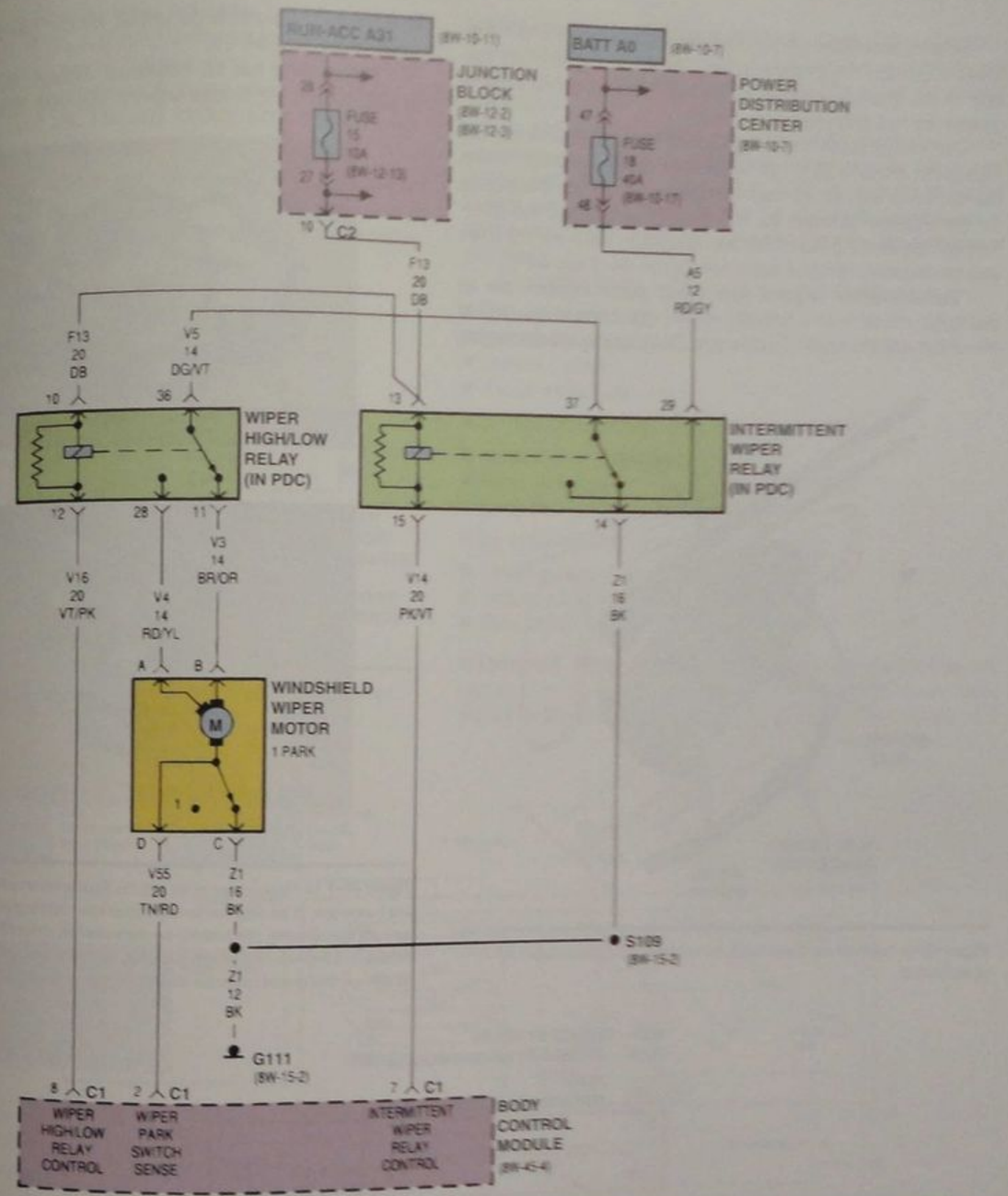


Figure 44–5 A circuit diagram is necessary to troubleshoot a windshield wiper problem.

required for diagnosing the system. See Figure 44–5. A typical combination wiper and washer system consists of:

- Wiper motor
- Gearbox
- Wiper arms and linkage
- Washer pump
- Hoses and jets
- Fluid reservoir
- Combination switch

The motor and gearbox assembly connects to the wiper switch in the instrument panel or steering column. See Figure 44–6. Some systems use either a one- or two-speed wiper motor, while others have a variable-speed motor.

WINDSHIELD WIPER MOTORS

The windshield wipers ordinarily use a special two-speed electric motor. Most are compound-wound motors, a motor type with both a **series-wound field** and a **shunt field**, which provides for two different speeds. The wiper switch provides the necessary electrical connections for either speed. Switches in the mechanical wiper motor assembly provide the necessary operation for "parking" and "controlling" of the wipers. See Figure 44–7 for a typical wiper motor assembly.

Most wiper motors use a permanent-magnet motor with a low-speed brush and a high-speed brush. The brush connects the battery to the internal windings of the motor, and the two brushes provide for two different motor speeds.

The ground brush is directly opposite the low-speed brush. The high-speed brush is off to the side of the low-speed brush. When current flows through the high-speed brush, there are fewer turns on the armature between the hot and ground brushes, and therefore the resistance is less. With less resistance, more current flows and the armature revolves faster. See Figures 44–8 and 44–9.

Variable-delay wipers (also called **pulse wipers**) use an electronic circuit with a variable resistor that controls the time of the charge and discharge of a capacitor. This charging and discharging of the capacitor controls the circuit for the operation of the wiper motor. See Figure 44–10.

The gearbox has an additional linkage arm to provide depressed parking for hidden wipers. This link extends to move the

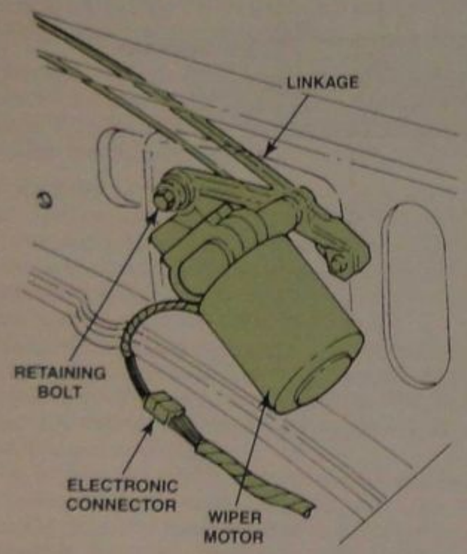


Figure 44–6 The motor and linkage bolt to the body and connect to the switch with a wiring harness.



(a)



(b)

Figure 44–7 (a) A typical wiper motor with the housing cover removed. The motor itself has a worm gear on the shaft that turns the small intermediate gear, which then rotates the gear and tube assembly, which rotates the crank arm (not shown) that connects to the wiper linkage. (b) If the brush retainer becomes loose, the wiper motor will stop because the brushes get their ground connection through the retainer and housing.

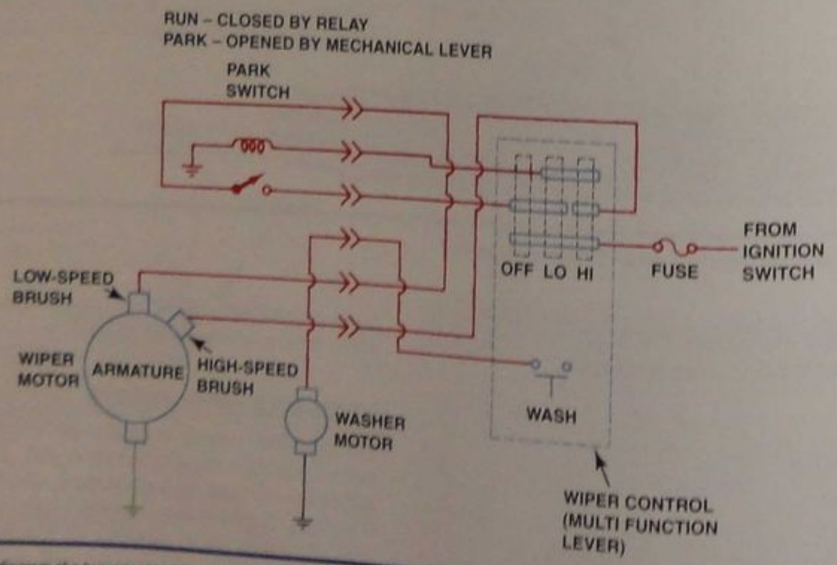


Figure 44–8 A typical wiring diagram of a two-speed windshield wiper circuit using a three-brush, two-speed motor. The dashed line for the multifunction lever indicates that the circuit shown is only a part of the total function of the steering column lever.

wipers into the park position when the motor turns in reverse of operating direction. With depressed park, the motor assembly includes an internal park switch. The park switch completes a circuit to reverse armature polarity in the motor when the windshield wiper switch is turned off. The park circuit opens once the wiper arms are in the park position.

Windshield Wiper Diagnosis Windshield wiper failure may be the result of an electrical fault or a mechanical problem, such as binding linkage. Generally, if the wipers operate at one speed setting but not another, the problem is electrical. There is one exception: If the wipers on a depressed or a positive park system do not depress or return properly, the problem may be either mechanical or electrical.

To distinguish between an electrical and mechanical problem, access the motor assembly and disconnect the wiper arm linkage from the motor and gearbox. Then, switch the motor on to each speed. If the motor operates at all speeds, the problem is mechanical. If the motor still does not operate, the problem is electrical.

If the wiper motor does not run at all, check for a:

- Tripped circuit breaker
- Grounded or inoperative switch
- Defective motor
- Circuit wiring fault

If the motor operates but the wipers do not, check for:

- Stripped gears in the gearbox
- Loose or separated motor-to-gearbox connection
- Loose linkage to the motor connection

If the motor does not shut off, check for a:

- Defective parking switch inside the motor
- Defective wiper switch
- Poor ground connection at the wiper switch

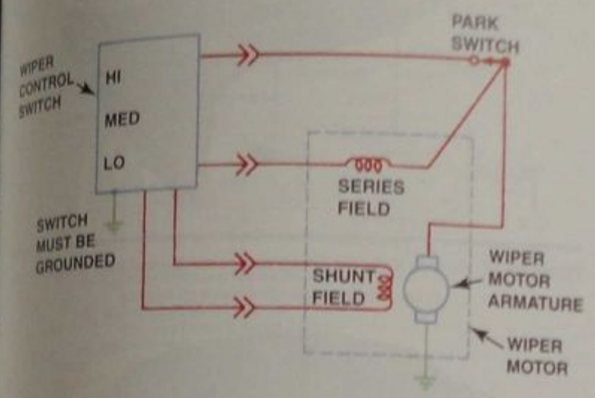


Figure 44–9 A typical wiring diagram of a three-speed windshield wiper circuit using a two-brush motor, but both a series and a shunt field coil.

Windshield Wiper Testing When the wiper motor does not operate with the linkage disconnected, a few simple voltmeter tests quickly isolate the circuit fault. Refer to the circuit diagram or a

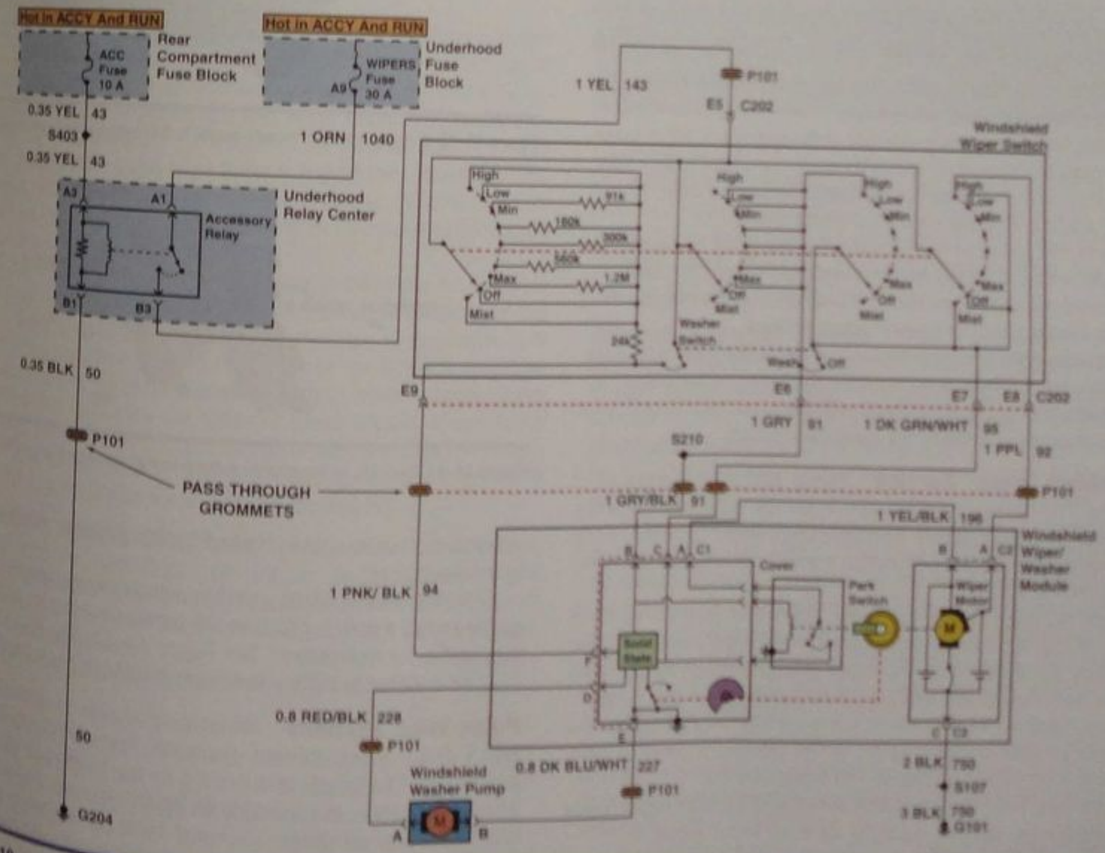
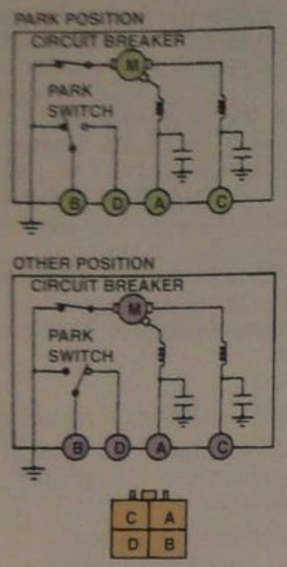


Figure 44–10 A variable pulse rate windshield wiper circuit. Notice that the wiring travels from the passenger compartment to underhood through rubber grommets called pass-throughs.



TERMINAL	OPERATION SPEED
C	LOW
A	HIGH

Figure 44–11 A typical wiper motor connector pin chart.

connector pin chart for the vehicle being serviced to determine where to take voltage readings. See Figure 44–11. To test the wiper system:

1. Switch the ignition on and set the wiper switch to a speed at which the motor does not operate.
2. Check for battery voltage available at the appropriate wiper motor terminal for the selected speed. If voltage is available to the motor, an internal motor problem is indicated. Replace the motor. No voltage available indicates a switch or circuit failure.
3. Check that battery voltage is available at the motor side of the wiper switch. If battery voltage is available, the circuit is open between the switch and motor. No voltage available indicates either a faulty switch or a power supply problem.
4. Check for battery voltage available at the power input side of the wiper switch. If voltage is available, the switch is defective. Replace the switch. No voltage available to the switch indicates a circuit problem between the battery and switch.

Windshield Wiper Service Wiper motors are replaced if defective. The motor usually mounts on the bulkhead (firewall). Bulkhead-mounted units are accessible from under the hood, while the cowl panel is removed to service a motor mounted in the cowl. See Figure 44–12.

After gaining access to the motor, removal is simply a matter of disconnecting the linkage, unplugging the electrical connectors, and unbolting the motor. Move the wiper linkage through its full travel by hand to check for any binding before installing the new motor.

Rear-window wiper motors are generally located inside the rear-door panel of station wagons, or the rear hatch panel on vehicles with a hatchback or liftgate. See Figure 44–13.

After removing the trim panel covering the motor, replacement is essentially the same as replacing the front wiper motor.

Wiper control switches are either installed on the steering column or on the instrument panel. Instrument panel switches are

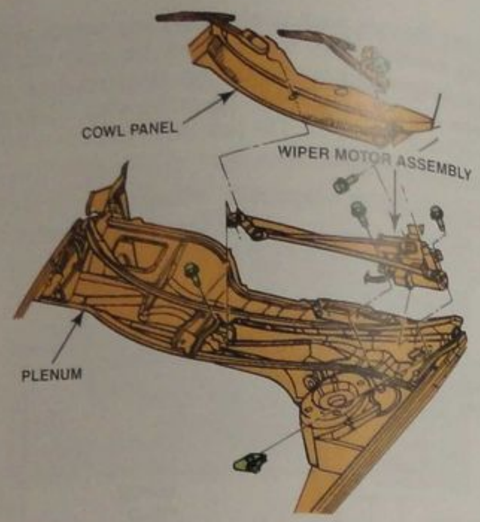


Figure 44–12 The wiper motor and linkage mount under the cowl panel on many vehicles.



Figure 44–13 A single wiper arm mounts directly to the motor on most rear-wiper applications.

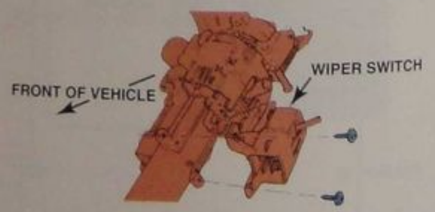
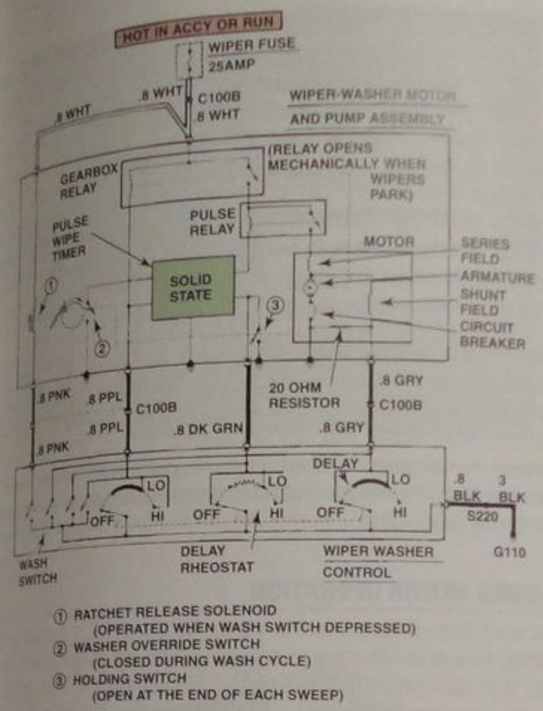


Figure 44–14 The wiper switch attaches to the steering column on many vehicles.

either snap-in units or are retained by one or more screws covered by a snap-in bezel.

Steering column wiper switches, which are operated by controls on the end of a switch stalk, require partial disassembly of the steering column for replacement. See Figure 44–14. The steering wheel must be removed to replace the wiper switch on some models.

Pulse-Wipe Systems Windshield wipers may also incorporate a delay, or intermittent operation, feature commonly called pulse wipe. The length of the delay, or the frequency of the intermittent operation, is adjustable on some systems. Pulse-wipe systems may rely on simple electrical controls, such as a variable resistance switch, or be controlled electronically through a control module.



① RATCHET RELEASE SOLENOID
(OPERATED WHEN WASH SWITCH DEPRESSED)
② WASHER OVERRIDE SWITCH
(CLOSED DURING WASH CYCLE)
③ HOLDING SWITCH
(OPEN AT THE END OF EACH SWEEP)

Figure 44–15 Circuit diagram of a rheostat-controlled, electronically timed interval wiper.

With any electronic control system, it is important to follow the diagnosis and test procedures recommended by the manufacturer for that specific vehicle.

A typical pulse, or interval, wiper system uses either a governor or a solid-state module that contains either a variable resistor or rheostat and capacitor. The module connects into the electrical circuitry between the wiper switch and wiper motor. The variable resistor or rheostat controls the length of the interval between wiper pulses. A solid-state pulse-wipe timer regulates the control circuit of the pulse relay to direct current to the motor at the prescribed interval. See Figure 44–15. The following troubleshooting procedure applies to most models.

If the wipers do not run at all, check the wiper fuse, fusible link, or circuit breaker and verify that voltage is available to the switch. Refer to a wiring diagram of the switch to determine how current is routed through it to the motor in the different positions. Next, disconnect the switch and use jumper wires to apply power directly to the motor on the different speed circuits. If the motor now runs, the problem is in the switch or module. Check for continuity in the circuit for each speed through the control-to-ground if the wiper motor runs at some, but not all, speeds.

Windshield Washer Diagnosis Most vehicles use a positive-displacement or centrifugal-type washer pump located in the washer reservoir. A momentary-contact switch, which is often part of a steering column–mounted combination switch assembly, energizes the washer pump.

Inoperative windshield washers may be caused by a:

- Blown fuse
- Empty reservoir
- Clogged nozzle
- Broken, pinched, or clogged hose
- Loose or broken wire
- Blocked reservoir screen
- Leaking reservoir

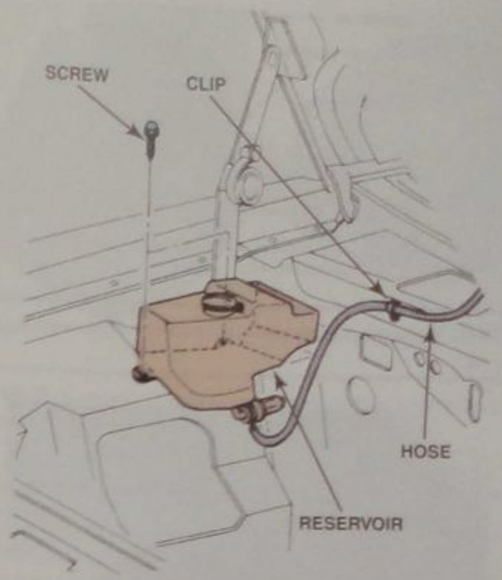


Figure 44–16 Disconnect the hose at the pump and operate the switch to check a washer pump.

To quick-check any washer system, make sure the reservoir has sufficient fluid, then disconnect the pump hose and operate the washer switch.

NOTE: Always use good-quality windshield washer fluid from a closed container to prevent contaminated fluid from damaging the washer pump. Radiator antifreeze (ethylene glycol) should never be used in any windshield wiper system.

See Figure 44–16.

If fluid squirts from the pump, the delivery system is at fault, not the motor, switch, or circuitry. If no fluid squirts from the pump, the problem is most likely a circuit failure, defective pump, or faulty switch. However, a clogged reservoir screen may be preventing fluid from entering the pump.

Windshield Washer Service When a fluid delivery problem is indicated, check for blocked, pinched, broken, or disconnected hoses, clogged nozzles, or a blocked washer pump outlet. If the pump motor does not operate, check for battery voltage available at the pump while operating the washer switch. If voltage is available and the pump does not run, check for continuity on the pump ground circuit. If there is no voltage drop on the ground circuit, replace the pump motor.

If battery voltage is not available at the motor, check for power through the washer switch. If voltage is available at and through the switch, there is a problem in the wiring between the switch and pump. Perform voltage-drop tests to locate the fault. Repair the wiring as needed and retest. If voltage is available to, but not through, the switch, replace the switch. Locate and correct the open or short circuit between the switch and the battery if battery voltage is not available to the switch.

Washer motors are not repairable and are simply replaced if defective. Centrifugal or positive-displacement pumps are located on or inside the washer reservoir tank or cover and secured with a retaining ring or nut. See Figure 44–17.

Washer pump switches are installed either on the steering column or on the instrument panel.

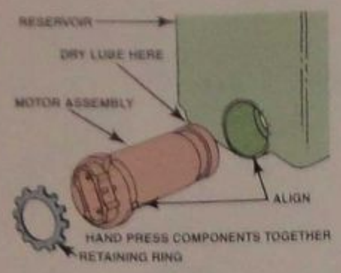


Figure 44–17 Washer pumps usually install into the reservoir and are held in place with a retaining ring.



Figure 44–18 A typical rain-sensing module located on the inside of the windshield near the inside rearview mirror.

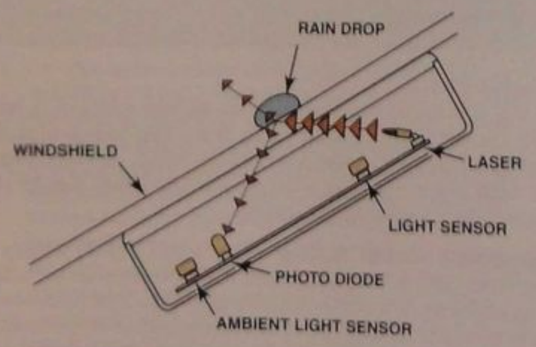


Figure 44–19 The electronics in the rain-sense wiper module can detect the presence of raindrops under various lighting conditions.

RAIN-SENSE WIPER SYSTEM

Parts and Operation **Rain-sense wiper** systems use a sensor located at the top of the windshield on the inside to detect rain droplets. This sensor is called the **rain sense module (RSM)** by General Motors and it determines and adjusts the time delay of the wiper based on how much moisture it detects on the windshield. The wiper switch can be left on the sense position all of the time and if no rain is sensed, the wipers will not swipe. See Figure 44–18.

The control knob is rotated to the desired wiper sensibility level. See Figure 44–19. The microprocessor in the RSM sends a command to the body control module (BCM). The RSM is a triangular-shaped black plastic housing. Fine openings on the windshield side of the housing are fitted with eight convex clear plastic lenses. The unit contains four infrared (IR) diodes, two photocells, and a microprocessor.

The IR diodes generate IR beams that are aimed by four of the convex optical lenses near the base of the module through the windshield glass. Four additional convex lenses near the top of the RSM are focused on the IR light beam on the outside of the windshield glass and allow the two photocells to sense changes in the intensity of the IR light beam. When sufficient moisture accumulates, the RSM detects a change in the monitored IR light beam intensity. The RSM processes the signal to the BCM over the data bus to command a swipe of the wiper.

Rain-Sense Wiper Diagnosis and Service If there is a complaint about the rain-sense wipers not functioning correctly, check the owner's manual to be sure that they are properly set and adjusted. Also, verify that the windshield wipers are functioning correctly on all speeds before diagnosing the rain-sensor circuits. Always follow the vehicle manufacturer's recommended diagnosis and testing procedures.

BLOWER MOTOR OPERATION

The same blower motor moves air inside the vehicle for air conditioning, heat, and defrosting or defogging. The fan switch controls the path that the current follows to the blower motor. The motor is usually a permanent-magnet, one-speed motor that operates at its maximum speed with full battery voltage. The switch gets current from the fuse panel with the ignition switch on, then directs full battery voltage to the blower motor for high speed and to the blower motor through resistors for lower speeds.

NOTE: Most Ford and some other vehicles place the blower motor resistors on the ground side of the motor circuit. The location of the resistors does not affect the operation because they are connected in series.

See Figures 44–20 through 44–22.

BLOWER MOTOR DIAGNOSIS

If the blower motor does not operate at any speed, the problem could be any of the following:

1. A defective ground wire or ground wire connection
2. A defective blower motor (not repairable; must be replaced)
3. An open circuit in the power-side circuit, including fuse, wiring, or fan switch

If the blower works on lower speeds but not on high speed, the problem is usually an inline fuse or high-speed relay that controls the heavy current flow for high-speed operation. The high-speed fuse or relay usually fails as a result of internal blower motor bushing wear, which causes excessive resistance to motor rotation. At slow blower speeds, the resistance is not as noticeable and the blower operates normally. The blower motor is a sealed unit, and if defective, must be replaced as a unit. If the blower motor operates normally at high speed but not at any of the lower speeds, the problem could be melted wire resistors or a defective switch. See Figure 44–23. The blower motor can be tested using a clamp-on DC ammeter, as shown in Figure 44–24.

Most blower motors do not draw more than 15 A on high speed. A worn or defective motor usually draws more current than normal and could damage the blower motor resistors or blow a fuse if not replaced.



Figure 44–20 A typical squirrel cage blower motor. A replacement blower motor usually does not come equipped with the squirrel cage blower, so it has to be switched from the old motor.



Figure 44–21 Typical blower motor resistors used to control blower motor speed.

TECH TIP ✓ **The 20-Ampere Fuse Test**

Most blower motors operate at about 12 amperes on high speed. If the bushings (bearings) on the armature of the motor become worn or dry, the motor turns more slowly. Because a motor also produces counter EMF, or CEMF, as it spins, a slower-turning motor will actually draw more amperes than a fast-spinning motor.

If a blower motor draws too many amperes, the resistors or the electronic circuit controlling the blower motor can fail. Testing the actual current draw of the motor is sometimes difficult because the amperage often exceeds the permissible amount for most digital meters.

One test recommended by General Motors is to unplug the power lead to the motor (retain the ground on the motor) and use a fused jumper lead with one end connected to the battery's positive terminal and the other end to the motor terminal. Use a 20-ampere fuse in the test lead, and operate the motor for several minutes. If the blower motor is drawing more than 20 amperes, the fuse will blow. Some experts recommend using a 15-ampere fuse. If the 15-ampere fuse blows and the 20-ampere fuse does not, then you know the approximate blower motor current draw.

ELECTRICAL ACCESSORY SYMPTOM GUIDE

The following list will assist technicians in troubleshooting electrical accessory systems.



Figure 44–22 A brushless DC motor that uses the body computer to control the speed. (Courtesy of Sammy's Auto Service, Inc.)

Problem	Possible Causes and/or Solutions
Blower Motor	
1. Blower motor does not operate.	1. Possible blown fuse. Possible poor ground connection on blower motor. Possible defective motor (use a jumper wire connected between the positive terminal of the battery and the blower motor power lead connection [lead disconnected] to check for blower motor operation).
2. Blower motor operates only on high speed.	2. Possible open in the resistors located in the air box near the blower motor. Possible stuck or defective high-speed relay. Possible defective blower motor control switch.
3. Blower motor operates in lower speed(s) only—no high speed.	3. Possible defective high-speed relay or blower high-speed fuse.
Windshield Wiper or Washer	
1. Windshield wipers are inoperative.	1. Possible blown fuse. Possible poor ground on the wiper motor or the control switch. Possible defective motor or linkage problem.
2. Windshield wipers operate on high speed or low speed only.	2. Possible defective switch. Possible defective motor assembly. Possible poor ground on the wiper control switch.
3. Windshield washers are inoperative.	3. Possible defective switch. Possible empty reservoir or clogged lines or discharge nozzles. Possible poor ground on the washer pump motor.
Horn	
1. Horn(s) are inoperative.	1. Possible poor ground on horn(s). Possible defective relay (if used). Possible open circuit in the steering column. Possible defective horn (use a jumper wire connected between the positive terminal of the battery and the horn [horn wire disconnected] to check for proper operation of the horn).
2. Horn(s) produce low volume or wrong sound.	2. Possible poor ground at horn. Possible incorrect frequency of horn.
3. Horn blows all the time.	3. Possible stuck horn relay (if used). Possible short-to-ground in the wire to the horn button.

NOTE: If the high-speed fuse blows a second time, check the current draw of the motor and replace the blower motor if the current draw is above specifications. Check for possible normal operation if the rear-window defogger is not in operation; some vehicles electrically prevent simultaneous operation of the high-speed blower and rear-window defogger to help reduce the electrical loads.

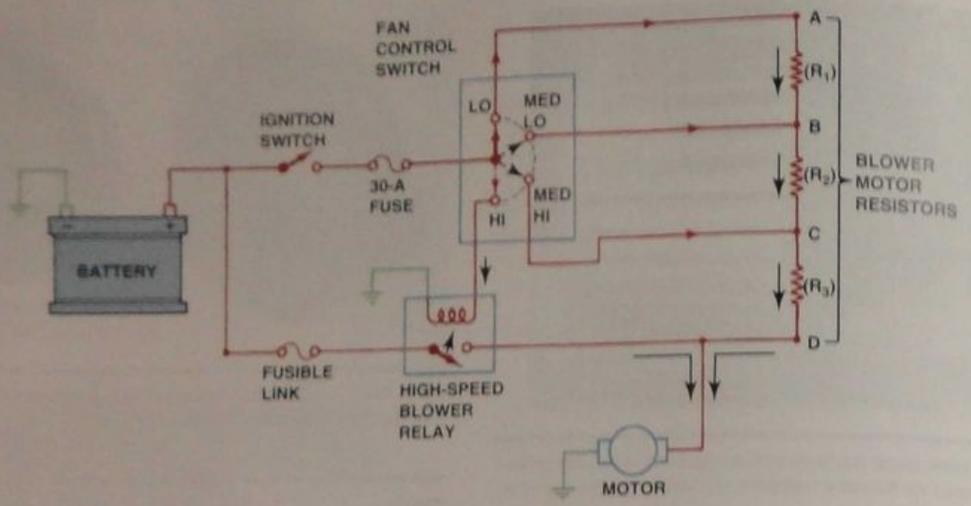


Figure 44–23 A typical blower motor circuit with four speeds. The three lowest fan speeds (low, medium-low and medium-high) use the blower motor resistors to drop the voltage to the motor and reduce current to the motor. On high, the resistors are bypassed. The "high" position on the fan switch energizes a relay, which supplies the current for the blower on high through a fusible link.



Figure 44–24 Using a mini AC/DC clamp-on multimeter to measure the current draw of a blower motor.

SUMMARY

1. Horn frequency can range from 1,800 to 3,550 Hz.
2. Most horn circuits use a relay, and the current through the relay coil is controlled by the horn switch.
3. Most windshield wipers use a three-brush, two-speed motor.
4. Windshield washer diagnosis includes checking the pump both electrically and mechanically for proper operation.
5. Most blower motors use resistors wired in series to control blower motor speed.
6. A good blower motor should draw less than 20 amperes.

REVIEW QUESTIONS

1. What are the three types of horn failure?
2. Explain how the horn switch is used to operate the horn.
3. Describe how to determine if a windshield wiper problem is electrical or mechanical.
4. Explain why a defective blower motor draws more current (amperes) than a good motor.

CHAPTER QUIZ

1. Technician A says that a defective high-speed blower motor relay could prevent high-speed blower operation, yet allows normal operation at low speeds. Technician B says that a defective (open) blower motor resistor can prevent low-speed blower operation, yet permit normal high-speed operation. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. To determine if a windshield wiper problem is electrical or mechanical, the service technician should _____.
   a. Disconnect the linkage arm from the windshield wiper motor and operate the windshield wiper
   b. Check to see if the fuse is blown
   c. Check the condition of the wiper blades
   d. Check the washer fluid for contamination
3. A weak-sounding horn is being diagnosed. Technician A says that a poor ground connector at the horn itself can be the cause. Technician B says an open relay can be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. What controls the operation of a pulse-wiper system?
   a. A resistor that controls current flow to the wiper motor
   b. A solid-state (electronic) module
   c. A variable-speed gem set
   d. A transistor
5. Which pitch horn is used for a single horn application?
   a. High-pitched
   b. Low-pitched
6. The horn switch on the steering wheel _____.
   a. Sends electrical power to the horns
   b. Provides the ground circuit for the horn
   c. Grounds the horn relay coil
   d. Provides power (12 V) to the horn relay
7. A rain-sense wiper system uses a rain sensor that is usually mounted _____.
   a. Behind the grille
   b. Outside of the windshield at the top
   c. Inside the windshield at the top
   d. On the roof
8. Technician A says a blower motor can be tested using a fused jumper lead. Technician B says a blower motor can be tested using a clamp-on ammeter. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A defective blower motor draws more current than a good motor because _____.
   a. The speed of the motor increases
   b. The CEMF decreases
   c. The airflow slows down, which decreases the cooling of the motor
   d. Both a and c
10. Windshield washer pumps can be damaged if _____.
    a. Pure water is used in freezing weather
    b. Contaminated windshield washer fluid is used
    c. Ethylene glycol (antifreeze) is used
    d. All of the above

CHAPTER 45 Accessory Circuits

OBJECTIVES: After studying Chapter 45, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "H" (Accessories Diagnosis and Repair). • Explain how cruise control operates and how to diagnose the circuit. • Describe how power door locks and windows operate. • Describe how a keyless remote can be reprogrammed.

KEY TERMS: adjustable pedals • backlight • control wires • cruise control • direction wires • electric adjustable pedals (EAP) • electronic throttle control (ETC) • HomeLink • independent switches • key fob • lockout switch • lumbar • master control switch • passive anti-theft system (PATS) • passkey I and II • passlock I, II, and truck • permanent-magnet (PM) electric motors • rubber coupling • screw jack assembly • sentry key immobilizer system (SKIS) • thermo-electric device (TED) • troxler effect • vehicle anti-theft system (VATS) • window regulator

CRUISE CONTROL

Cruise control (also called *speed* control) is a combination of electrical and mechanical components designed to maintain a constant, set vehicle speed without driver pressure on the accelerator pedal. Major components of a typical cruise control system include the following:

1. **Servo unit.** The servo unit attaches to the throttle linkage through a cable or chain. The servo unit controls the movement of the throttle by receiving a controlled amount of vacuum from a control module. See Figure 45–1. Some systems use a stepper motor and do not use engine vacuum.
2. **Computer or cruise control module.** This unit receives inputs from the brake switch, throttle position (TP) sensor, and vehicle speed sensor. It operates the solenoids or stepper motor to maintain the set speed.
3. **Speed set control.** A speed set control is a switch or control located on the steering column, steering wheel, dash, or console. Many cruise control units feature coast, accelerate, and resume functions. See Figure 45–2.
4. **Safety release switches.** Whenever the brake pedal is depressed, the cruise control system is disengaged through use of an electrical and vacuum switch, usually located on the brake pedal bracket. Both electrical and vacuum releases are used to be certain that the cruise control system is released, even in the event of failure of one of the release switches.

Cruise Control Operation A typical cruise control system can be set only if the vehicle speed is 30 mph or more. In a noncomputer-operated system, the transducer contains a low-speed electrical switch that closes whenever the speed-sensing section of the transducer senses a speed exceeding the minimum engagement speed.



Figure 45–1 This cruise control servo unit has an electrical connection with wires that go to the cruise control module or the vehicle computer, depending on the vehicle. The vacuum hoses supply engine manifold vacuum to the rubber diaphragm that moves the throttle linkage to maintain the preset speed.

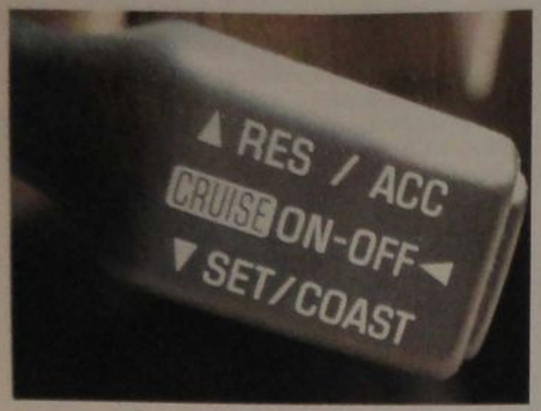


Figure 45–2 A cruise control used on a Toyota/Lexus.

NOTE: Toyota-built vehicles do not retain the set speed in memory if the vehicle speed drops below 25 MPH (40 km/h). The driver is required to set the desired speed again. This is normal operation and not a fault with the cruise control system.

When the set button is depressed on the cruise control, solenoid values on the servo unit allow engine vacuum to be applied to one side of the diaphragm, which is attached to the throttle plate of the engine through a cable or linkage. The servo unit usually contains two solenoids to control the opening and closing of the throttle.

- One solenoid opens and closes to control the passage, which allows engine vacuum to be applied to the diaphragm of the servo unit, increasing the throttle opening.
- One solenoid to bleed air back into the sensor chamber to reduce the throttle opening.

The throttle position (TP) sensor or a position sensor, inside the servo unit, sends the throttle position information to the cruise control module.

TECH TIP ✓ **Bump Problems**

Cruise control problem diagnosis can involve a complex series of checks and tests. The troubleshooting procedures vary from manufacturer to manufacturer (and year to year), so a technician should always consult a service manual for the exact vehicle being serviced. However, every cruise control system uses a brake safety switch and, if the vehicle has manual transmission, a clutch safety switch. The purpose of these safety switches is to ensure that the cruise control system is disabled if the brakes or clutch is applied. Some systems use redundant brake pedal safety switches, one electrical to cut off power to the system and the other vacuum to bleed vacuum away from the actuating unit.

If the cruise control "cuts out" or disengages itself while traveling over bumpy roads, the most common cause is a misadjusted brake (and/or clutch) safety switch(es). Often, a simple readjustment of these safety switches will cure the intermittent cruise control disengagement problems.

CAUTION: Always follow manufacturers' recommended safety switch adjustment procedures. If the brake safety switch(es) is misadjusted, it could keep pressure applied to the master brake cylinder, resulting in severe damage to the braking system.

Noncomputer-Controlled Resume-Type Cruise Control Most resume-style noncomputer-controlled cruise control systems use a two-piece rubber clutch to retain a "mechanical memory" of the vehicle road speed. Depressing the brake pedal causes a vacuum-release solenoid to release vacuum from the servo unit, and the cruise control stops maintaining vehicle speed. When "resume" is pushed, the vacuum solenoid closes and vacuum is again applied to the servo unit. The speed is "remembered" by the position of the split rubber clutch.

Computer-Controlled Cruise Control Most computer-controlled cruise control systems use the vehicle's speed sensor input to the engine-control computer for speed reference. Computer-controlled cruise control units also use servo units for throttle control, control switches for driver control of cruise control functions, and both electrical and vacuum brake pedal release switches. See Figure 45–3.

Electronic Throttle Cruise Control Many vehicles are equipped with an **electronic throttle control (ETC)** system. An electronic throttle control system uses a DC electric motor to move the throttle plate that is spring-loaded partially open. The motor actually closes the throttle at idle against spring pressure. The spring-loaded position is the default position and results in a high idle speed. The power train control module (PCM) uses the input signals from the accelerator pedal position (APP) sensor to determine the desired throttle position. The PCM then commands the throttle to the necessary position of the throttle plate. See Figure 45–4.

The cruise control on a vehicle equipped with an electronic throttle control system consists of a switch to set the desired speed. The PCM receives the vehicle speed information from the vehicle speed (VS) sensor and uses the ETC system to maintain the set speed.

Diagnosis and Service Any fault in the APP sensor or ETC system will disable the cruise control function. Always follow the specified troubleshooting procedures, which will usually include the use of a scan tool to properly diagnose the ETC system.

TECH TIP ✓ **Use Trailer Tow Mode**

Some customers complain that when driving in hilly or mountainous areas that the speed of the vehicle will sometimes go 5 to 8 mph below the set speed. The automatic transmission then downshifts, the engine speed increases, and the vehicle returns to the set speed. To help avoid the slowdown and rapid acceleration, ask the customer to select the trailer towing position. When this mode is selected, the automatic transmission downshifts almost as soon as the vehicle speed starts to decrease. This results in a smoother operation and is less noticeable to both the driver and passengers. See Figure 45–5 on page 508.

Troubleshooting Cruise Control Cruise control system troubleshooting is usually performed using the step-by-step procedure as specified by the vehicle manufacturer.

The usual steps in the diagnosis of an inoperative or incorrectly operating cruise control include the following:

Step #1 Check that the cruise control fuse is not blown and that the cruise control dash light is on when the cruise control is turned on.

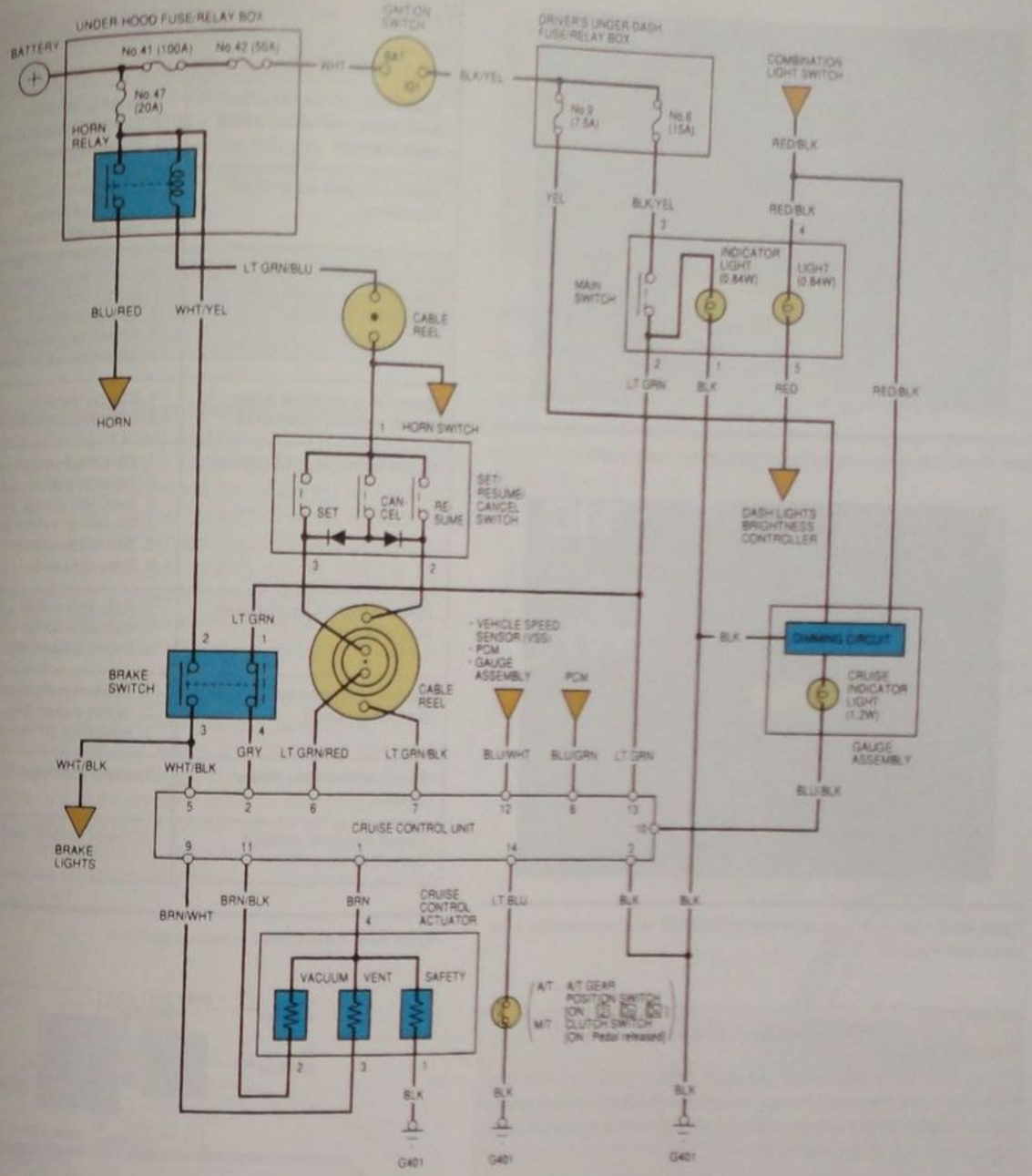


Figure 45–3 Circuit diagram of a typical electronic cruise control system.

Step #2 Check for proper operation of the brake and/or clutch switch.

Step #3 Inspect the throttle cable and linkage between the sensor unit and the throttle plate for proper operation without binding or sticking.

Step #4 Check the vacuum hoses for cracks or other faults.

Step #5 Use a hand-operated vacuum pump and check that the vacuum servo unit can hold vacuum without leaking.

Step #6 Check the servo solenoids for proper operation, including a resistance measurement check.

A quick method used by many dealers is to use known-good components that can be quickly plugged in to check for proper operation. See Figure 45–6.

CAUTION: Most vehicle manufacturers warn in the owner's manual that cruise control should not be used when it is raining or if the roads are slippery. Cruise control systems operate the throttle and, if the drive wheels start to hydroplane, the vehicle slows, causing the cruise control unit to accelerate the engine. When the engine is accelerated and the drive wheels are on a slippery road surface, vehicle stability will be lost and might possibly cause a crash.



Figure 45–4 A typical electronic throttle with the protective covers removed.



Figure 45–5 A trailer icon lights on the dash of this Cadillac when the transmission trailer towing mode is selected.

TECH TIP ✓ **Check the Third Brake Light**

On many General Motors vehicles, the cruise control will not work if the third brake light is out. This third brake light is called the centrally high-mounted stop light or CHMSL. Always check the brake lights first if the cruise control does not work on a General Motors vehicle.

HEATED REAR-WINDOW DEFOGGERS

An electrically heated rear-window defogger system uses an electrical grid baked on the glass that warms the glass to about 85°F (29°C) and clears it of fog or frost. The rear window is also called a **backlight**. The rear-window defogger system is controlled by a driver-operated switch and a timer relay. See Figure 45–7.

The timer relay is necessary because the window grid can draw up to 30 amperes, and continued operation would put a strain on the battery and the charging system. Generally, the timer relay permits current to flow through the rear-window grid for only 10 minutes. If the window is still not clear of fog after 10 minutes, the driver can turn the defogger on again, but after the first 10 minutes any additional defogger operation is limited to 5 minutes.

Electric grid type rear-window defoggers can be damaged easily by careless cleaning or scraping of the inside of the rear-window glass. Short broken sections of the rear-window grid can be repaired using a special epoxy-based electrically conductive material. If more than one section is damaged or if the damaged grid length is greater than approximately 1 1/2 inches (3.8 centimeters), a replacement rear-window glass may be required to restore proper defogger operation.

ELECTRONIC SPEED CONTROL SYMPTOM-BASED CHART	
PROBLEM	CHECK
Speed control operates, but does not accelerate or coast down properly	1. Control switch 2. Control switch circuit 3. Servo assembly
Speed changes up or down constantly	1. Throttle linkage adjustment 2. Servo assembly 3. Speedometer cable and sensor 4. Amplifier or reserve
Does not disengage when brakes are applied	1. Brake switch and circuit 2. Vacuum dump valve 3. Servo assembly 4. Amplifier or reserve
Does not disengage when clutch pedal is depressed	1. Clutch switch 2. Clutch switch circuit
Speed does not set in system	1. Throttle linkage adjustment 2. Control switch and circuit 3. Vacuum dump valve 4. Clutch or brake switch 5. Servo assembly 6. Speed sensor
Speed wanders up or down after it is set	1. Actuator cable adjustment 2. Vacuum dump valve 3. Servo assembly
System operates but does not resume properly	1. Control switch and circuit 2. Servo assembly 3. Amplifier or reserve
Speed will resume below 20 mph	Control module
Speed engages without operating set button	Control switch and circuit

Figure 45–6 A cruise control symptom-based chart.

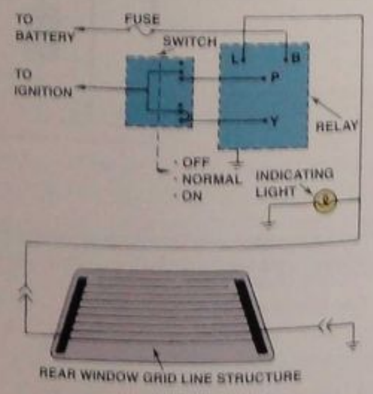


Figure 45–7 A switch and relay control current through the heating grid of a rear-window defogger.

The electrical current through the grids depends, in part, on the temperature of the conductor grids. As the temperature decreases, the resistance of the grids decreases and the current flow increases, helping to warm the rear glass. As the temperature of the glass increases, the resistance of the conductor grids increases and the current flow decreases. Therefore, the defogger system tends to self-regulate the electrical current requirements to match the need for defogging.

NOTE: Some vehicles use the wire grid of the rear-window defogger as the radio antenna. Therefore, if the grid is damaged, radio reception can also be affected.

Troubleshooting a Heated Rear-Window Defogger Troubleshooting a nonfunctioning rear-window defogger unit involves using a test light or a voltmeter to check for voltage to the grid. If no voltage is present at the rear window, check for voltage at the switch and relay timer assembly. A poor ground connection on the opposite side of the grid from the power side can also cause the rear defogger not to operate. Because most defogger circuits use an indicator light switch and a relay timer, it is possible to have the indicator light on, even if the wires are disconnected at the rear-window grid. A voltmeter can be used to test the operation of the rear-window defogger grid. See Figure 45–8.

With the negative test terminal attached to a good body ground, carefully probe the grid conductors. There should be a decreasing voltage reading as the probe is moved from the power ("hot") side of the grid toward the ground side of the grid. If there is a brake grid wire, it can be repaired using an electrically conductive substance available in a repair kit. See Figure 45–9.

Most vehicle manufacturers recommend that grid wire less than 2 inches long be repaired; otherwise, the entire rear window will need to be replaced.

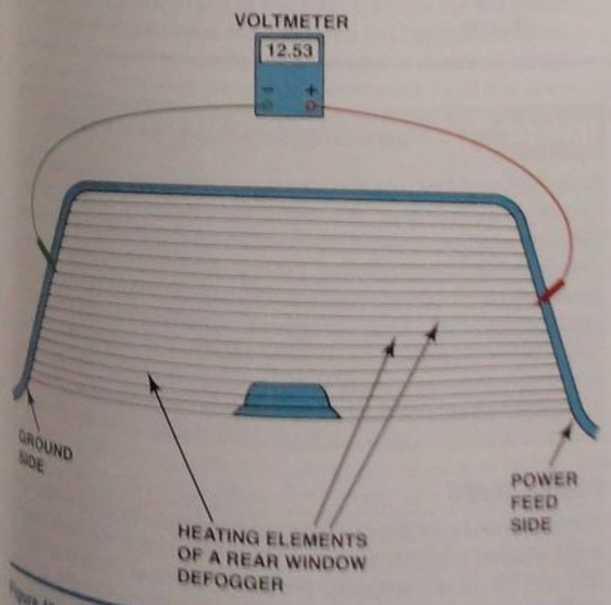


Figure 45–8 Checking a rear-window defogger grid with a voltmeter. As the voltmeter positive lead is moved along the grid (on the inside of the vehicle), the voltmeter reading should steadily decrease as the meter approaches the ground side of the grid.

TECH TIP ✓ **The Breath Test**

It is difficult to test for the proper operation of all grids of a rear-window defogger unless the rear window happens to be covered with fog. A common trick that works is to turn on the rear defogger and exhale onto the outside of the rear-window glass. In a manner similar to that of people cleaning eyeglasses with their breath, this procedure produces a temporary fog on the glass so that all sections of the rear grids can quickly be checked for proper operation.

HOMELINK GARAGE DOOR OPENER

Operation **HomeLink** is a device installed in many new vehicles that duplicates the radio frequency code of the original garage door opener. The frequency range that HomeLink is able to operate from is 288 to 418 MHz. The typical vehicle garage door opening system has three buttons that can be used to operate one or more of the following devices:

1. Garage doors equipped with a radio transmitter electric garage door opener
2. Gates
3. Entry door locks
4. Lighting or small appliances

The devices include both fixed frequency devices, usually older units, as well as rolling (encrypted) code devices. See Figure 45–10.

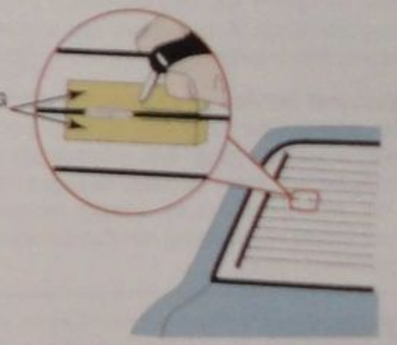


Figure 45–9 The typical repair material contains conductive silver-filled polymer, which dries in about 10 minutes and is usable in about 30 minutes.



Figure 45–10 A typical HomeLink garage door opener buttons. Notice that three different units can be controlled from the vehicle using the HomeLink system.

Programming a Vehicle Garage Door Opener When a vehicle is purchased, it must be programmed using the transmitter for the garage door opener or other device. The steps involved in programming the HomeLink module in the vehicle to the garage door opener include:

NOTE: The HomeLink® garage door opening controller can only be programmed by using a transmitter. If an automatic garage door system does not have a remote transmitter, HomeLink cannot be programmed.

Step #1 Unplug the garage door opener during programming to prevent it from being cycled on and off, which could damage the motor.

Step #2 Check that the frequency of the handheld transmitter is between 288 and 418 MHz.

Step #3 Install new batteries in the transmitter to be assured of a strong signal being transmitted to the HomeLink module in the vehicle.

Step #4 Turn the ignition key on, engine off (KOEO).

Step #5 While holding the transmitter 4 to 6 inches away from the HomeLink button, press and hold the HomeLink button while pressing and releasing the handheld transmitter every 2 seconds. Continue pressing and releasing the transmitter until the indicator light near the HomeLink button changes from slow blink to a rapid flash.

Step #6 Verify that the vehicle garage door system (HomeLink) button has been programmed. Press and hold the garage door button. If the indicator light blinks rapidly for 2 seconds and then comes on steady, the system has been successfully programmed using a rolling code design. If the indicator light is on steady, then it has been successfully programmed to a fixed frequency device.

Diagnosis and Service If a fault occurs with the HomeLink system, first verify that the garage door opener is functioning correctly. Also, check to see if the garage door opener remote control is capable of operating the door. Repair the garage door opener system as needed.

If the problem still exists, attempt reprogramming of the HomeLink vehicle system, being sure that the remote has a new recently purchased battery.

POWER WINDOWS

Power windows use electric motors to raise and lower door glass. They can be operated by both a **master control switch** located beside the driver and additional **independent switches** for each electric window. Some power window systems use a **lockout switch** located on the driver's controls to prevent operation of the power windows from the independent switches. Power windows are designed to operate only with the ignition switch in the "on" (run) position. This safety feature of power windows should never be defeated. Some manufacturers use a time delay for accessory power after the ignition switch is turned off. This feature permits the driver and passengers an opportunity to close all windows or operate other accessories for about 10 minutes or until a vehicle door is opened after the ignition has been turned off.

Most power window systems use **permanent-magnet (PM) electric motors.** It is possible to run a PM motor in the reverse direction simply by reversing the polarity of the two wires going to the motor. Most power window motors do not require that the motor be grounded to the body (door) of the vehicle. The ground for all the power windows is most often centralized near the driver's master control switch. The up-and-down motion of the individual window motors is controlled by double-pole, double-throw (DPDT) switches. These DPDT switches have five contacts and permit battery voltage to be applied to the power window motor; they also reverse the polarity and direction of the motor. See Figures 45–11 and 45–12 on page 511 and 512.

The power window motors rotate a mechanism called a **window regulator.** The window regulator is attached to the door glass and controls opening and closing of the glass. Door glass adjustments such as glass tilt and upper and lower stops are usually the same for both power and manual windows. See Figure 45–13 on page 512.

Troubleshooting Power Windows Before troubleshooting a power window problem, check for proper operation of all power windows. If one of the **control wires** that run from the independent switch to the master switch is cut (open), the power window may operate in just one direction. The window may go down but not up, or vice versa. However, if one of the **direction wires** that run from the independent switch to the motor is cut (open), the window will not operate in either direction. The direction wires and the motor must be electrically connected to permit operation and change of direction of the electric lift motor in the door.

1. If *both* rear-door windows fail to operate from the independent switches, check the operation of the window lockout (if the vehicle is so equipped) and the master control switch.
2. If one window can move in one direction only, check for continuity in the control wires (wires between the independent control switch and the master control switch).
3. If *all* windows fail to work or fail to work occasionally, check, clean, and tighten the ground wire(s) located either behind the driver's interior door panel or under the dash on the driver's side. A defective fuse or circuit breaker could also cause all the windows to fail to operate.
4. If one window fails to operate in both directions, the problem could be a defective window lift motor. The window could be stuck in the track of the door, which could cause the circuit breaker built into the motor to open the circuit to protect the wiring, switches, and motor from damage. To check for a stuck door glass, attempt to move (even slightly) the door glass up and down, forward and back, and side to side. If the window glass can move slightly in all directions, the power window motor should be able to at least move the glass.

TECH TIP ✔ **Programming Auto-Down Power Windows**

Many vehicles are equipped with automatic operation that can cause the window to go all the way down (or up) if the switch is depressed beyond a certain point or held for a fraction of a second. Sometimes this feature is lost if the battery in the vehicle has been disconnected. While this programming procedure can vary depending on the make and model, many times the window(s) can be reprogrammed without using a scan tool by simply depressing and holding the down button for 5 to 10 seconds. If the vehicle is equipped with an auto-up feature, repeat the procedure by holding the button up for 5 to 10 seconds. Always check service information for the specified method to use for the vehicle being serviced.

POWER SEATS

A typical power-operated seat includes a reversible electric motor and a transmission assembly that has three solenoids and six *drive cables* that turn the six seat adjusters. A 6-way power seat offers seat movement forward and backward, plus seat cushion movement up and down at the front and the rear. The drive cables are very similar to speedometer cables because they rotate inside a cable housing and connect the power output of the seat transmission to a gear or screw

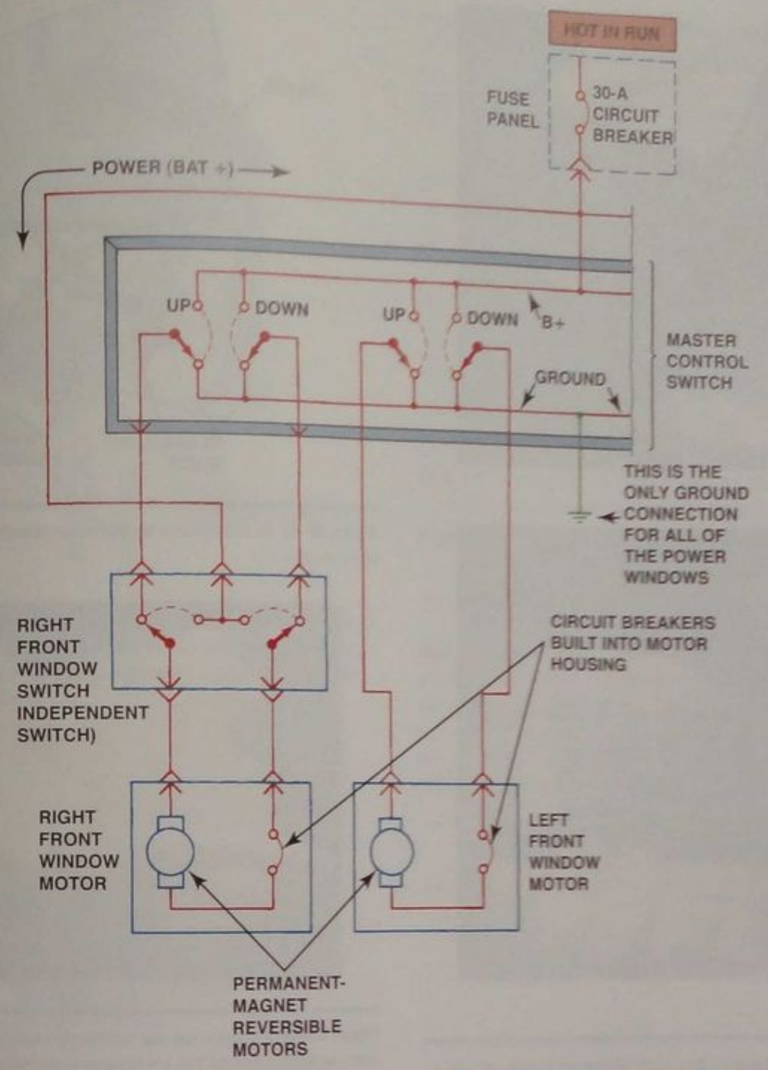


Figure 45–11 A typical power window circuit using PM motors. Control of the direction of window operation is achieved by directing the polarity of the current through the nongrounded motors. The only ground for the entire system is located at the master control (driver's side) switch assembly.

jack assembly that moves the seat. See Figure 45–14. A **screw jack assembly** is often called a *gear nut* and is used to move the front or back of the seat cushion up and down. See Figure 45–15 on page 513.

A **rubber coupling,** usually located between the electric motor and the transmission, could permit the electric motor to continue to rotate in the event of a jammed seat. This coupling is designed to prevent motor damage.

Most power seats use a permanent-magnet motor that can be reversed by simply reversing the polarity of the current sent to the motor by the seat switch. See Figure 45–16 on page 513.

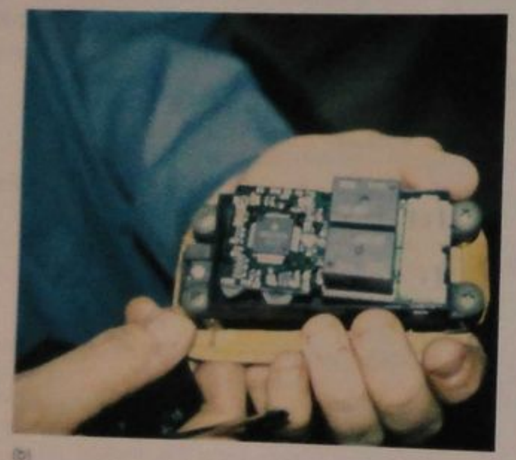
Most PM motors have a built-in circuit breaker to protect the motor from overheating. Many Ford power seat motors use three separate armatures inside one large permanent-magnet field housing. Some power seats use a series-wound electric motor with two separate field coils, one field coil for each direction of rotation. This type of power seat motor typically uses a relay to control the direction of current from the seat switch to the corresponding field coil of the seat motor. This type of power seat can be identified by the "click" heard whenever the seat switch is changed from up to down or front to back, or vice versa. The click is the sound of the relay switching the field coil current. Some power seats use as many as eight separate PM motors that operate all functions of the seat, including headrest height, seat length, and side bolsters, in addition to the usual 6-way power seat functions. Some power seats use a small air pump to inflate a bag or bags in the lower part of the back of the seat, called the **lumbar** because it supports the lumbar section of the spine.

Troubleshooting Power Seats Power seats are usually wired from the fuse panel so they can be operated without having to turn the ignition switch to "on" (run). If a power seat does not operate or make any noise, the circuit breaker (or fuse, if the vehicle is so equipped) should be checked first.

Step #1 Check the circuit breaker, usually located on the fuse panel, using a test light. The test light should light on both sides of the circuit breaker even with the ignition off. If the seat relay clicks, the circuit breaker is functioning, but the relay or electric motor may be defective.



(a)



(b)

Figure 45–12 (a) The independent (driver's door) power window switch plate looks like a normal simple switch until you turn it over (b) Notice that this power window contains a large integrated circuit with a lot of other electronic components to operate the express up and express down.

Step #2 Remove the screws or clips that retain the controls to the inner door panel or seat and check for voltage at the seat control.

Step #3 Also check the ground connection(s) at the transmission and clutch control solenoids (if equipped). The solenoids must be properly grounded to the vehicle body for the power seat circuit to operate.

If the power seat motor runs but does not move the seat, the most likely fault is a worn or defective rubber clutch sleeve between the electric seat motor and the transmission.

If the seat relay clicks but the seat motor does not operate, the problem is usually a defective seat motor or defective wiring between the motor and the relay. If the power seat uses a motor relay, the motor has a double reverse-wound field for reversing the motor direction. This type of electric motor must be properly grounded. Permanent-magnet motors do not require grounding for operation.

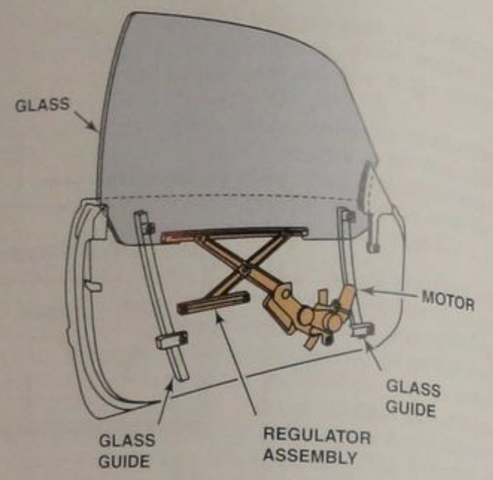


Figure 45–13 An electric motor and a regulator assembly raises and lowers the glass on a power window.



Figure 45–14 A typical power seat transmission assembly. Even though many of these units can be disassembled, they are designed to be replaced as an assembly if any part inside is defective.

HINT: Power seats are often difficult to service because of restricted working room. If the entire seat cannot be removed from the vehicle because the track bolts are covered, attempt to remove the seat from the top of the power seat assembly. These bolts are almost always accessible regardless of seat position.

TECH TIP ✔ **What Every Driver Should Know about Power Seats**

Power seats use an electric motor or motors to move the position of the seat. These electric motors turn small cables that operate mechanisms that move the seat. *Never* place rags, newspapers, or any other object under a power seat. Even ice scrapers can get caught between moving parts of the seat and can often cause serious damage or jamming of the power seat.

MEMORY SEATS

Components Memory seats are power seats that include a position sensor and a memory module that can store two or three different

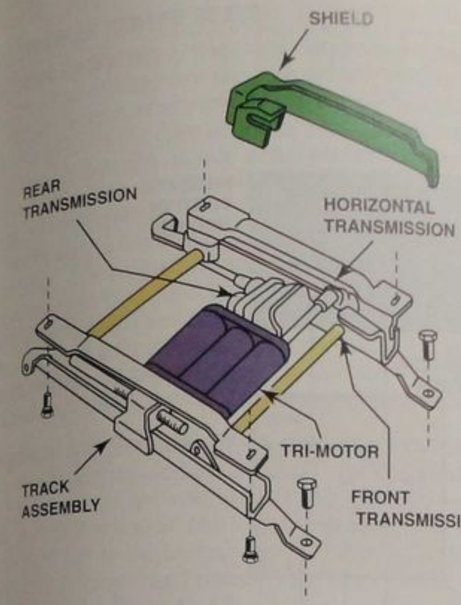


Figure **45–15** This power seat motor assembly houses three armatures to provide 6-way adjustment. Many power seats use one motor and a transmission assembly to operate the various gear nuts needed to move the seat.

positions. This feature allows different drivers to use the same vehicle without needing to reset the position of the seat. Memory seats use two or three numbered buttons, usually on the door panel, to select the position that has been stored in memory for that location. See Figure 45–17.

The memory seat position can also be set on some General Motors models by using a numbered key fob remote to unlock the door(s). When the receiver gets a signal from remote number one, for example, the seat and the outside mirrors are moved to the location in memory for driver number one.

Programming To program memory seats, most models include the following steps:

Step #1 Turn the ignition key on, engine off (KOEO).

Step #2 Put the gear selector in Park or Neutral.

Step #3 Move the seat and outside mirrors to the desired positions.

Step #4 Depress the set button and the memory 1, 2, or 3 buttons at the same time and hold until a beep is heard.

Step #5 Turn the ignition switch off.

Always check the owner's manual or service information for the exact setting procedure.

Operation Memory seats use a three-wire potentiometer as a seat position sensor. This voltage valve varies with the seat position and usually ranges from 0.5 to 4.5 volts. When a memory seat button is set, the seat position sensor voltage is stored in the memory seat module. There is also a position sensor for the seat back position and the headrest position if that is also powered and included

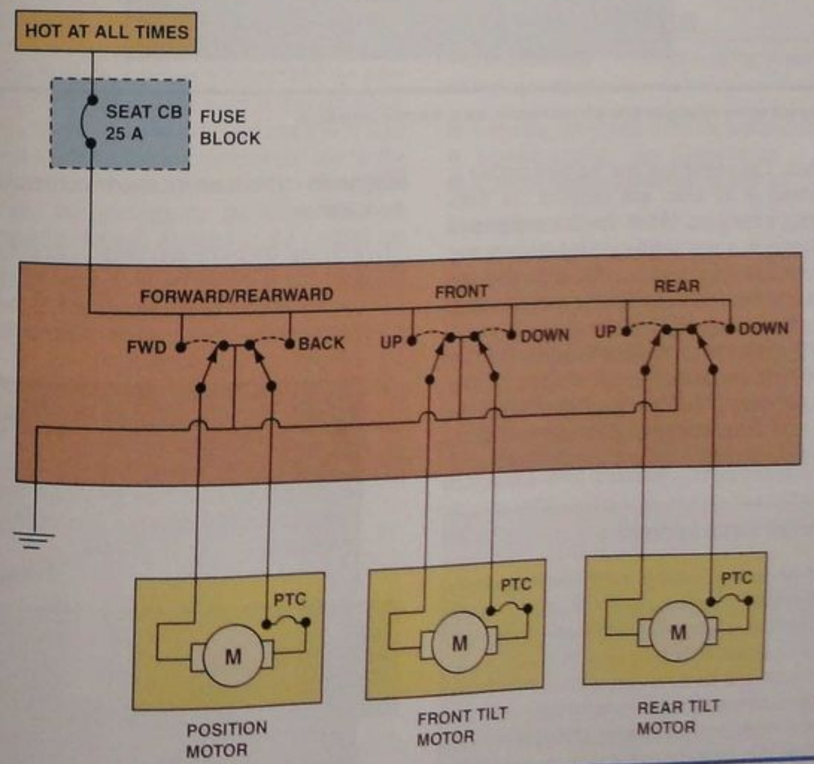


Figure 45–16 Typical power seat circuit diagram. Notice that each motor has a built-in electronic (solid-state) PTC circuit protector. The seat control switch can change the direction in which the motor(s) runs by reversing the direction in which the current flows through the motor.

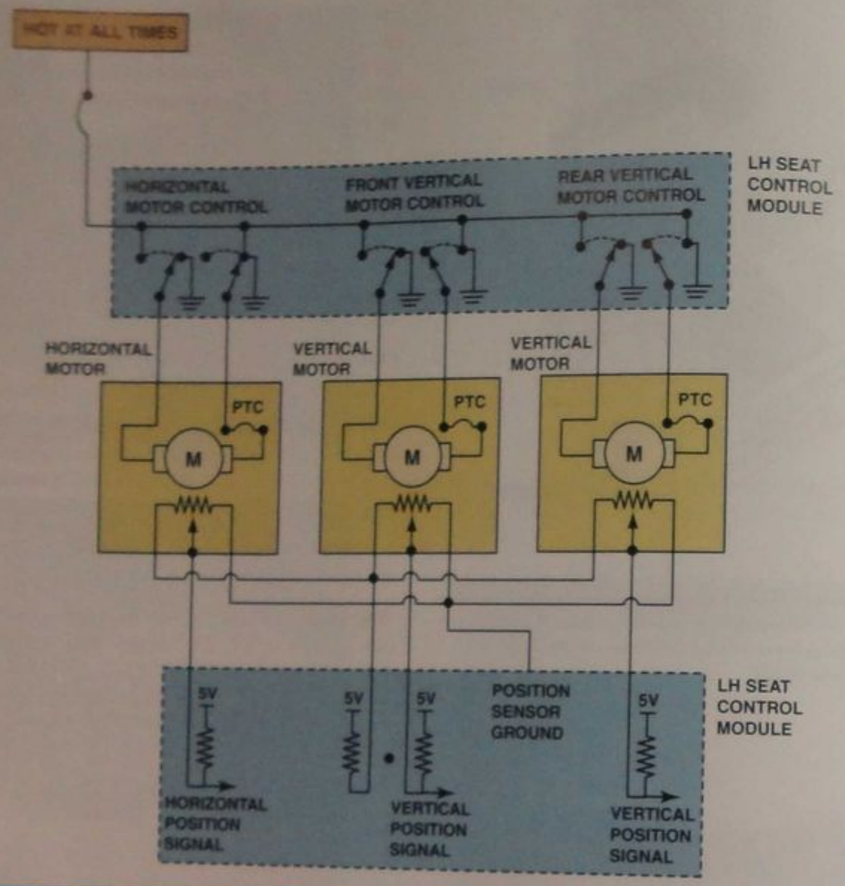


Figure 45–17 A typical memory seat module showing the three-wire potentiometer used to determine seat position.

with the memory function. The power seat and memory module is connected to battery power at all times and therefore can work without the ignition being turned on. When the driver depresses the key remote that is keyed to a seat position or the memory seat position button is depressed, the seat moves until it matches the position stored in the memory seat module. The memory seat module also commands the various seat motors to operate in a set sequence. For example, a typical memory seat may be commanded to move forward or backward to the memory position before the seat back position motor is activated. After the seat has achieved the memory position, most modules emit a beep. If the power seat cannot achieve the set position, a series of beeps is usually heard.

TECH TIP ✓ **Easy Exit Seat Programming**

Some vehicles are equipped with memory seats that allow the seat to move rearward when the ignition is turned off to allow easy exit from the vehicle. Vehicles equipped with this feature include an exit/entry button that is used to program the desired exit/entry position of the seat for each of two drivers.

If the vehicle is not equipped with this feature and only one driver usually uses the vehicle, the second memory position can be programmed for easy exit and entry. Simply set position one to the desired seat position and position two to the entry/exit position. Then, when exiting the vehicle, press memory number 2 to allow easy exit and easy entry the next time. Press memory one when in the vehicle to return the seat memory to the desired driving position.

Diagnosis If a memory seat is not working correctly, perform the following:

1. Verify that the power seat itself is functioning correctly. If the seat is not able to move forward or rearward, then the memory function will also not be able to function. If the power seat does not function, follow the testing procedure in the service information to locate and repair the fault.
2. Verify that the memory seat function is not functioning by trying all memory seat positions. If no seat movement is observed, reprogram the memory seat.
3. Attempt to reset the memory seat module by disconnecting the negative battery cable from the battery and wait 20 minutes. Reconnect the battery cable and attempt to program the memory seat module.

NOTE: This procedure may also delete all of the preset radio stations and clock settings. Be prepared to restore these settings before returning the vehicle to the customer.

4. Following service information procedures, check for proper power (voltage) and ground at the memory seat module.
5. Follow the vehicle manufacturer's recommended diagnostic and testing procedures.

ELECTRICALLY HEATED SEATS

Parts and Operation Heated seats use heating elements in the seat bottom, as well as in the seat back in many vehicles. The heating element is designed to warm the seat and/or back of the seat to about 100°F (37°C) or close to normal body temperature (98.6°F). Many heated seats also include a high-position or a variable temperature setting and the temperature of the seats can therefore be as high as 110°F (44°C).

A temperature sensor in the seat cushion is used to regulate the temperature. The sensor is a variable resistor which changes with temperature and is an input to a heated seat module. The heated seat module uses the seat temperature input, as well as the input from the high/low (or variable) temperature control to turn the current on or off to the heating element in the seat. Some vehicles are equipped with heated seats in the rear, as well as the front seats.

Diagnosis and Service When diagnosing a heated seat concern, start by verifying that the switch is in the on position and that the temperature of the seat is below normal body temperature. Using service information, check for power and ground at the control module and to the heating element in the seat. Most vehicle manufacturers recommend replacing the entire heating element if it is defective. See Figure 45–18.

HEATED AND COOLED SEATS

Parts and Operation Most electrically heated and cooled seats use a **thermo-electric device (TED)** located under the seat cushion and seat back. The thermo-electric device consists of positive and negative connections between two ceramic plates. Each ceramic plate has copper fins to allow the transfer of heat to air passing over the device and directed into the seat cushion. The thermo-electric device uses the Peltier effect, named after the inventor, Jean-Charles-Anthanase Peltier, a French clock maker. When electrical current flows through the module, one side is heated and the other side is cooled. Reversing the polarity of the current changes which side is heated. Most vehicles equipped with heated and cooled seats use two modules per seat—one for the seat cushion and one for the seat back. When the heated and cooled seats are turned on, air is forced through a filter and then through the thermo-electric modules. The air is then directed through passages in the foam of the seat cushion and seat back. Each thermo-electric device has a temperature sensor, a thermistor. The sensors are used by the control module to determine the temperature of the fins in the thermo-electric device so the controller can maintain the set temperature.



Figure 45–18 The heating wires of a heated seat are a replaceable part, but it does require that the upholstery be removed.

FREQUENTLY ASKED QUESTION ???

How Do Heated and Cooled Cup Holders Work?

Many heated and cooled cup holders use a thermo-electric device which uses the Peltier effect to cool or heat depending on the polarity of the current flowing through the unit. While some cooled glove boxes and cup holders use the air-conditioning system to cool, the thermo-electric device is the most efficient way to provide either cooling or heating.

Diagnosis and Service The first step in any diagnosis is to verify that the heated-cooled seat system is not functioning. Check the owner's manual or service information for the specified procedures. If the system works partially, check the air filter for each thermo-electric device. A partially clogged filter can restrict airflow and reduce the heating or cooling affect. If the system control indicator light is not on or the system does not work at all, check for power and ground at the thermo-electric devices. Always follow the vehicle manufacturer's recommended diagnosis and service procedures.

TECH TIP ✓ **Check the Seat Filter**

Heated and cooled seats usually use a filter to trap dirt and debris to help keep the air passages clean. If a customer complains of a slow heating or cooling of the seat, check the air filter and replace or clean as necessary.

HEATED STEERING WHEEL

Parts Involved A heated steering wheel usually consists of the following components:

- A steering wheel with a built-in heater in the rim
- A heated steering wheel control switch
- A heated steering wheel control module

Operation When the steering wheel heater control switch is turned on, a signal is sent to the control module and electrical current flows through the heating element in the rim of the steering wheel. See Figure 45–19.

The system remains on until the ignition switch is turned off or the driver turns off the control switch. The temperature of the steering wheel is usually calibrated to stay at about 90°F (32°C) and it requires about 3 to 4 minutes to reach that temperature depending on the outside temperature.

Diagnosis and Service Diagnosis of a heated steering wheel starts by verifying that the heated steering wheel is not working as designed.

NOTE: Most heated steering wheels do not work if the temperature inside the vehicle is about 90°F (32°C) or higher.

If the heated steering wheel is not working, follow the service information testing procedures, which would include checking the following:

1. Check the heated steering wheel control switch for proper operation. This is usually done by checking for voltage at both



Figure 45–19 The heated steering wheel is controlled by a switch on the steering wheel on this vehicle.

terminals of the switch. If voltage is available at only one of the two terminals of the switch and the switch has been turned on and off, an open (defective) switch is indicated.

2. Check for voltage and ground at the terminals leading to the heating element. If voltage is available at the heating element and the ground has less than 0.2 volt drop to a good chassis ground, the heating element is defective. The entire steering wheel has to be replaced if the element is defective. Always follow the service procedure for the vehicle.

ADJUSTABLE PEDALS

Adjustable pedals, also called **electric adjustable pedals (EAP),** place the brake pedal and the accelerator pedal on movable brackets that are motor operated. A typical adjustable pedal system includes the following components:

- *Adjustable pedal position switch,* which allows the driver to position the pedals.
- *Adjustable pedal assembly,* which includes the motor, threaded adjustment rods, and a pedal position sensor. See Figure 45–20.

The position of the pedals, as well as the position of the seat system, is usually included as part of the memory seat function and can be set for two or more drivers.

Diagnosis and Service The first step when there is a customer concern about the functioning of the adjustable pedals is to verify that the unit is not working as designed. Check the owner's manual or service information for the proper operation.

Follow the vehicle manufacturer's recommended troubleshooting procedure. Many diagnostic procedures include the use of a factory scan tool with bidirectional control capabilities to test this system.

TECH TIP **Check the Remote**

The memory function may be programmed to a particular key fob remote, which would command the adjustable pedals to move to the position set in memory. Always check both remote settings before attempting to repair a problem that may not be a problem.

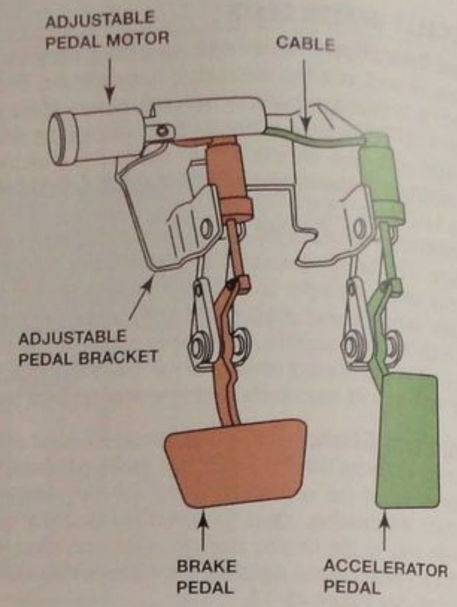


Figure 45–20 A typical adjustable pedal assembly. Both the accelerator and the brake pedal can be moved forward and rearward by using the adjustable pedal position switch.

AUTOMATIC DIMMING MIRRORS

Parts and Operation Automatic dimming mirrors use electrochromic technology to dim the mirror in proportion to the amount of headlight glare from other vehicles at the rear. The electrochromic technology developed by Gentex Corporation uses a gel that changes with light between two pieces of glass. One piece of glass acts as a reflector and the other has a transparent (clear) electrically conductive coating. The inside rearview mirror also has a forward-facing light sensor that is used to detect darkness and signal the rearward-facing sensor to begin to check for excessive glare from headlights behind the vehicle. The rearward-facing sensor sends a voltage to the electrochromic gel in the mirror that is in proportion to the amount of glare detected. The mirror dims in proportion to the glare and then becomes like a standard rearview mirror when the glare is no longer detected. If automatic dimming mirrors are used on the exterior, the sensors in the interior mirror and electronics are used to control both the interior and exterior mirrors.

FREQUENTLY ASKED QUESTION ???

What Is the Troxler Effect?

The **Troxler Effect,** also called *Troxler fading,* is a visual effect where an image remains on the retina of the eye for a short time after the image has been removed. The effect was discovered in 1804 by Igney Paul Vital Troxler (1780–1866), a Swiss physician. Because of the Troxler effect, headlight glare can remain on the retina of the eye and create a blind spot. At night, this fading away of the bright lights from the vehicle in the rear reflected by the rearview mirror can cause a hazard.

Diagnosis and Service If a customer concern states that the mirrors do not dim when exposed to bright headlights from the vehicle behind, the cause could be sensors or the mirror itself. Be sure that the mirror is getting electrical power. Most automotive dimming mirrors have a green light which indicates that it has electrical power. If no voltage is found at the mirror, follow standard troubleshooting procedures to find the cause. If the mirror is getting voltage, start the diagnosis by placing a strip of tape over the forward-facing light sensor. Turn the ignition key on, engine off (KOEO), and observe the operation of the mirror when a flashlight or trouble light is directed onto the mirror. If the mirror reacts and dims, the forward-facing sensor is defective. Most of the time, the entire mirror assembly has to be replaced if any sensor or mirror faults are found.



Figure 45–21 This auto dimming mirror also includes an outside temperature sensor and a compass. Follow the instructions in service information if the compass is not working correctly because it may need to be calibrated.

One typical fault that can occur to automatic dimming mirrors is that a crack can occur in the mirror assembly allowing the gel to escape from between the two layers of glass. This gel can drip onto the dash or center console and can cause harm to these surfaces. The mirror should be replaced at the first sign of any gel leakage. See Figure 45–21.

OUTSIDE FOLDING MIRRORS

Mirrors that can be electrically folded inward are a popular feature, especially on larger sport utility vehicles. A control inside is used to fold both mirrors inward when needed, such as when entering a garage or close parking spot. For diagnosis and servicing of outside folding mirrors, check service information for details.

REAL WORLD FIX **The Case of the Haunted Mirrors**

The owner complained that while driving, either one or the other outside mirror would fold in without any button being depressed. Unable to verify the customer concern, the service technician looked at the owner's manual to find out exactly how the mirrors were supposed to work. In the owner's manual, there was a caution statement that said that if the mirror is electrically folded inward and then manually pushed out, the mirror will not lock into position. The power folding mirrors must be electrically cycled outward, using the mirror switches to lock them in position. After cycling both mirrors inward and outward electrically, the problem was solved. See Figures 45–22 and 45–23.

ELECTRIC POWER DOOR LOCKS

Electric power door locks use either a solenoid or a permanent-magnet (PM) motor to lock or unlock all vehicle door locks from a control switch or switches. Large (heavy) solenoids were typically used in older vehicles. These solenoids normally used two-wire connections that carried a high-ampere current through a relay controlled by a door lock switch. With a solenoid-style door lock, only one of the two wires is used at any one time. If current flows through one wire to the solenoid, the door locks; the door unlocks when current flows through the other wire to the solenoid. The solenoids must be grounded to the metal of the door to complete the electrical circuit. Because of constant opening and closing of a typical vehicle door, a solenoid-style power door lock frequently vibrates loose from the mounting inside the door and fails to operate because of the poor ground connection with the metal door.



Figure 45–22 Electrically folded mirror in the folded position.



Figure 45–23 The electric mirror control is located on the driver's side door panel on this Cadillac Escalade.

Most electric door locks use a permanent-magnet (PM) reversible electric motor that operates the lock-activating rod. PM reversible motors do not require grounding because, as with power windows, the motor control is determined by the polarity of the current through the two motor wires. See Figure 45–24.

Some two-door vehicles do *not* use a power door lock relay because the current flow for only two PM motors can be handled through the door lock switches. However, most four-door vehicles and vans with power locks on rear and side doors use a relay to control the current flow necessary to operate four or more power door lock motors. The door lock relay is controlled by the door lock

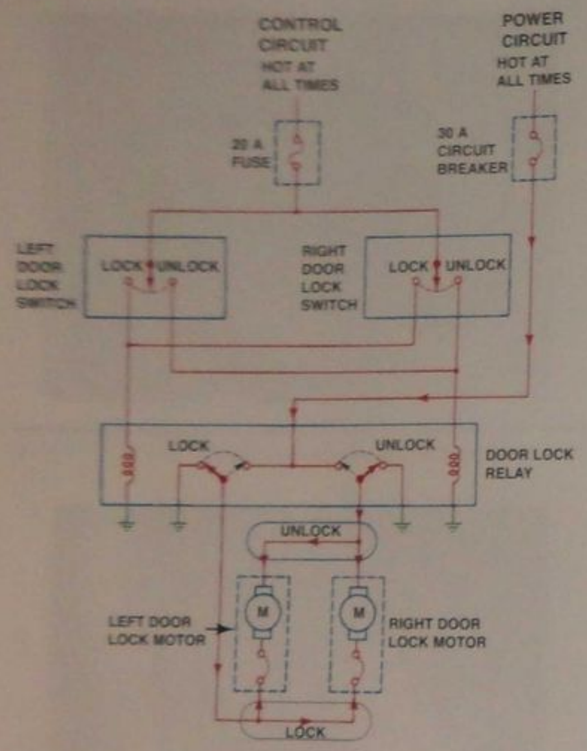


Figure 45–24 A typical electric power door lock circuit diagram. Note that the control circuit is protected by a fuse, whereas the power circuit is protected by a circuit breaker. As with the operation of power windows, power door locks typically use reversible PM nongrounded electric motors. These motors are geared mechanically to the lock-unlock mechanism.

switch and is commonly the location of the one and only *ground* connection for the entire door lock circuit.

KEYLESS ENTRY

Even though some Ford vehicles use a keypad located on the outside of the door, most keyless entry systems use a wireless transmitter built into the key or key fob. A **key fob** is a decorative tab or item on a key chain. See Figure 45–25.

The transmitter broadcasts a signal that is received by the electronic control module, which is generally mounted in the trunk or under the instrument panel. See Figure 45–26.

The electronic control unit sends a voltage signal to the door lock actuator(s) located in the doors. Generally, if the transmitter unlock button is depressed once, only the driver's door is unlocked. If the unlock button is depressed twice, then all doors unlock.

Rolling Code Reset Procedure Many keyless remote systems use a rolling code-type transmitter and receiver. In a conventional system, the transmitter emits a certain fixed frequency, which is received by the vehicle control module. This single frequency can be intercepted and rebroadcast to open the vehicle.

A rolling code-type transmitter emits a different frequency every time the transmitter button is depressed and then rolls over to another frequency so that it cannot be intercepted. Both the transmitter and the receiver must be kept in synchronized order so that the remote will function correctly.

If the transmitter is depressed when it is out of range from the vehicle, the proper frequency may not be recognized by the receiver,



Figure 45–25 A typical key fob remote with the cover removed showing the replaceable battery.

which did not roll over to the new frequency when the transmitter was depressed. If the transmitter does not work, try to resynchronize the transmitter to the receiver by depressing and holding both the lock and the unlock button for 10 seconds when within range of the receiver.

Keyless Entry Diagnosis A small battery powers the transmitter, thus a weak battery is a common cause of remote power locks failing to operate. If the keyless entry system fails to operate after the transmitter battery has been replaced, check the following items:

- Mechanical binding in the door lock
- Low vehicle battery voltage
- Blown fuse
- Open circuit to the control module
- Defective control module
- Defective transmitter

Programming a New Remote If a new or additional remote transmitter is to be used, it must be programmed to the vehicle. The programming procedure varies and may require the use of a scan tool. A typical reprogramming sequence for a Honda/Acura includes the following steps:

Step #1 Turn the ignition switch to ON.

Step #2 Within 1 to 4 seconds, push the transmitter lock or unlock button with the transmitter aimed at the receiver in the passenger's multiplex control unit.

Step #3 Within 1 to 4 seconds, turn the ignition switch to OFF.

Step #4 Within 1 to 4 seconds, turn the ignition switch to ON.

Step #5 Repeat steps 2, 3, and 4 two more times.

Step #6 Confirm you can hear the sound of the door lock actuators. Within 1 to 4 seconds, push the transmitter lock or unlock button again. The keyless receiver is now in the programming mode. You must push the transmitter lock or unlock button of the first transmitter again to program that transmitter.

Step #7 Within 10 seconds, aim the transmitters (up to three) whose codes you want to store at the receiver, and press the transmitter lock or unlock buttons. Confirm that you can hear the sound of the door lock actuators after each transmitter code is stored.

Step #8 Turn the ignition switch OFF, and pull out the key.

Step #9 Confirm the proper operation with the new codes(s).

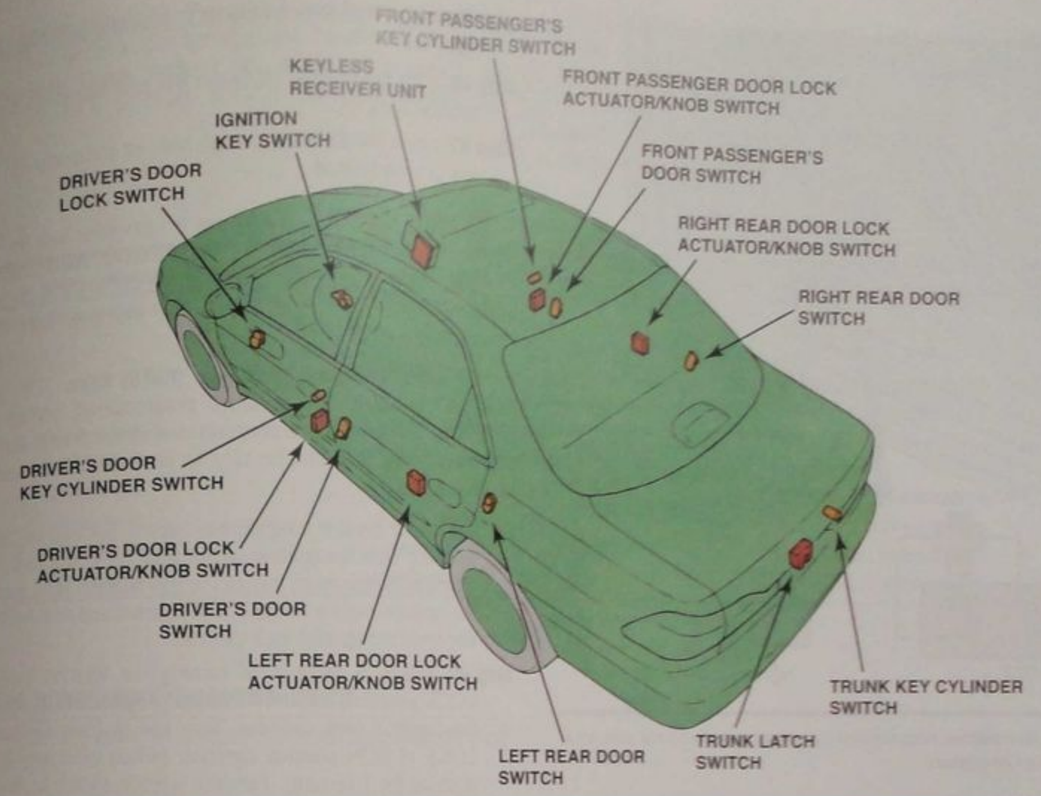


Figure 45–26 A typical vehicle showing the location of the various components of the remote keyless entry system.

ANTI-THEFT SYSTEMS

Anti-theft devices flash lights or sound an alarm if the vehicle is broken into or vandalized. In addition to the alarm, some systems prevent the engine from starting by disabling the starter, ignition, or fuel system once the anti-theft device is activated. Others permit the engine to start, but then disable it after several seconds. Switches in the door jambs, trunk, and hood provide an input signal to the control module should an undesirable entry occur on a typical system. Some anti-theft systems are more complex and also have electronic sensors that trigger the alarm if there is a change in battery current draw, a violent vehicle motion, or if glass is broken. These sensors also provide an input signal to the control module, which may be a separate anti-theft unit or incorporated into the PCM or BCM. See Figure 45–27 for an example of a shock sensor used in an anti-theft alarm system.

Anti-Theft System Diagnosis Most factory-installed anti-theft systems are integrated with several other circuits to form a complex, multiple-circuit system. Therefore, it is essential to have accurate diagrams, specifications, and test procedures for the specific model being serviced. The easiest way to reduce circuit complexity is to use the wiring diagram to break the entire system into its subcircuits, then check only those related to the problem. If any step indicates that a subcircuit is not complete, check the power source, ground, the components, and the wiring in that subcircuit.

Modern anti-theft systems, especially those supplied as original equipment, are electronically regulated and have a self-diagnostic program. This self-diagnostic program is generally accessed and activated using a scan tool. Diagnostic and test procedures are similar as for any of the other electronic control systems used on the vehicle.



Figure 45–27 A typical shock sensor used in alarm and anti-theft systems. If the vehicle is moved, the magnet will move relative to the coil inducing a small voltage, which will trigger the alarm.

Anti-Theft System Testing and Service Before performing any diagnostic checks, make sure that all of the following electrical devices function correctly:

- Parking and low-beam headlights
- Dome and courtesy lights
- Horn
- Electric door locks

Circuit information from these devices often provides basic inputs to the control module. If a problem is detected in any of these

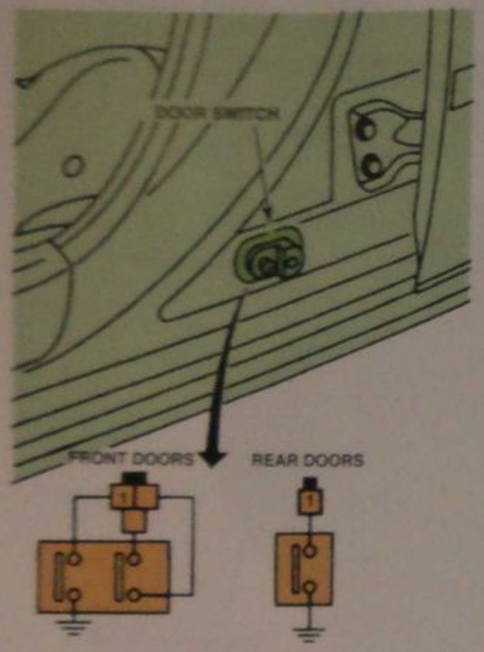


Figure 45–28 Door switches, which complete the ground circuit with the door open, are a common source of high resistance.

circuits, such as a missing signal or a signal that is out of range, the control module disables the anti-theft system and may record a diagnostic trouble code (DTC).

If all of the previously mentioned devices are operational, check all the circuits leading to the anti-theft control module. Make sure all switches are in their normal or off positions. Doorjamb switches complete the ground circuit when a door is opened. See Figure 45–28.

Frequently, corrosion that builds up on the switch contacts prevents the switch from operating properly. Conduct voltage-drop tests to isolate faulty components and circuit problems. Repair as needed and retest to confirm that the system is operational. Follow procedures from the manufacturer to clear DTC records, then run the self-diagnostic program to verify repairs.

Chrysler Remote Keyless Entry System Beginning in 1998, Chrysler started a security system known as the **Sentry Key Immobilizer System (SKIS).** When an attempt to start a vehicle arises, the onboard computer sends out a radio-frequency (RF) signal that is read by the electronic transponder chip embedded in the key. The transponder then returns a unique signal back to the vehicle computer, giving it the okay for the vehicle to start and continue to run. This all happens in under a second, and is completely transparent to the vehicle driver. For additional security, two preprogrammed keys are needed in order to register additional keys into the system. In the event of the loss of all keys, special programming equipment is needed to register new keys into the system.

Chrysler Self-Programming Additional Sentry Keys This procedure requires two original keys. The steps includes:

Step #1 Purchase a blank key and have it cut to fit the lock cylinder.

Step #2 Insert the original key #1 into the ignition and turn to ON.

Step #3 Wait 5 seconds and turn the key to OFF.

Step #4 Immediately insert the original key #2 into the ignition and turn to ON.

Step #5 Wait 10 seconds for the SKIS indicator on the dash to start to flash.

Step #6 Turn the ignition off, insert the new blank key, and turn the ignition back on.

Step #7 Once the SKIS light stops flashing and turns off, your new key is programmed.

Ford PATS System Ford uses a responder key for their anti-theft system, which is called the **Passive Anti-Theft System (PATS).** There is a computer chip inside the key and without it, the vehicle will not start even though the key may work in the lock cylinder.

Ford Programming for Additional (PATS) Keys This procedure will only work if two or more programmed ignition keys are available. If two or more programmed ignition keys are not available, then you will not be able to perform this procedure. The steps include:

Step #1 Insert the first programmed ignition key into the ignition lock cylinder. Turn the ignition switch from the LOCK to RUN position (ignition switch must stay in the run position for 1 second). Turn the ignition switch to the LOCK position and remove the ignition key from the ignition lock cylinder.

Step #2 Within 5 seconds of turning the ignition switch to the LOCK position, insert the second programmed ignition key into the ignition lock cylinder. Turn the ignition switch from the LOCK to RUN position (ignition switch must stay in the RUN position for 1 second). Turn the ignition switch to the LOCK position and remove the second ignition key from the ignition lock cylinder.

Step #3 Within 5 seconds of turning the ignition switch to the LOCK position, insert a new unprogrammed ignition key into the ignition lock cylinder. Turn the ignition switch from the LOCK to RUN position (the ignition switch must stay in the RUN position for 1 second). Turn the ignition switch to the LOCK position and remove the ignition key from the ignition lock cylinder. The new ignition key should now be programmed. To program additional key(s), repeat the key programming procedure from step 1.

FREQUENTLY ASKED QUESTION ???

How Do I Know If My Ford Is Equipped with a Factory Anti-Theft System?

To determine if a Ford has a factory-installed alarm system, look at the keyless remote fob.

- If the keychain hole is at the side of the fob, the vehicle has a factory anti-theft system.
- If the keychain hole is in the center of the fob, the vehicle does not have a factory anti-theft system.

General Motors Anti-Theft System The type of anti-theft system used on General Motors vehicles has included many different systems starting with an anti-theft system that used a resistor pellet in the ignition key. If the key fit the lock cylinder and the resistance was the correct value, the engine would crank and start. This system was called the **Vehicle Anti-Theft System** or **VATS.** A special tester was required to test this system. See Figure 45–29 on page 522.

Newer systems include the **Passkey I** and Passkey II, which also use a resistor pellet in the ignition key. Passlock I, **Passlock II, and Passlock truck** systems use a Hall-effect sensor and magnets in the lock cylinder with a conventional key. See Figure 45–30.

Passkey III systems use a transponder embedded into the head of the key, which is stamped "SK3." Most of the systems disable the starter and the fuel injectors, but Passlock I disables fuel after the engine starts; the theft light will then flash. Due to the various systems, service information must be used and followed to diagnose and repair a fault in these systems.

Specific Systems

Make	Vehicles Equipped with Factory Alarms	Vehicles Equipped with Factory Starter Anti-Theft	Vehicles Equipped with Factory Alarm and Anti-Theft
	1988 to present	1985 to present (VATS)	1988 to present (VATS)
		1995 to present (Passlock)	1995 to present (Passlock)
		1998 to present (Passlock II)	1998 to present (Passlock II)
		1999 to present (Passlock III)	1999 to present (Passlock III)
	1994 to present	1996 to present (PATS)	1996 to present (PATS)
	1997 to present	1999 to present (TRANSPONDER)	1999 to present (TRANSPONDER)
	1996 to present	1998 to present (TRANSPONDER)	1998 to present (TRANSPONDER)
	1997 to present	1998 to present (TRANSPONDER)	1998 to present (TRANSPONDER)
	1986 to present	1998 to present (TRANSPONDER)	1998 to present (TRANSPONDER)
	1996 to present	1998 to present (TRANSPONDER)	1998 to present (TRANSPONDER)

ELECTRICAL ACCESSORY SYMPTOM GUIDE

The following list will assist technicians in troubleshooting electrical accessory systems.

Problem	Possible Causes and/or Solutions
Cruise Control	
1. Cruise (speed) control is inoperative.	1. Possible broken speedometer cable. Possible blown fuse. Possible defective or misadjusted electrical or vacuum safety switch near the brake pedal arm. Possible lack of engine vacuum to servo or transducer. Possible defective transducer. Possible defective speed control switch.
2. Cruise (speed) control speed is incorrect or variable.	2. Possible misadjusted activation cable or chain. Possible defective or pinched vacuum hose. Possible binding of speedometer cable (remove and lubricate). Possible misadjustment of transducer.
Power Windows	
1. Power windows are inoperative.	1. Possible defective (blown) fuse (circuit breaker). Possible defective relay (if used). Possible poor ground for master control switch. Possible poor connections at switch(es) or motor(s). Possible open circuit (usually near the master control switch). Possible defective lockout switch.
2. One power window is inoperative.	2. Possible defective motor. Possible defective or open control switch. Possible open or loose wiring to the switch or the motor.
3. Only one power window can be operated from the master switch.	3. Poor connection or open circuit in the control wire(s).
Power Seats	
1. Power seats are inoperative—no click or noise.	1. Possible defective circuit breaker. Possible poor ground at the switch or relay (if used). Possible open in the wiring between the switch and relay (if used). Possible defective switch. Possible defective solenoid(s) or wiring. Possible defective door switch.
2. Power seats are inoperative—click is heard.	2. Check for "flex" in the cables from the motor(s) to check for motor operation. If flex is felt, the motor is trying to operate the gear nut or the screw jack. Check for possible binding or obstruction. Possible defective motor (the click is generally the relay sound). Possible defective solenoid(s) or wiring to the solenoid(s).
3. All power seat functions are operative except one.	3. Possible defective motor. Possible defective solenoid or wiring to the solenoid.
Electric Power Door Lock	
1. Power door locks are inoperative.	1. Possible defective circuit breaker, fuse, or wiring to the switch or relay (if used). Possible defective relay (if used). Possible defective switch. Possible defective door lock solenoid or ground for solenoid (if solenoid operated). Possible open in the wiring to the door lock solenoid or the motor. Possible mechanical obstruction of the door lock mechanism.
2. Only one door lock is inoperative.	2. Possible defective switch. Possible poor ground on the solenoid (if solenoid operated). Possible defective door lock solenoid or motor. Possible poor electrical connection at the motor or solenoid.
Rear-Window Defogger	
1. Rear-window defogger is inoperative.	1. Check for proper operation by performing breath test and/or voltmeter check at the power side of the rear-window grid. Possible defective relay or timer assembly. Possible defective switch. Possible open ground connection at the rear-window grid. See. Figure 45–31
2. Rear-window defogger cleans only a portion of the rear window.	2. The most common cause of partial operation of a heated rear-window defogger is a broken grid wire(s) or poor electrical connections at either the power side or the ground side of the wire grid.

NOTE: If there is an open circuit (power side or ground side), the dash indicator light will still operate in most cases.



Figure 45–29 A special tool is needed to diagnose a General Motors VATS security system and special keys that contain a resistor pellet.

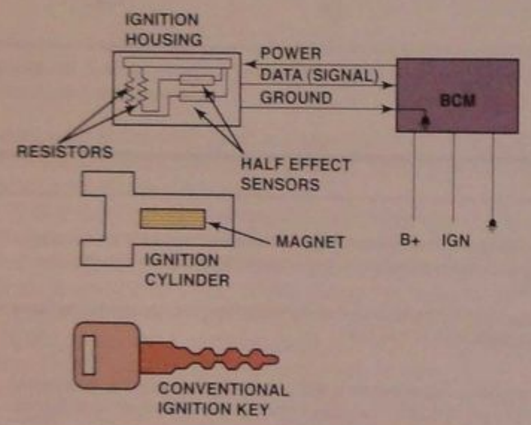


Figure 45–30 The Passlock series of General Motors security systems use a conventional key. The magnet is located in the ignition lock cylinder and triggers the Hall-effect sensors.



Figure 45–31 Corrosion or faults at the junction between the wiring and the rear-window electrical grid are the source of many rear-window defogger problems.

SUMMARY

1. Most power windows and power door locks use a permanent-magnet motor that has a built-in circuit breaker and is reversible. The control switches and relays direct the current through the motors.
2. The current flow through a rear-window defogger is often self-regulating. As the temperature of the grid increases, its resistance increases, reducing current flow. Some rear-window defoggers are also used as radio antennas.
3. Remote keyless entry systems use a wireless transmitter built into the key fob to operate the power door lock.
4. Factory anti-theft systems must function properly to allow the engine to crank and/or start.

REVIEW QUESTIONS

1. Describe how power door locks on a four-door vehicle can function with only one ground wire connection.
2. Explain how a rear-window defogger can regulate how much current flows through the grids based on temperature.
3. What is the usual procedure to follow to resynchronize a remote keyless entry transmitter?
4. Which anti-theft system(s) uses a resistor pellet in the ignition key?

PHOTO SEQUENCE Door Panel Removal



P45–1 Looking at the door panel there appears to be no visible fasteners.



P45–2 Gently prying at the edge of the light shows that it snaps in place and can be easily removed.



P45–3 Under the red "door open" warning light is a fastener.

PHOTO SEQUENCE Door Panel Removal—continued



P45–4 Another screw is found under the armrest.



P45–5 A screw is removed from the bezel around the interior door handle.



P45–6 The electric control panel is held in by clips.



P45–7 Another screw is found after the control panel is removed.



P45–8 The panel beside the outside mirror is removed by gently prying.



P45–9 A gentle tug and the door panel is removed.



P45–10 The sound-deadening material also acts as a moisture barrier and would need to be removed to gain access to the components inside the door.



P45–11 Carefully inspect the door panel clips before reinstalling the door panel.



P45–12 Align and press the door panel clips into the openings and reinstall all of the fasteners and components.

CHAPTER QUIZ

1. The owner of a vehicle equipped with cruise control complains that the cruise control often stops working when driving over rough or bumpy pavement. Technician A says the brake switch may be out of adjustment. Technician B says a defective servo unit is the most likely cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that the cruise control on a vehicle that uses an electronic throttle control (ETC) system uses a servo to move the throttle. Technician B says that the cruise control on a vehicle with ETC uses the APP sensor to set the speed. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. All power windows fail to operate from the independent switches but all power windows operate from the master switch. Technician A says the window lockout switch may be on. Technician B says the power window relay could be defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that a defective ground connection at the master control switch (driver's side) could cause the failure of all power windows. Technician B says that if *one* control wire is disconnected, all windows will fail to operate. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. A typical 6-way power seat _____.
   a. Uses six separate PM nongrounded electric motors
   b. Uses one or three motors (depending on manufacturer)

c. Uses six separate grounded electric motors only
d. Uses two electric motors and a three way direct-acting solenoid-controlled transmission device

6. When checking the operation of a rear-window defogger with a voltmeter, _____.
   a. The voltmeter should be set to read AC volts
   b. The voltmeter should read close to battery voltage anywhere along the grid
   c. Voltage should be available anytime at the power side of the grid because the control circuit just completes the ground side of the heater grid circuit
   d. The voltmeter should indicate decreasing voltage when the grid is tested across the width of the glass

7. PM motors used in power windows, mirrors, and seats can be reversed by _____.
   a. Sending current to a reversed field coil
   b. Reversing the polarity of the current to the motor
   c. Using a reverse relay circuit
   d. Using a relay and a two-way clutch

8. If only one power door lock is inoperative, a possible cause is _____.
   a. A poor ground connection at the power door lock relay
   b. A defective door lock motor (or solenoid)
   c. A defective (open) circuit breaker for the power circuit
   d. A defective (open) fuse for the control circuit

9. A keyless remote control stops working. Technician A says the battery in the remote could be dead. Technician B says that the key fob may have to be resynchronized. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Two technicians are discussing anti-theft systems. Technician A says that some systems require a special key. Technician B says that some systems use a computer chip in the key. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 46

Restraint Systems and Airbags

OBJECTIVES: After studying Chapter 46, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "H" (Accessories Diagnosis and Repair). • List the safety precautions for working around an airbag. • Describe the procedures to diagnose and troubleshoot airbag faults.

KEY TERMS: airbag • arming sensor • clockspring • deceleration sensor • dual-stage airbags • event data recorder (EDR) • event file • integral sensor • occupant detection systems • passenger presence system (PPS) • pretensioners • squib • supplemental air restraints (SAR) • supplemental inflatable restraints (SIR) • supplemental restraint system (SRS) • unbelted

SAFETY BELTS AND RETRACTORS

Safety Belts Safety belts are used to keep the driver and passengers secured to the vehicle in the event of a collision. Most safety belts include three-point support and are constructed of nylon webbing 1¾ to 2 inches wide (5 cm). The three support points include two points on either side of the seat for the belt over the lap and one crossing over the upper torso, which is attached to the "B" pillar or seat back. Every crash has three types of collisions:

Collision 1 The vehicle strikes another vehicle or object.

Collision 2 The driver and/or passengers hit objects inside the vehicle if **unbelted.**

Collision 3 The internal organs of the body hit other organs or bones, which causes internal injuries.

If a safety belt is being worn, the belt stretches, absorbing a lot of the impact, thereby preventing collision with other objects in the vehicle and reducing internal injuries. See Figure 46–1.

Belt Retractors Safety belts are also equipped with one of the following types of retractors:

- Nonlocking retractors, which are usually only used on reclining lap belts
- Emergency locking retractors, which lock the position of the safety belt in the event of a collision or rollover
- Emergency and web speed-sensitive retractors, which allow freedom of movement for the driver and passenger but lock if the vehicle is accelerating too fast or if the vehicle is decelerating too fast. See Figure 46–2 for an example of an inertia-type seat belt locking mechanism.

Safety Belt Lights and Chimes All late-model vehicles are equipped with a safety belt warning light on the dash and a chime that sounds if the belt is not fastened. See Figure 46–3.

Some vehicles will intermittently flash the reminder light and sound a chime until the driver and sometimes the front passenger fasten their safety belts.

PRETENSIONERS

A **pretensioner** is an explosive (pyrotechnic) device that tightens the seat belt as the airbag is being deployed. The purpose of the pretensioning device is to force the occupant back into position against the seat back and to remove any slack in the seat belt. See Figure 46–4.

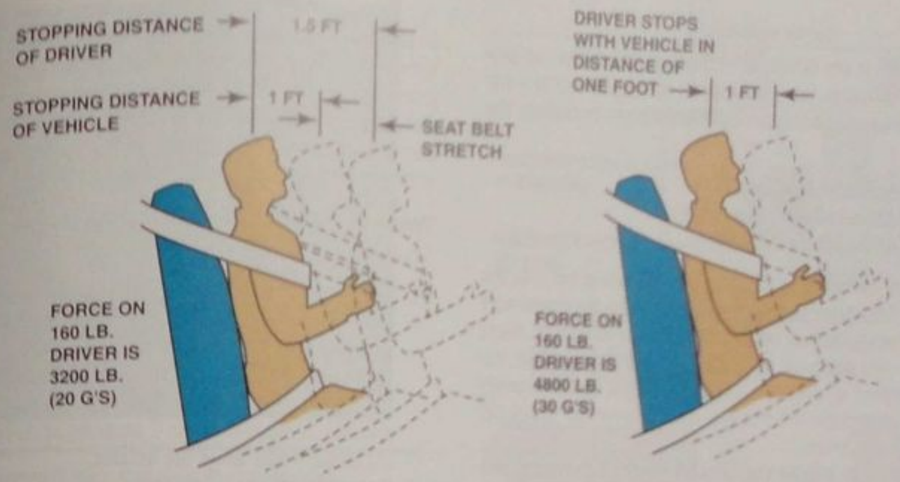


Figure 46–1 (a) Safety belts are the primary restraint system. (b) During a collision the stretching of the safety belt slows down the impact to help reduce bodily injury.

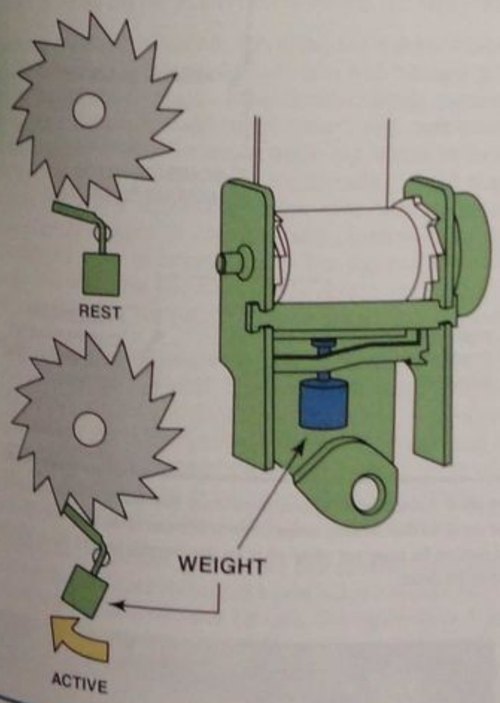


Figure 46–2 Most safety belts have an inertia-type mechanism that locks the belt in the event of rapid movement.

CAUTION: The seat belt pretensioner assemblies must be replaced in the event of an airbag deployment. Always follow the vehicle manufacturer's recommended service procedure.

Pretensioners are explosive devices that could be ignited if voltage is applied to the terminals. Do not use a jumper wire or powered test light around the wiring near the seat belt latch wiring. Always follow the vehicle manufacturer's recommended test procedures.



Figure 46–3 A typical safety belt warning light.



Figure 46–4 A small explosive charge forces the end of the seat belt down the tube, which removes any slack in the seat belt.

AIRBAGS

Airbag passive restraints are designed to cushion the driver (or passenger, if the passenger side is so equipped) during a frontal collision. Airbags may be known by many different names including the following:

1. **Supplemental restraint system (SRS)**
2. **Supplemental inflatable restraints (SIR)**
3. **Supplemental air restraints (SAR)**

Most airbags are designed to supplement the safety belts in the event of a collision, and front airbags are meant to be deployed only in the event of a frontal impact within 30 degrees of center. Most airbag systems are *not* designed to inflate during side or rear impact. The force required to deploy a typical airbag is approximately equal to the force of a vehicle hitting a wall at over 10 miles per hour (16 kilometers per hour).

The force required to trigger the sensors within the system prevents accidental deployment if curbs are hit or the brakes are rapidly applied. The system requires a substantial force to deploy the airbag to help prevent accidental inflation.

Operation See Figure 46–5 for an overall view of the parts included in a typical airbag system. The parts include:

1. Sensors
2. Airbag (inflator) module
3. Clockspring wire coil in the steering column
4. Control module
5. Wiring and connectors

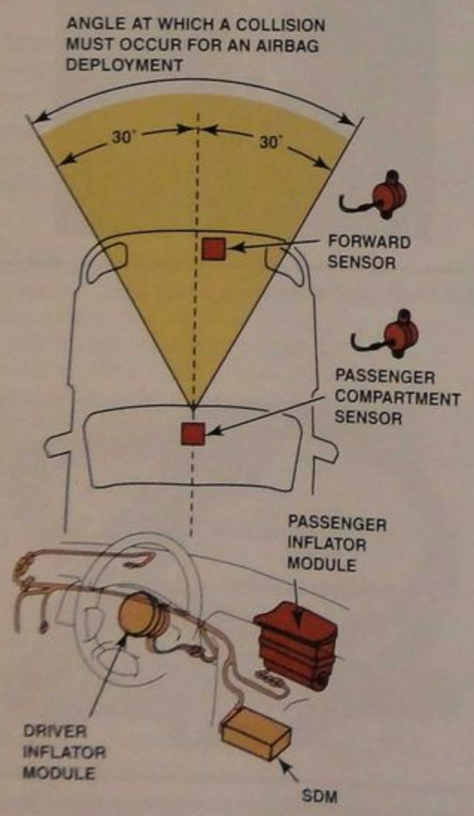


Figure 46–5 A typical airbag system showing many of the components.

To cause inflation, the closing of the **arming sensor** is required to provide the power-side voltage to the inflator module. Before the airbag can inflate, however, the squib circuit also must have a ground. The ground is provided through the actuation of either the *forward* or the *passenger discriminating sensor*. In other words, two sensors *must* be triggered *at the same time* before the airbag will be deployed. See Figure 46–6.

Types of Airbag Inflators There are two different types of inflators used in airbags, including:

1. **Solid fuel.** This type uses sodium azide pellets and when ignited, generates a large quantity of nitrogen gas that quickly inflates the airbag. This is the first type used and is still commonly used in driver- and passenger-side airbag inflator modules. See Figure 46–7. The **squib** is the heating element used to ignite the gas-generating material. It requires about 2 amperes of current to heat the heating element and ignite the inflator.
2. **Compressed gas.** Commonly used in passenger-side airbags and roof-mounted systems, this system uses a canister filled with argon gas, plus a small percentage of helium at 3,000 PSI

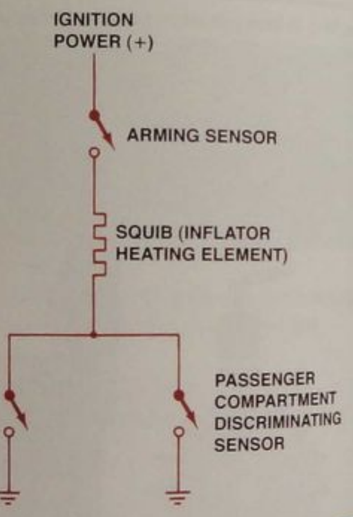


Figure 46–6 A simplified airbag deployment circuit. Note that both the arming sensor and at least one of the discriminating sensors must be activated at the same time. The arming sensor provides the power and either one of the discriminating sensors can provide the ground for the circuit.



Figure 46–7 Lifting the squib from the airbag housing. The squib is the heating element that ignites the pyrotechnic gas generator that rapidly produces nitrogen gas to fill the airbag.



Figure 46–8 This shows a deployed side-curtain airbag on a training vehicle.

(435 kPa). A small igniter ruptures a burst disc to release the gas when energized. The compressed gas inflators are long cylinders that can be installed inside the instrument panel, seat back, door panel, or along any rail or pillar of the vehicle. See Figure 46–8.

Once the inflator is ignited, the nylon bag quickly inflates (in about 30 milliseconds [ms] or 0.030 seconds) with nitrogen gas generated by the inflator. During an actual frontal collision accident, the driver is being thrown forward by the driver's own momentum toward the steering wheel. The strong nylon bag inflates at the same time. Personal injury is reduced by the spreading of the stopping force over the entire upper-body region. The normal collapsible steering column remains in operation and collapses in a collision when equipped with an airbag system. The bag is equipped with two large side vents that allow the bag to deflate immediately after inflation, once the bag has cushioned the occupant in a collision.

Sensors All three sensors are basically switches that complete an electrical circuit when activated. The sensors are similar in construction and operation, and the *location* of the sensor determines its name. All airbag sensors are rigidly mounted to the vehicle and *must* be mounted with the arrow pointing toward the front of the vehicle to ensure that the sensor can detect rapid forward deceleration.

There are three basic styles (designs) of airbag sensors:

1. **Magnetically retained gold-plated ball sensor.** This sensor uses a permanent magnet to hold a gold-plated steel ball away from two gold-plated electrical contacts. See Figure 46–9. If the vehicle (and the sensor) stops rapidly enough, the steel ball is released from the magnet and makes contact with the two gold-plated electrodes. The steel ball only remains in contact with the electrodes for a relatively short time because the steel ball is drawn back into contact with the magnet.
2. **Rolled up stainless-steel ribbon-type sensor.** This sensor is housed in an airtight package with nitrogen gas inside to prevent harmful corrosion of the sensor parts. See Figure 46–10. If the vehicle (and the sensor) stops rapidly, the stainless-steel roll "unrolls" and contacts the two gold-plated contacts. Once the force is stopped, the stainless-steel roll rolls back into its original shape.
3. **Integral sensor.** Some vehicles use electronic **deceleration sensors** built into the inflator module. These sensors measure the rate of deceleration and, through the computer logic, determine if the airbags should be deployed. See Figure 46–11 for a timeline that illustrates how quickly a typical airbag system can react and inflate.

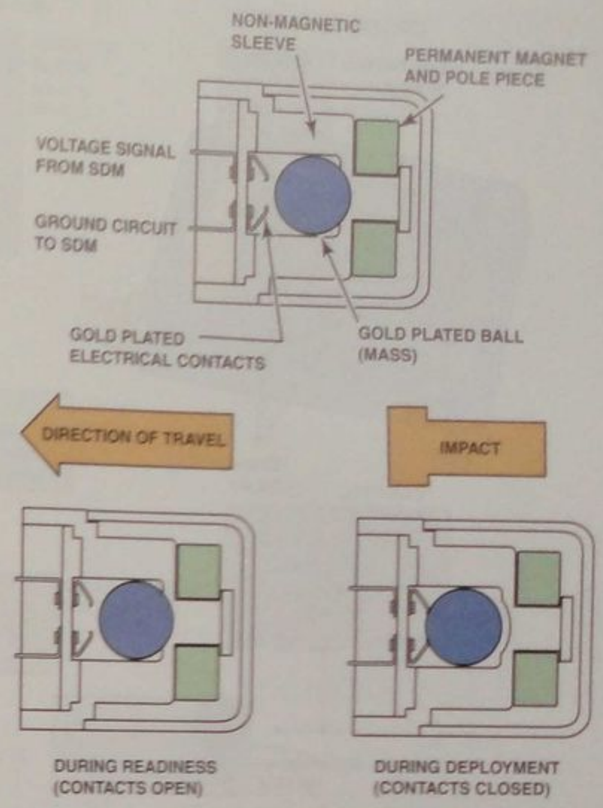


Figure 46–9 An airbag magnetic sensor.

CAUTION: In the event of a collision that causes the airbag to deploy, some vehicle manufacturers require that all sensors be replaced along with the airbag assembly. The force of impact can cause unseen damage inside the sensor; the sensor may not work correctly if used again.

Wiring By worldwide agreement, all electrical wiring for airbags is yellow. To ensure proper electrical connection to the inflator module in the steering wheel, a coil assembly is used in the steering column. This coil is a ribbon of copper wires that operates much like a window shade when the steering wheel is rotated. This coil, called an SIR coil or a **clockspring,** prevents the lack of continuity between the sensors and the inflator assembly that might result from a horning type of sliding conductor. See Figure 46–12 on page 529.

Most airbag systems also contain a diagnostic unit that often includes an auxiliary power supply, which is used to provide the current to inflate the airbag if the battery is disconnected from the vehicle during a collision. This auxiliary power supply usually uses capacitors that are discharged through the squib of the inflation module. See Figures 46–13 and 46–14 on page 530.

Troubleshooting The electrical portion of most airbag systems is constantly checked by the circuits within the airbag energizing power unit or through the vehicle's computer system. The electrical system is monitored through the electronic system by the application of a small-signal voltage through the various sensors and components. If continuity exists, a small voltage drop will be measured by the testing circuits. If an open or short circuit occurs, a dash warning light is lighted and a possible diagnostic trouble code

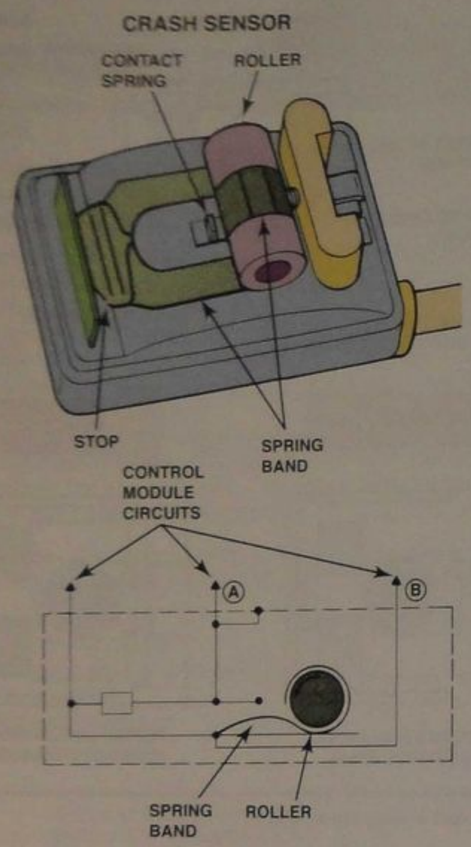


Figure 46–10 Some vehicles use a ribbon-type crash sensor.

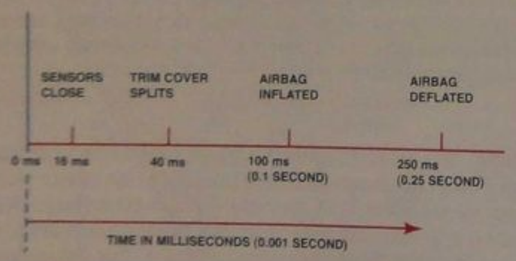


Figure 46–11 Notice that within 1/4 second of a collision, the sensors have closed, the airbag has deployed, and the airbag has deflated.

(DTC) is stored. Follow exact manufacturer's recommended procedures for accessing and erasing airbag diagnostic trouble codes.

AIRBAG DIAGNOSIS TOOLS AND EQUIPMENT

Diagnosis and service of airbag systems usually require some or all of the following items:

- Digital multimeter (DMM)
- Airbag simulator, often called a load tool
- Scan tool
- Shorting bar or shorting connector(s)
- Airbag system tester
- Vehicle-specific test harness
- Special wire repair tools or connectors, such as crimp-and-seal weatherproof connectors

CAUTION: Most vehicle manufacturers specify that the negative battery terminal be removed when testing or working around airbags. Be aware that a memory saver device used to keep the computer and radio memory alive can supply enough electrical power to deploy an airbag.

TECH TIP ✓ **Pocket the Ignition Key to Be Safe**

When replacing any steering gear such as a rack-and-pinion steering unit, be sure that no one accidentally turns the steering wheel. If the steering wheel is turned without being connected to the steering gear, the airbag wire coil (clockspring) can become off center. This can cause the wiring to break when the steering wheel is rotated after the steering gear has been replaced. To help prevent this from occurring, simply remove the ignition key from the ignition and keep it in your pocket while servicing the steering gear.

Precautions Take the following precautions when working with or around airbags.

1. Always follow all precautions and warning stickers on vehicles equipped with airbags.
2. Maintain a safe working distance from all airbags to help prevent the possibility of personal injury in the unlikely event of an unintentional airbag deployment.
   - Side impact airbag—5-inch distance (13 cm)
   - Driver front airbag—10-inch distance (25 cm)
   - Passenger frontal airbag—20-inch distance (50 cm)
3. In the event of a collision in which the bag(s) were deployed, the inflator module *and* all sensors usually must be replaced to ensure proper future operation of the system.
4. Avoid using a self-powered test light around the yellow airbag wiring. Even though it is highly unlikely, a self-powered test light could provide the necessary current to accidentally set off the inflator module and cause an airbag deployment.
5. Use care when handling the inflator module section when it is removed from the steering wheel. Always hold the inflator away from your body.
6. If handling a deployed inflator module, always wear gloves and safety glasses to avoid the possibility of skin irritation from the sodium hydroxide dust, which is used as a lubricant on the bag(s) and that remains after deployment.
7. Never jar or strike a sensor. The contacts inside the sensor may be damaged, preventing the proper operation of the airbag system in the event of a collision.
8. When mounting a sensor in a vehicle, make certain that the arrow on the sensor is pointing toward the front of the vehicle. Also be certain that the sensor is securely mounted.

SAFETY TIP **Dual-Stage Airbags**

Many vehicles are equipped with **dual-stage airbags** (two-stage airbags) that actually contain two separate inflators; one for less severe crashes and one for higher-speed collisions. During some airbag deployment, both stages are deployed. If one stage is deployed, the other stage is still active and could be accidentally deployed. A service technician cannot tell by looking at the airbag whether both stages have deployed. Always handle a deployed airbag as if it has not been deployed and take all precautions necessary to keep any voltage source from getting close to the inflator module terminals.

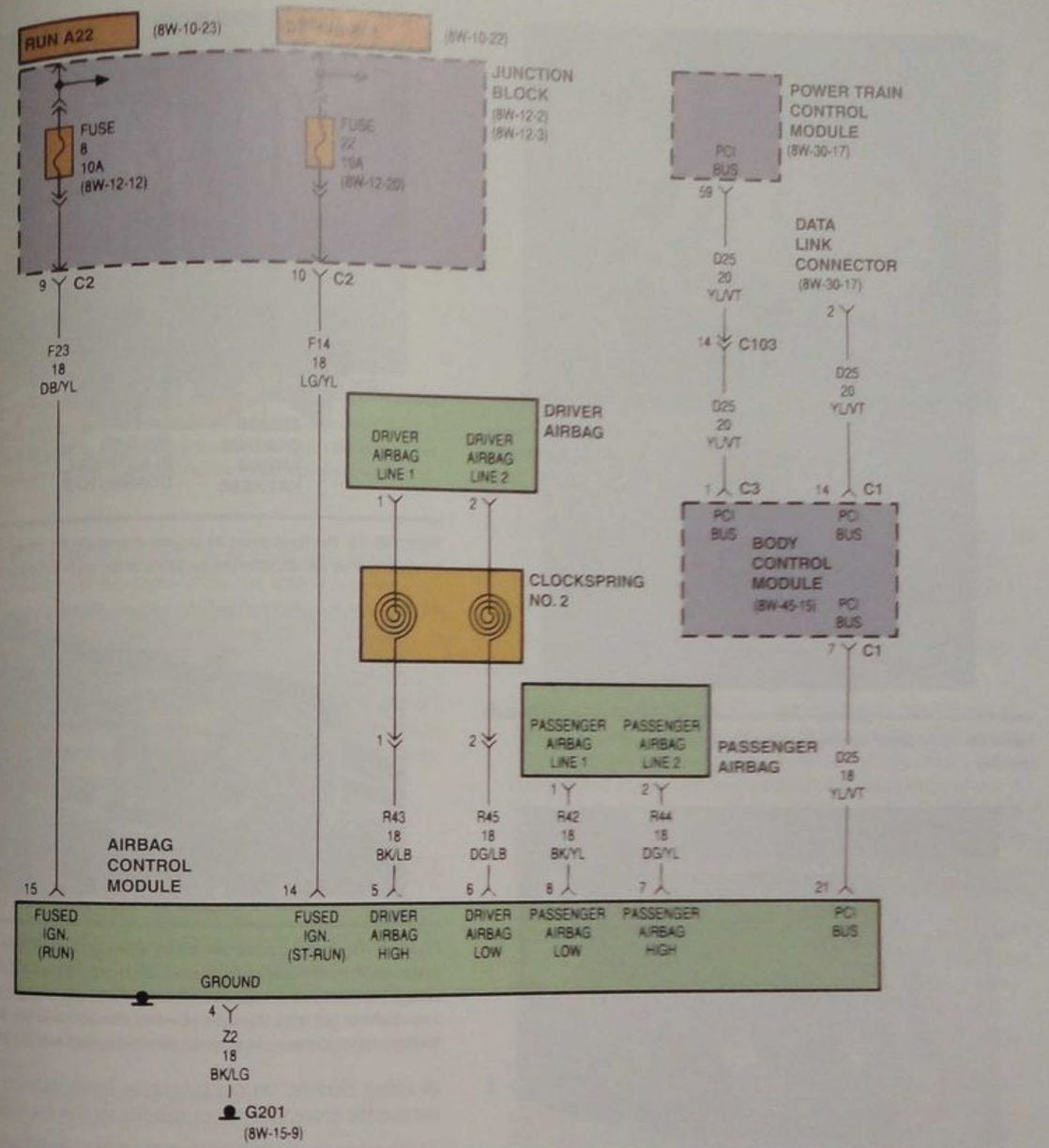


Figure 46–12 The airbag control module is linked to the power train control module (PCM) and the body control module (BCM) on this Chrysler system. Notice the airbag wire connecting the module to the airbag through the clockspring.

AIRBAG TESTING AND SERVICE

Airbag system components and their location in the vehicle vary according to system design, but the basic principles of testing are the same as for other electrical circuits. Use service information to determine how the circuit is designed and the correct sequence of tests to be followed.

Some airbag systems require the use of special testers. The built-in safety circuits of such testers prevent accidental deployment of the airbag. If such a tester is not available, follow the recommended alternative test procedures specified by the manufacturer. Access the self-diagnostic system and check for diagnostic trouble code (DTC) records. The factory scan tool is needed to access the data stream on some systems.

An SRS has a diagnostic module that detects system electrical faults, disables the system, and notifies the driver through a system readiness indicator or airbag warning lamp in the instrument cluster. Depending on circuit design, a system fault may cause the warning lamp to fail to illuminate, remain lit continuously, or flash. Some systems use a tone generator that produces an audible warning when a system fault occurs or if the warning lamp is inoperative.

The warning lamp should illuminate with the ignition key on and engine off as a bulb check. If not, the diagnostic module is likely disabling the system. If the airbag warning light remains on, the airbags may or may not be disabled, depending on the specific vehicle and the fault detected. Some warning lamp circuits have a timer that



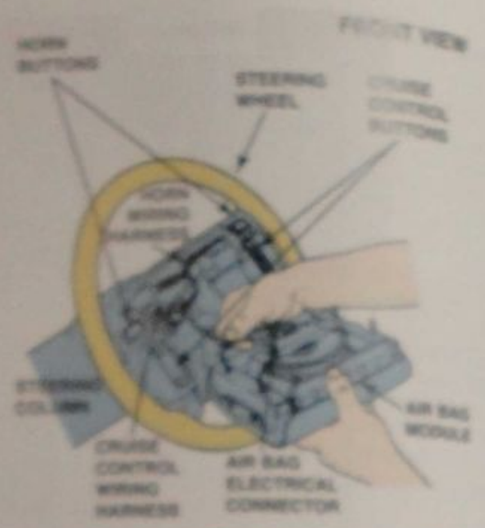


Figure 46–15 This figure shows the process of removing the airbag inflator module from the steering wheel and disconnecting the yellow airbag electrical connector.









Figure 46–18 A bladder-type occupant detection sensor showing the pressure sensor and wiring.

- If 99 pounds (45 kg) or more is detected on the passenger seat, the airbag will deploy at full force, depending on the severity of the crash, speed of the vehicle, and other factors which may result in the airbag deploying at a reduced force.

The occupant detection systems use one of three types of sensors.

- **Gel-filled bladder sensor.** This type of occupant sensor uses a silicone-filled bag that has a pressure sensor attached. The weight of the passenger is measured by the pressure sensor, which sends a voltage signal to the module controlling the airbag deployment. A safety belt tension sensor is also used with a gel-filled bladder system to monitor the tension on the belt. The module then uses the information from both the bladder and the seat belt sensor to determine if a tightened belt may be used to restrain a child seat. See Figure 46–18.
- **Capacitive strip sensors.** This type of occupant sensor uses several flexible conductive metal strips under the seat cushion. These sensor strips transmit and receive a low-level electric field, which changes due to the weight of the front passenger seat occupant. The module determines the weight of the occupant based on the sensor values.
- **Force-sensing resistor sensors.** This type of occupant sensor uses resistors, which change their resistance based on the stress that is applied. These resistors are part of the seat structure, and the module can determine the weight of the occupant based on the change in the resistance of the sensors. See Figure 46–19.

CAUTION: Because the resistors are part of the seat structure, it is very important that all seat fasteners be torqued to factory specifications to ensure proper operation of the occupant detection system. A seat track position sensor is used by the airbag controller to determine the position of the seat. If the seat is too close to the airbag, the controller may disable the airbag.

Diagnosing Occupant Detection Systems A fault in the systems may cause the passenger-side airbag light to turn on when there is no weight on the seat. A scan tool is often used to check or calibrate the seat, which must be empty, by commanding the module to rezero the seat sensor. Some systems, such as those used on Chrysler vehicles, use a unit that has various weights along with a scan tool to calibrate and diagnose the occupant detection system. See Figure 46–20.



Figure 46–19 A resistor-type occupant detection sensor. The weight of the passenger strains these resistors, which are attached to the seat, thereby signaling to the module the weight of the occupant.



Figure 46–20 A test weight is used to calibrate the occupant detection system on a Chrysler vehicle.

SEAT AND SIDE-CURTAIN AIRBAGS

Side-curtain airbags use a variety of sensors to determine if they need to be deployed. Side airbags are mounted in one of two general locations:

- In the side bolster of the seat. See Figure 46–21.
- In the door panel

Most side-airbag sensors use an electronic accelerometer to detect when to deploy the airbags, which are usually mounted to the bottom of the left and right B-pillars (where the front doors latch) behind a trim panel on the inside of the vehicle.

CAUTION: Avoid using a lockout tool (for example, a "slim jim") in vehicles equipped with side airbags to help prevent damage to the components and wiring in the system.

Side-curtain airbags are usually deployed by the side-curtain airbag module based on input from many different sensors, including a lateral acceleration sensor and wheel speed sensors. For example, in one system used by Ford, the ABS controller commands that the brakes on one side of the vehicle be applied, using down pressure while monitoring the wheel speed sensors. If the wheels slow down with little brake pressure, the controller assumes that the vehicle could roll over, thereby deploying the side-curtain airbags.

EVENT DATA RECORDERS

Parts and Operation Event data recorders are part of the airbag controller on many vehicles. The purpose of the **event data recorder (EDR)** is to record parameters just before and slightly after an airbag deployment. The parameters recorded include:



Figure 46–21 A typical seat (side) airbag that deploys from the side of the seat.

- Vehicle speed
- Brake on/off
- Seat belt fastened
- G-forces as measured by the accelerometer

Unlike an airplane event data recorder, a vehicle unit is not a separate unit and does not record voice conversations and does not include all crash parameters. This means that additional crash data, such as skid marks and physical evidence at the crash site will be needed to fully reconstruct the incident.

TECH TIP ✔ **Aggressive Driving and OnStar**

If a vehicle equipped with the OnStar system is being driven aggressively and the electronic stability control system has to intercede to keep the vehicle under control, OnStar may call the vehicle to see if there has been an accident. The need for a call from OnStar® usually will be determined if the accelerometer registers slightly over one-g of force, which could be achieved while driving on a race track.

The EDR is embedded into the airbag controller and receives data from many sources and at varying sample rates. The data is constantly being stored in a memory buffer and not recorded into the EPROM unless an airbag deployment has been commanded. The data is known as an **event file.** The airbag is commanded based on input mainly from the accelerometer sensor. This sensor usually built into the airbag controller is located inside the vehicle. The accelerometer calculates the rate of change of the speed of the vehicle. This determines the acceleration rate and is used to predict if that rate is high enough to deploy the frontal airbags. The airbags will be deployed if the threshold g-value is exceeded. The passenger side airbag will also be deployed unless it is suppressed because of either of the following:

- No passenger is detected
- The passenger-side airbag switch is off

Data Extraction Data from the event data recorder from the airbag controller can only be achieved using a piece of equipment known as the Crash Data Retrieval System manufactured by Vetronics Corporation. This is the only authorized method for retrieving event files and only certain organizations are allowed access to the data. These groups or organizations include:

- Original equipment manufacturer's representatives
- National Highway Traffic Safety Administration
- Law enforcement agencies
- Accident reconstruction companies

Crash data retrieval must only be done by a person who has been trained as a crash data retrieval (CDR) technician or analyst, which requires specialized training and the passing of an examination. An analyst must attend additional training beyond that of a technician to achieve CDR analyst certification. A list of CDR-supported vehicles can be viewed at: http://sbcommerce.vetronix.com/CDR/CDRvehicleLIST.pdf.

SUMMARY

1. Airbags use a sensor(s) to determine if the rate of deceleration is enough to cause bodily harm. All airbag wiring is yellow. When working around an airbag, disconnect the wiring connectors to help prevent accidental deployment.
2. Frontal airbags only operate within 30 degrees from center and do not deploy in the event of a rollover, side, or rear collision.
3. Two sensors must be triggered at the same time for an airbag deployment to occur.
4. All electrical terminals are gold-plated to protect against corrosion.
5. Pretensioners are explosive (pyrotechnic) devices that remove the slack from the seat belt and help position the occupant.
6. Occupant detection systems use sensors in the seat to determine whether the airbag will be deployed and with full or reduced force.

REVIEW QUESTIONS

1. What are the safety precautions to follow whenever working around an airbag?
2. What sensor(s) must be triggered for an airbag deployment?
3. How should deployed inflation modules be handled?
4. What is the purpose of pretensioners?

CHAPTER QUIZ

1. A vehicle is being repaired after an airbag deployment. Technician A says that the inflator module should be handled as if it is still live. Technician B says rubber gloves should be worn to prevent skin irritation. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

2. A seat belt pretensioner is _____.
   a. A device that contains an explosive charge
   b. Used to remove slack from the seat belt in the event of a collision
   c. Used to force the occupant back into position against the seat back in the event of a collision
   d. All of the above
3. What conducts power and ground to the driver's side airbag?
   a. Twisted pair wires
   b. Clockspring
   c. Carbon contact and brass surface plate on the steering column
   d. Magnetic reed switch
4. Two technicians are discussing dual-stage airbags. Technician A says that a deployed airbag is safe to handle regardless of which stage caused the deployment of the airbag. Technician B says that both stages ignite, but at different speeds depending on the speed of the vehicle. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Where are shorting bars used?
   a. In pretensioners
   b. At the connectors for airbags
   c. In the crash sensors
   d. In the airbag controller
6. Technician A says that a deployed airbag can be repacked, reused, and reinstalled in the vehicle. Technician B says that a deployed airbag should be discarded and replaced with an entire new assembly. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. What color is airbag wiring?
   a. Blue
   b. Red
   c. Yellow
   d. Orange
8. Driver- and/or passenger-side airbags will only deploy if a collision occurs how many degrees from straight ahead?
   a. 10°
   b. 30°
   c. 60°
   d. 90°
9. How many sensors must be triggered at the same time to cause an airbag deployment?
   a. One
   b. Two
   c. Three
   d. Four
10. The electrical terminals used for airbag systems are unique because they are _____.
    a. Solid copper
    b. Tin-plated heavy-gauge steel
    c. Silver-plated
    d. Gold-plated

CHAPTER 47

Audio System Operation and Diagnosis

OBJECTIVES: After studying Chapter 47, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "F" (Accessories Diagnosis and Repair). • Describe how AM and FM radio works. • Explain how to test speaker polarity. • Explain how to match speaker impedance. • Explain how crossovers work. • List causes and corrections of radio noise and interference.

KEY TERMS: active crossover • alternator whine • amplitude modulation (AM) • bluetooth • carrier wave • crossover • decibels (dB) • electronically tuned receiver (ETR) • floating ground system • flutter • frequency • frequency modulation (FM) • ground plane • hertz • high-pass filter • impedance • low-pass filter • modulation • picket fencing • powerline capacitor • radio choke • radio frequency (RF) • root-mean-square (RMS) • satellite digital audio radio services (SDARS) • sideband operation • speakers • stiffening capacitor • subwoofer • total harmonic distortion (THD) • tweeter • voice recognition • wavelength

The audio system of today's vehicles is a complex combination of antenna system, receiver, amplifier, and speakers all designed to provide living room–type music reproduction while the vehicle is traveling in city traffic or at highway speed.

AUDIO FUNDAMENTALS

There are two types of energy that affect audio systems.

- **Electromagnetic energy or radio waves.** Antennas capture the radio waves which are then sent to the radio or receiver to be amplified.
- **Acoustical energy, usually called sound.** Radios and receivers amplify the radio wave signals and drive speakers which reproduce the original sound that was transmitted by radio waves.

See Figure 47–1.

Electromagnetic energy moves through the air while acoustical energy moves air. Radio waves travel at approximately the speed of light (186,282,000 miles per second). Radio waves are measured in two ways: wavelength and frequency. A radio wave has a series of high points and low points. A **wavelength** is the time and distance between two consecutive points, either high or low. A wavelength is measured in meters. **Frequency,** also known as **radio frequency,** or **RF,** is the number of times a particular waveform repeats itself in a given amount of time and is measured in **hertz.** A signal with a frequency of one hertz is one radio wavelength per second. Radio frequencies are measured in kilohertz, thousands of wavelengths per second, and megahertz, millions of wavelengths per second. See Figure 47–2 and the following examples:

- The higher the frequency, the shorter the wavelength.
- The lower the frequency, the longer the wavelength.

A longer wavelength can travel a farther distance than a shorter wavelength. Therefore, lower frequencies provide better reception at farther distances.

- AM radio frequencies range from 530 kHz, to 1,710 kilohertz.
- FM radio frequencies range from 87.9 MHz to 107.9 MHz.

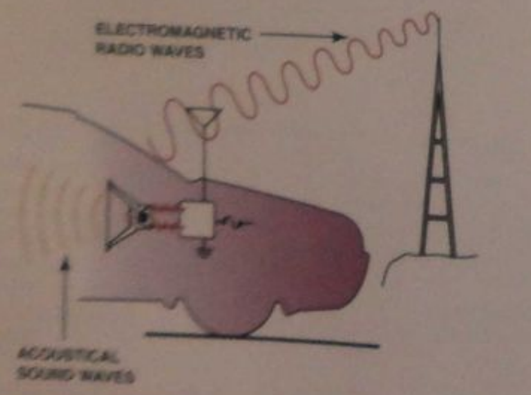


Figure 47–1 Audio systems use both electromagnetic radio waves and sound waves to reproduce sound inside the vehicle.

Modulation **Modulation** is the term used to describe when information is added to a constant frequency. The base radio frequency used for RF is called the **carrier wave.** A carrier is a radio

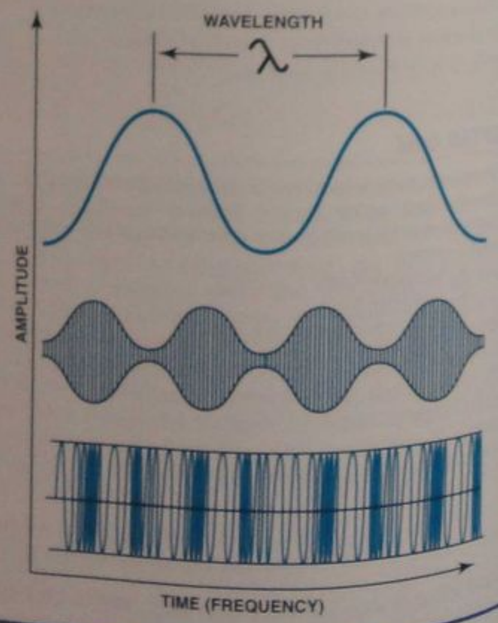


Figure 47–2 The relationship among wavelength, frequency, and amplitude.

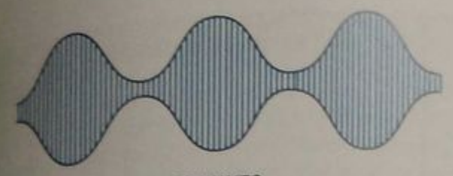


Figure 47–3 The amplitude changes in AM broadcasting.

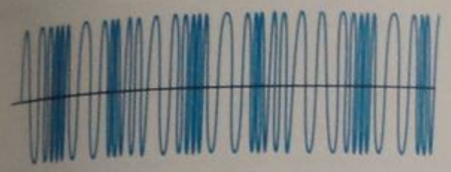


Figure 47–4 The frequency changes in FM broadcasting and the amplitude remains constant.

wave that is changed to carry information. The two types of modulation are:

- **Amplitude Modulation (AM)**
- **Frequency Modulation (FM)**

AM waves are radio waves that have amplitude that can be varied, transmitted, and detected by a receiver. Amplitude is the height of the wave as graphed on an oscilloscope. See Figure 47–3.

FM waves are radio waves that have a frequency that can be varied, transmitted, and detected by a receiver. This type of modulation changes the number of cycles per second, or frequency, to carry the information. See Figure 47–4.

Radio Wave Transmission More than one signal can be carried by a radio wave. This process is called **sideband operation.** Sideband frequencies are measured in kilohertz. The amount of the signal above the assigned frequency is referred to as the upper sideband. The amount of the signal below the assigned frequency is called the lower sideband. This capability allows radio signals to carry stereo broadcasts. Stereo broadcasts use the upper sideband to carry one channel of the stereo signal, and the lower to carry the other channel. When the signal is decoded by the radio, these two signals become the right and left channels. See Figure 47–5.

Noise Because radio waves are a form of electromagnetic energy, other forms of energy can impact them. For example, a bolt of lightning generates broad radio frequency bandwidths known as electromagnetic Interference, or EMI. When EMI is received by an AM radio, the radio amplifies it and plays the sound as static or noise. When outside electromagnetic inference occurs within the radio frequencies, it is called radio frequency interference or RFI. In other words, RFI is a part of EMI.

FM Characteristics Because FM waves have a high RF and a short wavelength, they travel only a short distance. The waves cannot follow the shape of the earth but instead travel in a straight line from the transmitter to receiver. FM waves will travel through the atmosphere and into space and do not reflect back to earth like AM waves.

Multi-path is caused by reflected, refracted, or line of sight signals reaching an antenna at different times. Multi-path results from the radio receiving two signals to process on the same frequency. This causes an echo effect in the speakers. **Flutter,** or **picket fencing** as it is sometimes called, is caused by the blocking of part of the FM signal. This blocking causes a weakening of the signal resulting in only part of the signal getting to the antenna causing an on-again off-again radio sound. Flutter also occurs when the transmitter and the receiving antenna are far apart.

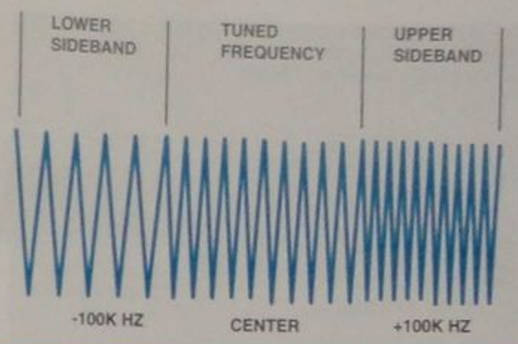


Figure 47–5 Using upper and lower sidebands allows stereo to be broadcast. The receiver separates the signals to provide left and right channels.

RADIOS AND RECEIVERS

The antenna receives the radio wave where it is converted into very weak, fluctuating electrical current. This current travels along the antenna lead-in to the radio, which amplifies the signal and sends the new signal to the speakers where it is converted into acoustical energy.

Most late-model General Motors radios and receivers use five inputs:

1. Power—usually a constant 12-volt feed to keep the internal clock alive
2. Ground
3. Serial data—used to turn the unit on and off and provide other functions such as steering wheel control operation
4. Antenna input
5. Speaker outputs

Most newer radios are called **electronically tuned receivers (ETRs).**

Types of Antennas The typical radio electromagnetic energy from the broadcast antenna induces a signal in the antenna that is very small—only about 25 micro volts AC (0.000025 VAC) in strength.

There are five types of antennas currently used on General Motors vehicles. They include:

- **Slot antenna**—The slot antenna is concealed in the roof of some plastic-body vehicles such as the U van. This antenna is surrounded by metal on a Mylar sheet.
- **Rear-window defogger grid antenna**—This type of system uses the heating wires to receive the signals and special circuitry to separate the RF from the DC heater circuit.
- **Powered mast antenna**—Powered mast antennas are controlled by the radio. When the radio is turned on, the antenna is raised, when the radio is shut off, the antenna is retracted. The antenna system consists of an antenna mast and a drive motor.
- **Fixed-mast antenna**—The fixed-mast antenna offers the best overall performance currently available. The mast is simply a vertical rod. Mast antennas are typically located on the fender or rear quarter panel of the vehicle.

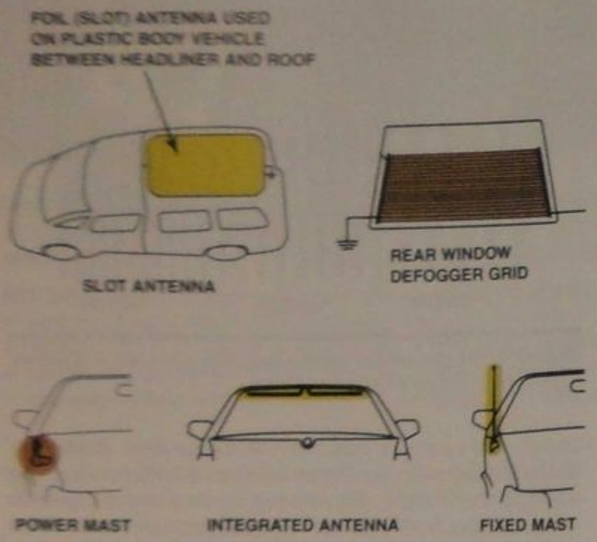


Figure 47–6 The five types of antennas used on General Motors vehicles include the slot antenna, fixed-mast antenna, rear-window defogger grid antenna, a powered mast antenna, and an integrated antenna.

- **Integrated antenna**—This type of antenna is sandwiched in the windshield and an appliqué on the rear window glass. The antenna in the rear window is the primary antenna and receives both AM and FM signals. The secondary antenna is located in the front windshield typically on the passenger side of the vehicle. This antenna receives only FM signals.

See Figure 47–6.

FREQUENTLY ASKED QUESTION ???

What Is a Ground Plane?

Antennas designed to pick up the electromagnetic energy that is broadcast through the air to the transmitting antenna are usually one-half wavelength high, and the other half of the wavelength is the **ground plane.** This one-half wavelength in the ground plane is literally underground.

For ideal reception, the receiving antenna should also be the same as the wavelength of the signal. Because this length is not practical, a design compromise uses the length of the antenna as one-fourth of the wavelength; in addition, the body of the vehicle itself is one-fourth of the wavelength. The body of the vehicle, therefore, becomes the ground plane. See Figure 47–7.

Any faulty condition in the ground plane circuit will cause the ground plane to lose effectiveness such as:

- Loose or corroded battery cable terminals
- Acid buildup on battery cables
- Engine grounds with high resistance
- Loss of antenna or audio system grounds
- A defective generator (alternator) causes an AC ripple exceeding 50 millivolts (0.050 V)

ANTENNA DIAGNOSIS

The antenna collects all radio-frequency signals. An AM radio operates best with as long an antenna as possible, but FM reception is best when the antenna height is exactly 31 inches (79 centimeters). Most fixed-length antennas are, therefore, exactly this height. Even the horizontal section of a windshield antenna is 31 inches (79 centimeters) long.

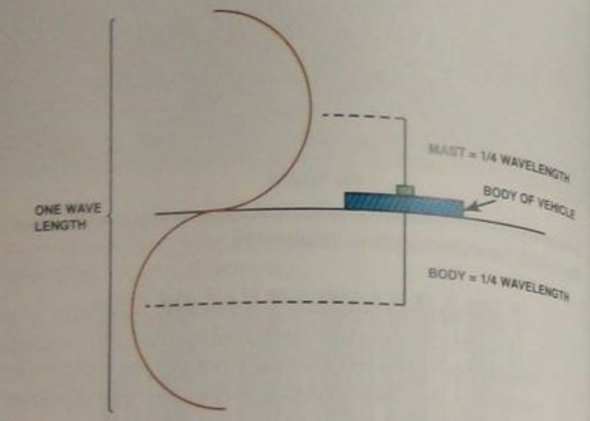


Figure 47–7 The ground plane is actually one-half of the antenna.

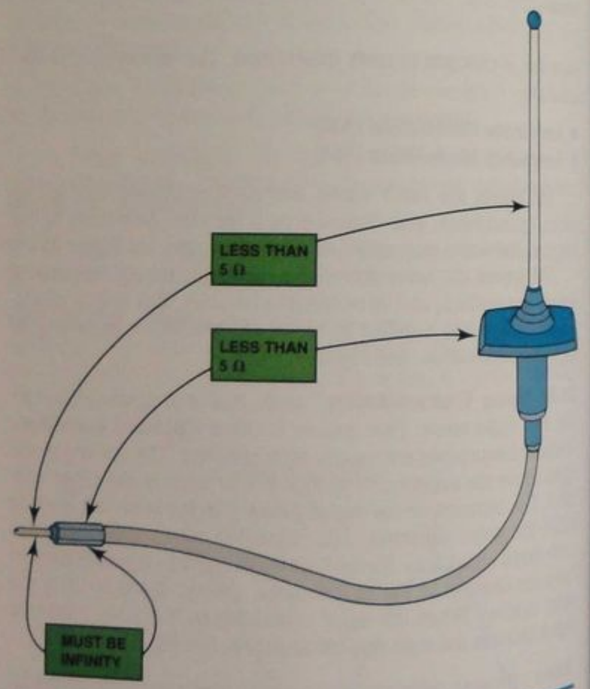


Figure 47–8 If all ohmmeter readings are satisfactory, the antenna is good.

A defective antenna will be most noticeable with AM radio reception.

Antenna Testing If the antenna or lead-in cable is broken (open), FM reception will be heard but may be weak, and there will be no AM reception. An ohmmeter should read infinity between the center antenna lead and the antenna case. For proper reception and lack of noise, the case of the antenna must be properly grounded to the vehicle body. See Figure 47–8.

TECH TIP **The Hole in the Fender Cover Trick**

A common repair is to replace the mast of a power antenna. To help prevent the possibility of causing damage to the body or paint of the vehicle, cut a hole in a fender cover and place it over the antenna. See Figure 47–9. If a wrench or tool slips during the removal or installation process, the body of the vehicle will be protected.



Figure 47–9 Cutting a small hole in a fender cover helps to protect the vehicle when replacing or servicing an antenna.

Power Antenna Testing and Service Most power antennas use a circuit breaker and a relay to power a reversible, permanent-magnet (PM) electric motor that moves a nylon cord attached to the antenna mast. Some vehicles have a dash-mounted control that can regulate antenna mast height and/or operation, whereas many operate automatically when the radio is turned on and off. The power antenna assembly is usually mounted between the outer and inner front fender or in the rear quarter panel. The unit contains the motor, a spool for the cord, and upper- and lower-limit switches. The power antenna mast is tested in the same way as a fixed-mast antenna. (An infinity reading should be noted on an ohmmeter when the antenna is tested between the center antenna terminal and the housing or ground.) Except in the case of cleaning or mast replacement, most power antennas are either replaced as a unit or repaired by specialty shops. See Figure 47–10.

Many power antenna problems can be prevented by making certain that the drain holes in the motor housing are not plugged with undercoating, leaves, or dirt. All power antennas should be kept clean by wiping the mast with a soft cloth and lightly oiling with a light oil.



Figure 47–10 A typical power antenna assembly. Note the braided ground wire used to make sure that the antenna has a good ground plane.

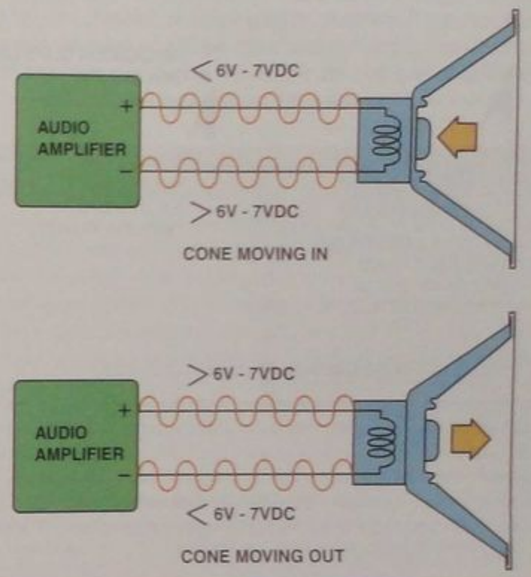


Figure 47–11 Between 6 and 7 volts is applied to each speaker terminal and the audio amplifier then increases the voltage on one terminal and at the same time decreases the voltage on the other terminal causing the speaker cone to move. The moving cone then moves the air causing sound.

SPEAKERS

The purpose of any **speaker** is to reproduce the original sound as accurately as possible. Speakers are also called *loudspeakers.* The human ear is capable of hearing sounds from a very low frequency of 20 Hz (cycles per seconds) to as high as 20,000 Hz. No one speaker is capable of reproducing sound over such a wide frequency range. See Figure 47–11.

Good-quality speakers are the key to a proper-sounding radio or sound system. Replacement speakers should be securely mounted and wired according to the correct *polarity.* See Figures 47–12 and 47–13.

All speakers used on the same radio or amplifier should have the same internal coil resistance, called **impedance.** If unequal-impedance speakers are used, sound quality may be reduced and serious damage to the radio may result. See Figure 47–14.

Impedance Matching All speakers should have the same impedance. For example, if two 4-ohm speakers are being used for



Figure 47–12 A typical automotive speaker with two terminals. The polarity of the speakers can be identified by looking at the wiring diagram in the service manual or by using a 1 1/2-volt battery to check.

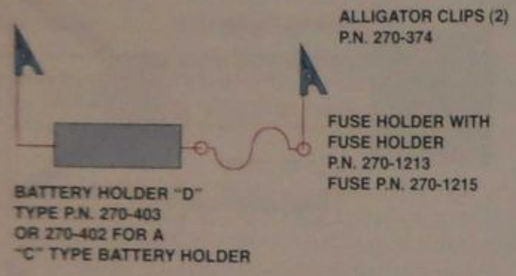


Figure 47–13 A speaker polarity tester can be easily constructed using a 1 1/2-volt battery. To test a speaker, connect the positive (+) lead of the battery to one speaker terminal and the negative (−) lead to the other speaker terminal for just a second and observe the direction the speaker cone moves. The positive (+) terminal of the speaker is the terminal that causes the speaker cone to move away from the magnet when touched with the positive (+) battery lead.

the rear and they are connected in parallel, the total impedance is 2 ohms.

$$R_T = \frac{4\Omega \text{ (impedance of each speaker)}}{2 \text{ (number of speakers in parallel)}} = 2 \text{ ohms}$$

The front speakers should also represent a 2-ohm load from the radio or amplifier. See examples:

Two front speakers—each 2 ohms

Two rear speakers—each 8 ohms

Solution: Connect the front speakers in series (connect the positive [+] of one speaker to the negative [−] of the other) for a total impedance of 4 ohms ($2\Omega + 2\Omega = 4\Omega$). Connect the two rear speakers in parallel (connect the positive [+] of each speaker together and the negative [−] of each speaker together) for a total impedance of 4 ohms ($8\Omega \div 2 = 4\Omega$).

Speaker Wiring The wire used for speakers should be as large a wire (as low an AWG number) as is practical in order to be assured that full power is reaching the speakers. Typical "speaker wire" is about 22 gauge (0.35 square millimeter), yet tests conducted by audio engineers have concluded that increasing the wire gauge to 14 (2.0 square millimeters) or larger greatly increases

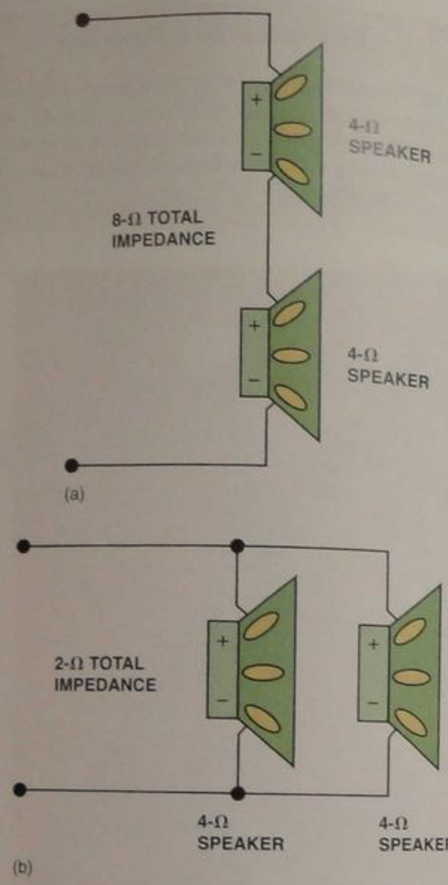


Figure 47–14 (a) Two 4-ohm speakers connected in series result in a total impedance of 8 ohms. (b) Two 4-ohm speakers connected in parallel result in total impedance of 2 ohms.

sound quality. All wiring connections should be soldered after making certain that all speaker connections have the correct polarity.

Be careful when installing additional audio equipment on a General Motors vehicle system that uses a two-wire speaker connection called a **floating ground system.** Other systems run only one power (hot) lead to each speaker and ground the other speaker lead to the body of the vehicle.

CAUTION: Regardless of radio speaker connections used, *never* operate any radio without the speakers connected, or the speaker driver section of the radio may be damaged as a result of the open speaker circuit.

FREQUENTLY ASKED QUESTION ???

What Is a "Floating Ground"?

A floating ground means that all audio components such as the receiver head, amplifier, and speakers share a common ground that is above and not connected to the chassis ground. This arrangement helps prevent interference and static that could occur if these components were connected to a chassis (vehicle) ground. If the components are chassis grounded, there may be a difference in the voltage potential (voltage); this condition is called a *ground loop.*

SPEAKER TYPES

Tweeter A **tweeter** is a speaker designed to reproduce high-frequency sounds, usually between 4,000 Hz (4 kHz) and 20,000 Hz (20 kHz). Tweeters are very directional. This means that the human ear is most likely to be able to detect the location of the speaker while listening to music. This also means that a tweeter should be mounted in the vehicle where the sound can be directed line-of-sight to the listener. Tweeters are usually mounted on the inside door near the top, windshield "A" pillar, or similar locations.

Midrange A midrange speaker is designed and manufactured to be able to best reproduce sounds in the middle of the human hearing range from 400 Hz to 5,000 Hz. Most people are sensitive to the sound produced by these midrange speakers. These speakers are also directional in that the listener can usually locate the source of the sound.

Subwoofer A **subwoofer,** sometimes called a *woofer,* produces the lowest frequency of sounds, usually 125 Hz and lower. A midbass speaker may also be used to reproduce those frequencies between 100 Hz and 500 Hz. Low-frequency sounds from these speakers are *not* directional. This means that the source of the sound from these speakers usually cannot be detected by the listener. The low-frequency sounds seem to be everywhere in the vehicle, so the location of the speakers is not as critical as with the higher-frequency speakers.

The subwoofer can be placed almost anywhere in the vehicle. Most subwoofers are mounted in the rear of the vehicle where there is more room for the larger subwoofer speakers.

Speaker Frequency Response Frequency response is how a speaker responds to a range of frequencies. A typical frequency response for a midrange speaker may be 500 Hz to 4,000 Hz with a tolerance of 3 **decibels (dB).** A decibel is a measure of sound power, and it is the faintest sound a human can hear in the midband frequencies. The dB scale is not linear (straight line) but rather logarithmic, meaning that a small change in the dB reading results in a large change in volume of noise. An increase of 10 dB in sound pressure is equal to doubling the perceived volume. Therefore, a small difference in dB rating means a big difference in the sound volume of the speaker.

CROSSOVERS

A **crossover** is designed to separate the frequency of a sound and send a certain frequency range, such as low bass sounds, to a woofer designed to reproduce these low-frequency sounds. There are two types of crossovers: passive and active.

Passive Crossover A passive crossover does not use an external power source. Rather it uses a coil and a capacitor to block certain frequencies that a particular type of speaker cannot handle and allow those frequencies that can be handled to be applied to the speaker. For example, a 6.6-millihenry coil and a 200-microfarad capacitor can effectively pass 100-Hz frequency sound to a large 10-inch subwoofer. This type of passive crossover is called a **low-pass filter,** because it passes (transfers) only the low-frequency sounds to the speaker and blocks all other frequencies. A **high-pass filter** is used to transfer higher frequency (over 100 Hz) to smaller speakers.

FREQUENTLY ASKED QUESTION ???

What Is a Bass Blocker?

A bass blocker is a capacitor and coil assembly that effectively blocks low frequencies. A bass blocker is normally used to block low frequencies being sent to the smaller front speakers. Using a bass blocker allows the smaller front speakers to more efficiently reproduce the midrange and high-range frequency sound.

Active Crossover **Active crossovers** use an external power source and produce superior performance. An active crossover is also called an *electronic crossover.* These units include many powered filters and are considerably more expensive than passive crossovers. Two amplifiers are necessary to fully benefit from an active crossover. One amplifier is for the higher frequencies and midrange and the other amplifier is for the subwoofers. If you are on a budget and plan to use just one amplifier, then use passive crossover. If you can afford to use two or more amplifiers, then consider using the electronic (active) crossover. See Figure 47–15 for an example of crossovers used in General Motors factory-installed systems.

TECH TIP ✓ **Use a Powerline Capacitor If Upgrading a Sound System**

A **powerline capacitor,** also called a **stiffening capacitor,** refers to a large capacitor (often abbreviated CAP) of 0.25 farad or larger connected to an amplifier power wire. The purpose and function of this capacitor is to provide the electrical reserve energy needed by the amplifier to provide deep bass notes. See Figure 47–16. Battery power is often slow to respond and when the amplifier attempts to draw a large amount of current, the capacitor will try to stabilize the voltage level at the amplifier by discharging stored current as needed.

A rule of thumb is to connect a capacitor with a capacity of 1 farad for each 1,000 watts of amplifier power. See the following chart.

Powerline Capacitor Usage Guide

Watts (Amplifier)	Recommended Capacitor in Farads (Microfarads)
100 W	0.10 farad (100,000 μF)
200 W	0.20 farad (200,000 μF)
250 W	0.25 farad (250,000 μF)
500 W	0.50 farad (500,000 μF)
750 W	0.75 farad (750,000 μF)
1,000 W	1.00 farad (1,000,000 μF)

Capacitor Installation A powerline capacitor connects to the power leads between the inline fuse and the amplifier. See Figure 47–17.

If the capacitor were connected to the circuit as shown, the capacitor would draw so much current that it would blow the inline fuse. To safely connect a large capacitor, it must be *precharged.* To precharge the capacitor, follow these steps:

Step #1 Connect the negative (−) terminal of the capacitor to a good chassis ground.

Step #2 Insert an automotive 12-V light bulb, such as a headlight or parking light, between the positive (+) terminal of the capacitor and the positive terminal of the battery. The light will light as the capacitor is being charged and then go out when the capacitor is fully charged.

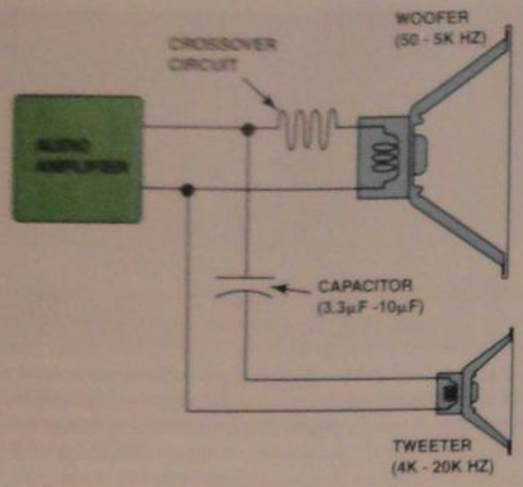


Figure 47–15 Crossovers are used in audio systems to send high-frequency sounds to the small (tweeter) speakers and the low-frequency sounds to larger (woofer) speakers.



Figure 47–16 Two capacitors connected in parallel provide the necessary current flow to power large subwoofer speakers.

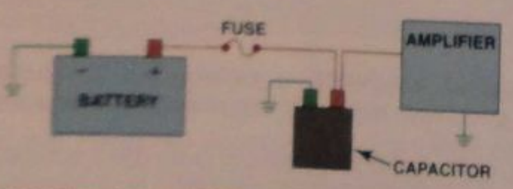


Figure 47–17 A powerline capacitor should be connected through the power wire to the amplifier as shown. When the amplifier requires more electrical power (watts) than the battery can supply, the capacitor will discharge into the amplifier and supply the necessary current for the fraction of a second it is needed by the amplifier. At other times when the capacitor is not needed, it draws current from the battery to keep it charged.

Step #3 Disconnect the light from the capacitor, then connect the power lead to the capacitor. The capacitor is now fully charged and ready to provide the extra power necessary to supplement battery power to the amplifier.

FREQUENTLY ASKED QUESTION ???

What Do the Amplifier Specifications Mean?

RMS power	**RMS** means root-mean-square and is the rating that indicates how much power the amplifier is capable of producing continuously.
RMS power at 2 ohms	This specification in watts indicates how much power the amplifier delivers into a 2-ohm speaker load. This 2-ohm load is achieved by wiring two 4-ohm speakers in parallel or by using 2-ohm speakers.
Peak power	Peak power is the maximum wattage an amplifier can deliver in a short burst during a musical peak.
THD	**Total harmonic distortion (THD)** represents the amount of change of the signal as it is being amplified. The lower the number, the better the amplifier (for example, a 0.01% is better than 0.07% rating).
Signal-to-noise ratio	This specification is measured in decibels (dB) and compares the strength of the signal with the level of the background noise (hiss). A higher volume indicates less background noise (for example, 105-dB rating is better than a 100-dB rating).

VOICE RECOGNITION

Parts and Operation **Voice recognition** is an expanding technology. It allows the driver of a vehicle to perform tasks, such as locate an address in a navigation system by using voice commands rather than buttons. In the past, users had to say the exact words to make it work such as the following examples listed from an owner's manual for a vehicle equipped with a voice-actuated navigation system:

"Go home"

"Repeat guidance"

"Nearest ATM"

The problem with these simple voice commands was that the exact wording had to be spoken. The voice recognition software would compare the voice command to a specific list of words or phrases stored in the system in order for a match to occur. Newer systems recognize speech patterns and take action based on learned patterns. Voice recognition can be used for the following functions:

1. Navigation system operation. See Figure 47–18.
2. Sound system operation
3. Climate control system operation
4. Telephone dialing and other related functions. See Figure 47–19.

A microphone is usually placed in the driver's side sun visor or in the overhead console in the center top portion of the windshield area.

Diagnosis and Service Voice recognition is usually incorporated into many functions of the vehicle. If a problem occurs with the system, perform the following steps:

1. Verify the customer complaint (concern). Check the owner's manual or service information for the proper voice commands and verify that the system is not functioning correctly.



Figure 47–18 Voice commands can be used to control many functions, including navigation systems, climate control, telephone, and radio.



Figure 47–19 The voice command icon on the steering wheel of a Cadillac.

2. Check for any aftermarket accessories that may interfere or were converted to components used by the voice recognition system, such as remote start units, MP3 players, or any other electrical component.
3. Check for stored diagnostic trouble codes (DTCs) using a TECH 2 scan tool.
4. Follow the recommended troubleshooting procedures as stated in service information.

BLUETOOTH

Operation **Bluetooth** is a radio frequency standard for short-range communications. The range of a typical Bluetooth device is 10 meters (33 feet) and it operates in the ISM (industrial, scientific, and medical) band between 2.4000 and 2.4835 MHz.

FREQUENTLY ASKED QUESTION ???

Where Did Bluetooth Get Its Name?

The term Bluetooth was used by the early adopters of the standard and they named it for Harald Bluetooth, the king of Denmark in the late 900s. The king was able to unite Denmark and part of Norway into a single kingdom.

Bluetooth is a wireless standard that works on two levels:

- It provides physical communication using low power, requiring only about one milliwatt (1/1,000 of a watt) of electrical power making it suitable for use with small handheld or portable devices, such as an ear-mounted speaker/microphone.



Figure 47–20 Bluetooth earpiece that contains a microphone and speaker unit that is paired to a cellular phone. The telephone has to be within 33 feet of the earpiece.

- It provides a standard protocol for how bits of data are sent and received.

The Bluetooth standard is an advantage because it is wireless, low cost, and automatic. The automotive use of Bluetooth technology is in the operation of a cellular telephone being tied into the vehicle. The vehicle allows the use of hands-free telephone usage. A vehicle that is Bluetooth telephone equipped has the following components:

- A Bluetooth receiver can be built into the navigation or existing sound system.
- A microphone allows the driver to use voice commands as well as telephone conversations from the vehicle to the cell via Bluetooth wireless connections.

Many cell phones are equipped with Bluetooth, which may allow the user to use an ear-mounted microphone and speaker. See Figure 47–20.

If the vehicle and the cell phone are equipped with Bluetooth, the speaker and microphone can be used as a hands-free telephone when the phone is in the vehicle. The cell phone can be activated in the vehicle by using voice commands.

FREQUENTLY ASKED QUESTION ???

Can Two Bluetooth Telephones Be Used in a Vehicle?

Usually. In order to use two telephones, the second phone needs to be given a name. When both telephones enter the vehicle, check which one was recognized. Say "phone status" and the system will tell you to which telephone the system is responding. If not the one you want, simply say, "next phone" and it will move to the other one.

SATELLITE RADIO

Parts and Operation Satellite radio, also called **Satellite Digital Audio Radio Services** or **SDARS** uses satellites to broadcast high-quality radio. SDARS broadcasts on the S-band of 2.1320 GHz to 2.345 GHz.

XM Radio XM radio is standard equipment or optional in most General Motors vehicles. XM radio uses two satellites launched in 2001 called Rock (XM-2) and Roll (XM-1) in a geosynchronous orbit above North America. Two replacement satellites, Rhythm

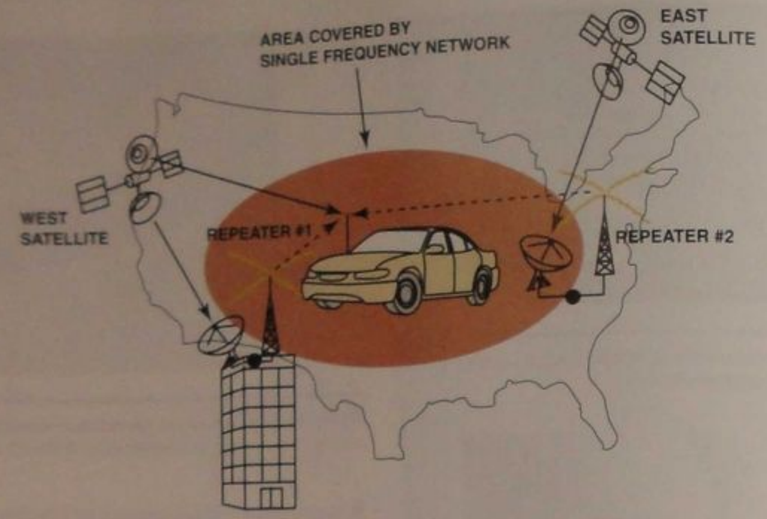


Figure 47–21 SDARS uses satellites and repeater stations to broadcast radio.

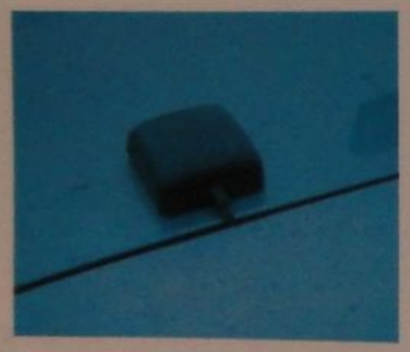


Figure 47–22 An aftermarket XM radio antenna mounted on the rear deck lid. The deck lid acts as the ground plane for the antenna.



Figure 47–23 A shark-fin-type factory antenna used for both XM and OnStar.

(XM-3) and Blues (XM-4) were launched in 2006. XM radio offers 150 channels of digital audio including:

- 68 commercial-free music channels
- 33 news, sports, talk, and entertainment channels
- 21 traffic and weather channels
- Major league baseball

Reception Reception from satellites can be affected by tall buildings and mountains. To help ensure consistent reception, both SDARS providers do the following:

- Include in the radio itself a buffer circuit that can store several seconds of broadcasts to provide service when traveling out of a service area.
- Provide land-based repeater stations in most cities. See Figure 47–21.

Antenna To be able to receive satellite radio, the antenna needs to be able to receive signals from both the satellite, as well as repeater stations located in many large cities. There are various types and shapes of antenna, including those shown in Figures 47–22 and 47–23.

Most satellite radios contain a buffer or temporary memory so that the radio will continue to operate even if the signal from the satellite or repeater station is temporarily disrupted due to tall buildings or other objects.

Diagnosis and Service The first step in any diagnosis is to verify the customer complaint (concern). If no satellite service is being received, first check with the customer to verify that the monthly service fee has been paid and the account is up to date. If poor reception is the cause, carefully check the antenna for damage or faults with the lead-in wire.

For all other satellite radio fault problems, check service information for the exact tests and procedures. Always follow the factory recommended procedures. Check the website for additional information: *www.xmradio.com* and *www.sirius.com*.

FREQUENTLY ASKED QUESTION ???

What Does "ESN" Mean?

ESN means electronic serial number. This is necessary information to know when reviewing satellite radio subscriptions. Each radio has its own unique ESN.

RADIO INTERFERENCE

Radio interference is caused by variations in voltage in the powerline or picked up by the antenna. A "whine" that increases in frequency with increasing engine speed is usually referred to as **alternator whine** and is eliminated by installing a radio choke or a filter capacitor in the power feed wire to the radio. See Figure 47–24.

Ignition noise is usually a raspy sound that varies with the speed of the engine. This noise is usually eliminated by the installation of a capacitor on the positive side of the ignition coil. The capacitor should be connected to the power feed wire to either the radio or the amplifier or both. The capacitor *has* to be grounded. If a standard automotive condenser is not available, use a 470-µF 50-volt electrolytic capacitor, which is readily available from most radio supply stores. A special coaxial capacitor can also be used in the powerline. See Figure 47–25.

A **radio choke,** which is a coil of wire, can also be used to reduce or eliminate radio interference. Again, the radio choke is installed in the power feed wire to the radio equipment. Radio interference being picked up by the antenna can best be eliminated by stopping the source of the interference by making certain that all units containing a coil, such as electric motors, have a capacitor or diode attached to the power-side wire.

Most radio interference complaints come when someone installs an amplifier, power booster, equalizer, or other radio accessory. *A major cause of this interference is the variation in voltage through the ground circuit wires. To prevent or reduce this interference, make sure all ground connections are clean and tight.* Placing a capacitor in the ground circuit also may be beneficial.

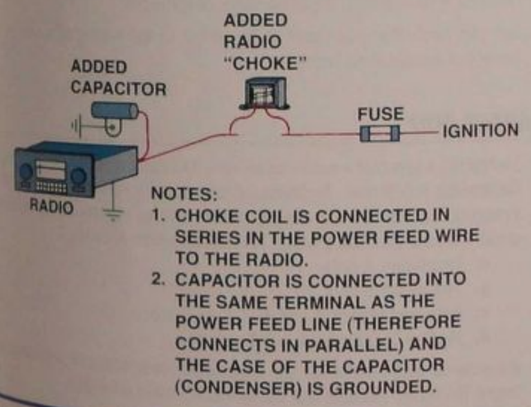


Figure 47–24 A radio choke and/or a capacitor can be installed in the power feed lead to any radio, amplifier, or equalizer.

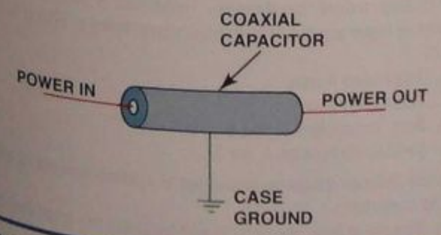


Figure 47–25 Many automobile manufacturers install a coaxial capacitor, like this one, in the power feed wire to the blower motor to eliminate interference caused by the blower motor.

CAUTION: Amplifiers sold to boost the range or power of an antenna often increase the level of interference and radio noise to a level that disturbs the driver.

In summary, radio noise can be broadcast or caused by noise (voltage variations) in the power circuit to the radio. A capacitor and/or radio choke are the most commonly used components. Two or more capacitors can be connected in parallel to increase the capacity of the original capacitor. A "sniffer" can be used to locate the source of the radio noise. See Figure 47–26.

TECH TIP ✔ **The Separate Battery Trick**

Whenever diagnosing sound system interference, try running separate 14-gauge wire(s) from the sound system power lead and ground to a separate battery outside of the vehicle. If the noise is still heard, the interference is *not* due to a generator diode or other source in the wiring of the vehicle.

REAL WORLD FIX **The General Motors Security Radio Problem**

A customer replaced the battery in a General Motors vehicle and now the radio display shows "**LOC.**" This means that the radio is locked and there is a customer code stored in the radio.

Other displays and their meaning include:

"InOP"	This display indicates that too many incorrect codes have been entered and the radio must be kept powered for one hour and the ignition turned on before any more attempts can be made.
"SEC"	This display means there is a customer's code stored but the radio is unlocked.
"—"	This means there is no customer code stored and the radio is unlocked.
"REP"	This means the customer's code has been entered once and the radio now is asking that the code be repeated to verify it was entered correctly the first time.

To unlock the radio, the technician used the following steps (the code number being used is 4321).

Step 1	Press the "HR" (hour) button—"000" is displayed.
Step 2	Set the first two digits using the hour button—"4300" is displayed.
Step 3	Set the last two digits of the code using the "MIN" (minutes) button—"4321" is displayed.
Step 4	Press the AM-FM button to enter the code. The radio is unlocked and the clock displays "1:00."

Thankfully, the owner had the security code. If the owner had lost the code, the technician would have to secure a scrambled factory backup code from the radio and then call a toll-free number to obtain another code for the customer. The code will only be given to authorized dealers or repair facilities.



Figure 47–25 A "sniffer" can be made from an old antenna lead-in cable by removing about 2 inches of the outer shielding from the end. Plug the lead-in cable into the antenna input of the radio and tune the radio to a weak station. Wave the end of the antenna wire around the vehicle dash area. The sniffer is used to locate components that may not be properly shielded or grounded and can cause radio interference through the case (housing) of the radio itself.

Audio Noise Control Symptom Chart

Noise Source	What It Sounds Like	What to Try
Generator (alternator)	A whine whose pitch changes with engine speed	Install a capacitor to a ground at the generator (alternator) output
Ignition	Ticking that changes with engine speed	Use a sniffer to further localize the source of the problem
Turn signals	Popping in time with the turn signals	Install a capacitor across the turn signal flasher
Brake lights	Popping whenever the brake pedal is depressed	Install a capacitor across the brake light switch contacts
Blower motor	Ticking in time with the blower motor	Install a capacitor to ground at the motor hot lead
Dash lamp dimmer	A buzzy whine whose pitch changes with the dimmer setting	Install a capacitor to ground at the dimmer hot lead
Horn switch	Popping when the horn is sounded	Install a capacitor between the hot lead and horn lead at the horn relay
Horn	Buzzing synchronized with the horn	Install a capacitor to ground at each horn hot lead
Amplifier power supply	A buzz, not affected by engine speed	Ground the amplifier chassis using a braided ground strap

REAL WORLD FIX — **Lightning Damage**

A radio failed to work in a vehicle that was outside during a thunderstorm. The technician checked the fuses and verified that power was reaching the radio. Then the technician noticed the antenna. It had been struck by lightning. Obviously, the high voltage from the lightning strike traveled to the radio receiver and damaged the circuits. Both the radio and the antenna were replaced to correct the problem. See Figure 47–27.

SUMMARY

1. Radios receive AM (amplitude modulation) and FM (frequency modulation) signals that are broadcast through the air.
2. The radio antenna is used to induce a very small voltage signal as an input into the radio from the electromagnetic energy from the broadcast station.



Figure 47–27 The tip of an antenna that was struck by lightning.

3. AM requires an antenna whereas FM may be heard from a radio without an antenna.
4. Speakers reproduce the original sound, and the impedance of all speakers should be equally matched.
5. Crossovers are used to block certain frequencies to allow each type of speaker to perform its job better. A low-pass filter is used to limit high-frequency sounds being sent to large woofer speakers, and a high-pass filter blocks low-frequency sounds being sent to tweeters.
6. Radio interference can be caused by many different things, such as a defective generator (alternator), a fault in the ignition system, or a fault in a relay or solenoid.

REVIEW QUESTIONS

1. Explain why AM signals travel farther than FM signals.
2. Explain the purpose and function of the ground plane.
3. Describe how to match the impedance of speakers.
4. List two items that may need to be added to the wiring of a vehicle to control or reduce radio noise.

CHAPTER QUIZ

1. Technician A says that a radio can receive AM signals, but not FM signals, if the antenna is defective. Technician B says that a good antenna should give a reading of about 500 ohms when tested with an ohmmeter between the center antenna wire and ground. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. An antenna lead-in wire should have how many ohms of resistance between the center terminal and the grounded outer covering?
   a. Less than 5 ohms
   b. 5 to 50 ohms
   c. 300 to 500 ohms
   d. Infinity (OL)
3. Technician A says that a braided ground wire is best to use for audio equipment to help reduce interference. Technician B says to use insulated 14-gauge or larger ground wire to reduce interference. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. What maintenance should be performed to a power antenna to help keep it working correctly?
   a. Remove it from the vehicle and lubricate the gears and cable
   b. Clean the mast with a soft cloth
   c. Disassemble the mast and pack the mast with silicone grease (or equal)
   d. Loosen and then retighten the retaining nut

5. If two 4-ohm speakers are connected in parallel (positive [+] to positive [+] and negative [–] to negative [–]), the total impedance will be _____.
   a. 8 ohms
   b. 4 ohms
   c. 2 ohms
   d. 1 ohm
6. If two 4-ohm speakers are connected in series (positive [+] of one speaker connected to the negative [–] of the other speaker), the total impedance will be _____.
   a. 8 ohms
   b. 4 ohms
   c. 2 ohms
   d. 1 ohm
7. An aftermarket satellite radio has poor reception. Technician A says that a lack of a proper ground plane on the antenna could be the cause. Technician B says that mountains or tall buildings can interfere with reception. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. 100,000 µF means _____.
   a. 0.10 farad
   b. 0.01 farad
   c. 0.001 farad
   d. 0.0001 farad
9. A radio choke is actually a _____.
   a. Resistor
   b. Capacitor
   c. Coil (inductor)
   d. Transistor
10. What device passes AC interference to ground and blocks DC voltage and is used to control radio interference?
    a. Resistor
    b. Capacitor
    c. Coil (inductor)
    d. Transistor

SECTION VIII

Heating and Air Conditioning

48 Heating and Air-Conditioning Components and Operation

49 Automatic Air-Conditioning System Operation

50 Heating and Air-Conditioning System Diagnosis

51 Heating and Air-Conditioning System Service



CHAPTER 48

Heating and Air-Conditioning Components and Operation

OBJECTIVES: After studying Chapter 48, the reader will be able to: Prepare for ASE Heating and Air-conditioning (A7) certification test content area "A" (Air Conditioning System Diagnosis and Repair) and content area "C" (Heating and Engine Cooling Systems Diagnosis and Repair). • Describe how the heater functions. • Describe how the refrigeration cycle functions. • List the parts of a typical air-conditioning system. • Explain how the air-conditioning system removes heat from the passenger compartment.

KEY TERMS: absolute humidity • axial compressor • barrier hose • blower motor • boiling point • calorie (c) • capillary tube • CFC-12 (R-12) • compressor • condenser • condensate line • condensation point • condenser • cycling clutch orifice tube (CCOT) • electromagnetic clutch • ester oil • evaporator • evaporator pressure regulator (EPR) valve • freon • heat • heater core • heater hoses • heating, ventilation, and air-conditioning system (HVAC) • HFC-134a (R-134a) • humidity • H-valve • hygrometer • kinetic energy • latent heat of vaporization • liquid • miscible • pilot operated absolute (POA) valve • pintle valve • positive-displacement compressor • psychrometer • reed valve • relative humidity • section 609 (clean air act) • solid • superheat • swash plate • thermostatic expansion valve (TEV or TXV) system • thermo switch (cycling switch or defrost switch) • vapor

PRINCIPLES OF HEATING AND REFRIGERATION

Driver and passenger comfort is the primary purpose of the heating, ventilation, and air-conditioning system, often abbreviated **HVAC**. The heater is also needed in cold climates to prevent freezing or death.

On earth, matter is found in one of three different phases or states: solid, liquid, or vapor (gas). The state depends upon the nature of the substance, the temperature, and the pressure or force exerted on it. Water occurs naturally in all three states: solid ice, liquid water, and water vapor, depending upon the temperature and pressure of the location. See Figure 48–1.

Changes of State A **solid** is a substance that cannot be compressed and has strong resistance to flow. The molecules of a solid attract each other strongly, and resist changes in volume and shape.

A substance is solid at any temperature below its melting point. A melting point is a characteristic of a substance, and is related to the temperature at which a solid turns to a liquid. For water, the melting point is 32°F (0°C), which means that we can observe changes between liquid water and ice under normal weather conditions.

A **liquid** is a substance that cannot be compressed. A substance in a liquid state has a fixed volume, but no definite shape.

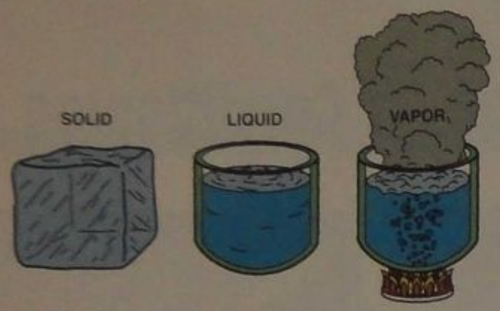


Figure 48–1 Water is a substance that can be found naturally in solid, liquid, and vapor states.

The **boiling point** is the temperature at which a solid substance turns to a vapor. For water at normal seal level conditions, the boiling point is 212°F (100°C).

A **vapor** is a substance that can be easily compressed, has no resistance to flow, and no fixed volume. Since a vapor flows, it is considered a fluid just like liquids are.

A substance changes to a vapor if the temperature rises above its boiling point. A vapor condenses to liquid if the temperature falls below it. Just like melting and freezing, the boiling point and **condensation point** are the same temperature. Again, the difference is simply whether heat is being added or taken away. Boiling point and condensation point temperatures are not fixed; they vary with pressure.

Heat and Temperature Molecules in a substance tend to vibrate rapidly in all directions, and this disorganized energy is called **heat.** The intensity of vibration depends on how much **kinetic energy,** or energy of motion, the atom or molecule contains. We measure the level of this energy as temperature.

Heat and temperature are not the same. Heat is measured in **calories (c).** The calorie is a metric unit that expresses the amount of heat needed to raise the temperature of one gram of water one degree Celsius.

Heat is also measured in British Thermal Units (BTU). One BTU is the heat required to raise the temperature of one pound of water 1°F at sea level. One BTU equals 252 calories.

FREQUENTLY ASKED QUESTION ???

Why Is Liquid Sprayed from a Can Cold?

If you spray a can of liquid continuously, the can becomes cold, and the liquid being sprayed becomes cold. The can becomes cold because the pressure in the can is reduced while spraying, allowing the liquid propellant inside the can to boil and absorb heat. The liquid being sprayed has also been cooled by the liquid propellant. The propellant vapor is further cooled as it decompresses when it hits the open air. Rapid decompression results in a rapid temperature drop.

Latent Heat Latent heat is the "extra" heat that is needed to transform a substance from one state to another. Imagine that a solid or a liquid is being heated on a stove. When the solid reaches its melting point, or the liquid reaches its boiling point, their temperatures stop rising. The solid begins to melt, and the liquid begins to boil. This occurs without any change in temperature, even though heat is still being poured in from the burner.

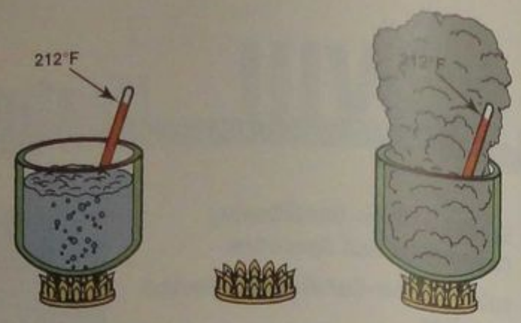


Figure 48–2 The extra heat required to change a standard amount of water at its boiling point to a vapor is called **latent heat of vaporization**.

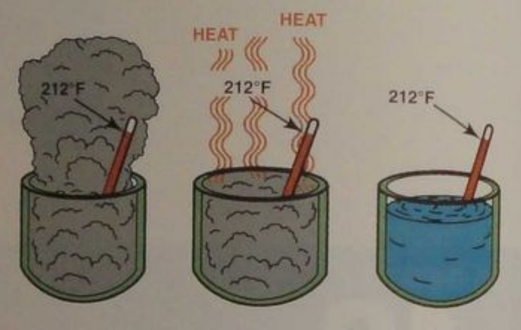


Figure 48–3 The latent heat of vaporization that water vapor stores is given off when the vapor condenses to a liquid. The temperature stays the same.

The water in the container on the stove boils at a temperature of 212°F (100°C) at sea level, for as long as any liquid water remains. As you continue to add heat with the burner, it will all be absorbed in changing the state of the liquid to a vapor. This extra, hidden amount of energy necessary to change the state of a substance is called latent heat. See Figures 48–2 and 48–3.

Latent heat is important in air-conditioning system operation because the cooling effect is derived from changing the state of liquid refrigerant to a vapor. The refrigerant absorbs latent heat of vaporization, cooling the air blown into the passenger compartment. You take away the heat to cool the air.

Temperature, Volume, and Pressure of a Vapor Unlike a solid, a vapor has no fixed volume. Increasing the temperature of a vapor, while keeping the volume confined in the same space, increases the pressure. This happens as the vibrating vapor molecules collide more and more energetically with the walls of the container. Conversely, decreasing the temperature decreases the pressure. This relationship between temperature and pressure in vapor is why a can of nonflammable refrigerant can explode when heated by a flame—the pressure buildup inside the can will eventually exceed the can's ability to contain the pressure.

Increasing the pressure by compressing a vapor increases the temperature. Decreasing the pressure by permitting the vapor to expand decreases the temperature.

Pressure-Temperature Relationships There are two aspects of the relationship between pressure and temperature that are important to understanding the operating of an HVAC system:

- The temperature at which a liquid boils (and vapor condenses) rises and falls with the pressure.
- Pressure in a sealed system that contains both liquid and vapor rises and falls with the temperature.

Humidity Water vapor is in the air in varying concentrations. **Humidity** refers to water vapor present in the air. The level of humidity depends upon the amount of water vapor present and the temperature of the air.

The amount of water vapor in the air tends to be higher near lakes or the ocean, because more water is available to evaporate from their surfaces. In desert areas with little open water, the amount of water vapor in the air tends to be low.

Absolute humidity is the measurement of the weight of the water vapor in a given volume of air. **Relative humidity** is the percentage of how much moisture is present in the air compared to how much moisture the air is capable of holding at that temperature.

Relative humidity is commonly measured with a **hygrometer** or a **psychrometer.** A hygrometer depends on a sensitive element that expands and contracts, based on the humidity. Hygrometers typically resemble a clock, with the scale reading from 0% to 100% relative humidity. Permanent-recording hygrometers may be constructed so that an ink pen or electric stylus makes a continuous record on a rotating paper disc or paper-covered drum.

A psychrometer uses two thermometers, one of which has the bulb covered in a cotton wick soaked in distilled water from a built-in reservoir. See Figure 48–4. The wick keeps the bulb of the "wet thermometer" wet so that it can be cooled by evaporation. To take a relative humidity reading, the psychrometer is placed in the airflow for a certain time. As the evaporator blows air, the wet bulb's temperature drops, and the dry bulb reads the temperature of the airflow. Sling psychrometers are spun round in the air a certain number of times. Water evaporates from the cotton wick at a rate inversely proportional to the relative humidity of the air; faster if the humidity is low, and slower if the humidity is high.

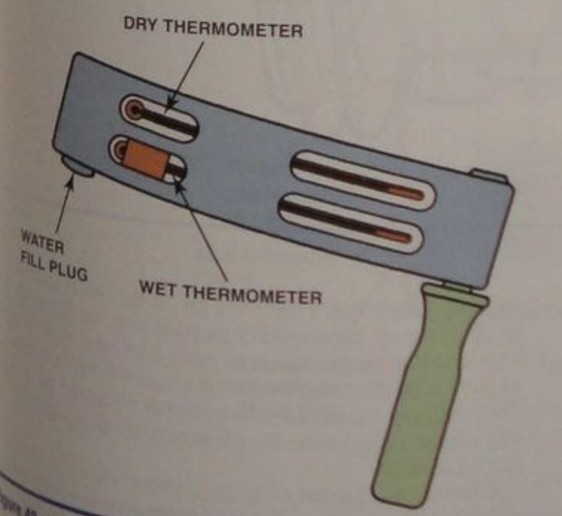


Figure 48–4 A sling psychrometer is used to measure relative humidity.

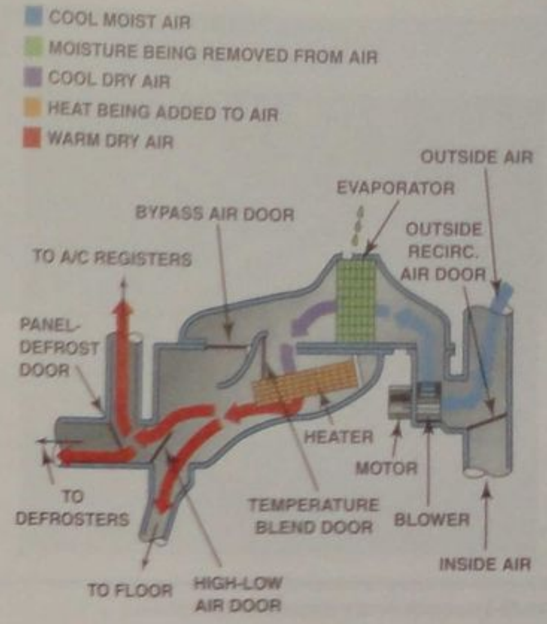


Figure 48–5 Typical flow of air through an automotive heat, ventilation, and air-conditioning system when placed in the heat position.

The "dry thermometer" registers ordinary air temperature. The higher the relative humidity, the closer the readings of the two thermometers, and the lower the humidity, the greater the difference. The different temperatures indicated by the wet and dry thermometers are compared to a chart, which gives the relative humidity.

HEATING SYSTEM

All automotive and light-truck heater systems use the hot coolant from the engine to produce heat. The engine coolant (antifreeze and water) flows through **heater hoses** and a **heater core.** The engine water pump supplies the force necessary to circulate the engine coolant through the heater core. The heater core is a small radiator with tubes and fins that help transfer the heat from the coolant to the air flowing through the heater core. See Figure 48–5. A **blower motor** with a squirrel cage-type fan is usually used to force air through the heater core and into the passenger compartment. See Figure 48–6. Before the heater can function correctly, the cooling system has to be functioning correctly.

FREQUENTLY ASKED QUESTION ???

What Is an Auxiliary Electric Water Pump?

Some vehicles are equipped with an auxiliary electric water pump. The purpose and function of this pump is to help warm the interior of the vehicle by circulating coolant from the engine through the heater core when the engine is at idle speed. At idle speed, the water pump does not pump a sufficient quantity of coolant through the heater core to warm the interior in freezing weather.

AIR-CONDITIONING REFRIGERATION CYCLE

All automotive air-conditioning systems are closed and sealed. A refrigerant is circulated through the system by a **compressor** that is powered by the engine through an accessory drive belt. Older

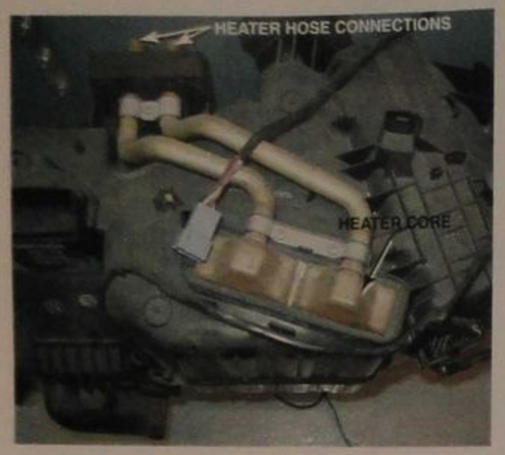


Figure 48–6 A typical heater core as installed in an HVAC housing.

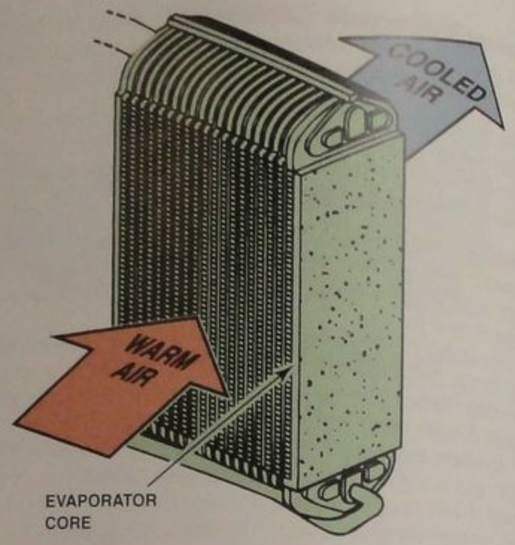


Figure 48–7 The evaporator removes heat from the air that enters a vehicle by transferring it to the vaporizing refrigerant.

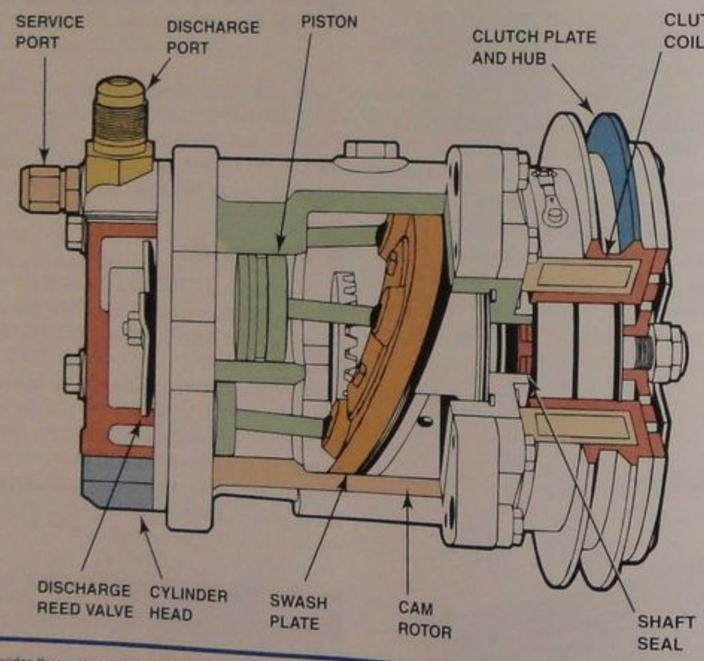


Figure 48–8 The compressor provides the mechanical force needed to pressurize the refrigerant.

systems used a refrigerant, CFC-12, commonly referred to by its Dupont trade name of Freon or R-12. Starting in the early 1990s, vehicle manufacturers now all use HFC-134a, a refrigerant that is less harmful to the atmosphere. The basic principle of the refrigeration cycle is that as a liquid changes into a gas, heat is absorbed. The heat that is absorbed by an automotive air-conditioning system is the heat from inside the vehicle. This is how the system works:

1. The liquid refrigerant evaporates in a small radiator-type unit called the **evaporator**. As the refrigerant evaporates, it absorbs heat as it changes from a liquid to a gas. As the heat is absorbed by the refrigerant, the evaporator becomes cold. See Figure 48–7.
2. After the refrigerant has evaporated into a *low-pressure gas* in the evaporator, the refrigerant flows into the engine-driven compressor. The compressor compresses the low-pressure refrigerant gas into a high-pressure gas and forces the refrigerant through the system. See Figure 48–8.
3. This high-pressure gas flows into the condenser located in front of the cooling system radiator. The **condenser** looks like another radiator, and its purpose and function is the same as the cooling system radiator, to remove heat from the high-pressure gas. In the condenser, the high-pressure gas changes (condenses) to form a high-pressure liquid as the heat from the refrigerant is released to the air. See Figure 48–9.
4. The high-pressure liquid then flows through a device that meters the flow into the evaporator. When the high pressure of the liquid drops, it causes the refrigerant to vaporize.
5. Air is blown through the evaporator by the blower motor. The air is cooled as heat is removed from the air and transferred to the refrigerant in the evaporator. This cooled air is then directed inside the passenger compartment through vents.

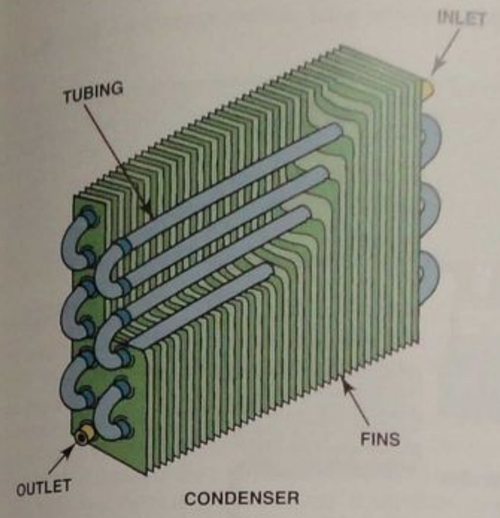


Figure 48–9 The condenser changes the refrigerant vapor into a liquid by transferring heat from the refrigerant to the air stream that flows between the condenser fins.

FREQUENTLY ASKED QUESTION ???

How Does the Inside of the Vehicle Get Cooled?

The underlying principle involved in air-conditioning or refrigeration is that "cold attracts heat." Therefore, a cool evaporator attracts the hot air inside the vehicle. Heat always travels toward cold and when the hot air passes through the cold evaporator, the heat is absorbed by the cold evaporator, which lowers the temperature of the air. The cooled air is then forced into the passenger compartment by the blower through the air-conditioning vents.

EXPANSION VALVE SYSTEMS

An expansion valve is attached to the inlet to the evaporator and controls the amount of refrigerant flow into the evaporator. The expansion valve controls the flow of the refrigerant based on the temperature at the outlet of the evaporator, which is measured by a temperature-sensing bulb and tube. When the outlet of the evaporator is warm, the opening of the expansion valve is increased. This opening allows refrigerant to flow into the evaporator. As the temperature at the outlet of the evaporator decreases, the sensing bulb and tube cause the expansion valve to restrict the flow of refrigerant into the evaporator. This type of system is called the **thermostatic expansion valve** system—usually abbreviated **TEV** or **TXV.** See Figure 48–10.

ORIFICE TUBE SYSTEMS

Many air-conditioning systems today use a fixed-orifice tube at the inlet to the evaporator. As refrigerant flows through this orifice (small hole), it expands inside the evaporator, where it absorbs heat and expands into a low-pressure gas. A pressure switch located in

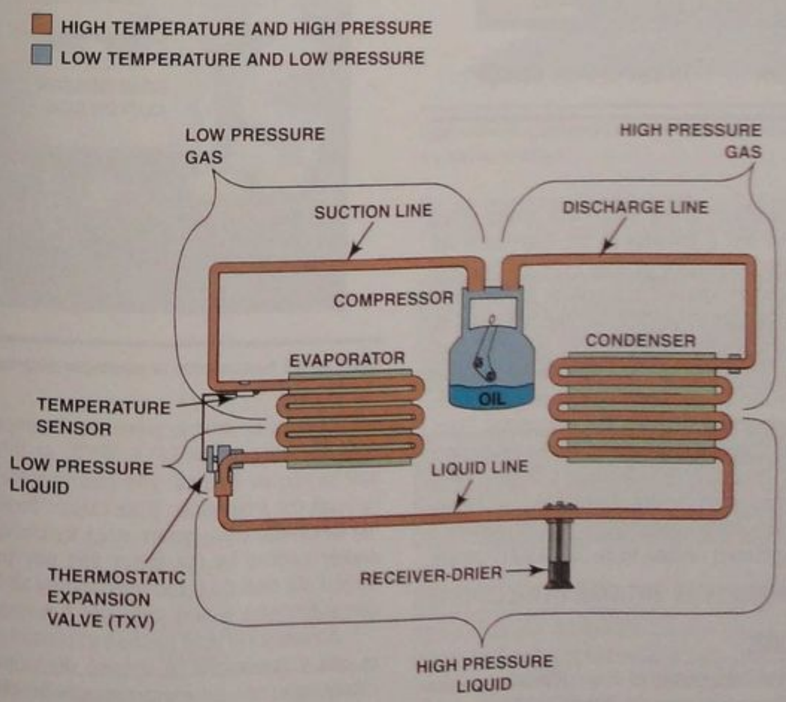


Figure 48–10 A typical air-conditioning system that uses an expansion valve. A temperature sensor bulb is attached to the outlet of the evaporator to control the amount of refrigerant allowed to flow into the evaporator.

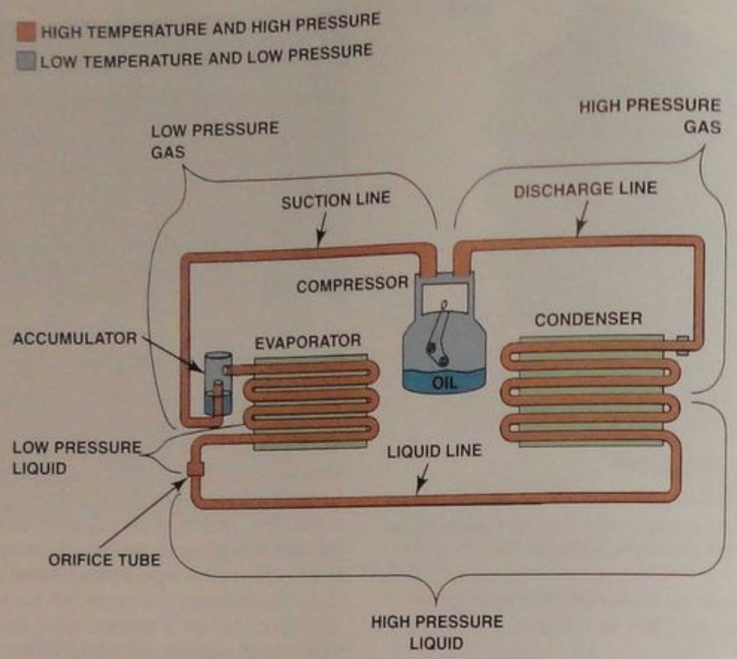


Figure 48–11 A typical automotive air-conditioning system that uses a cycling clutch and an orifice tube.

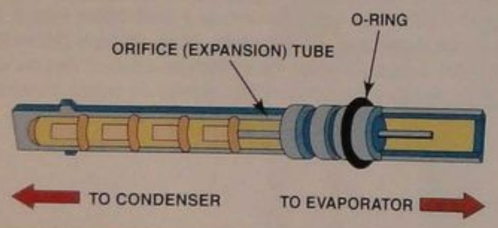


Figure 48–12 Typical orifice tube.

the low-pressure line at the outlet of the evaporator senses when the pressure is too low. Too low a pressure in the evaporator can cause the temperature of the evaporator to drop to below freezing. A cold evaporator can therefore cause the moisture in the air to freeze into ice, creating a blockage to air flow through the evaporator. Therefore, whenever the pressure drops below a certain pressure (typically about 3 to 33 PSI [214 to 228 kPa]), a pressure switch breaks the circuit to the air-conditioning compressor clutch, which stops the flow of refrigerant through the evaporator. Then, when the temperature (and pressure) increases in the evaporator, the pressure switch closes, restoring the electrical current flow to the compressor clutch and causing the compressor to start forcing refrigerant through the evaporator again. This type of system is commonly called a **cycling clutch orifice tube** (or **CCOT**) system. See Figures 48–11 and 48–12.

THERMOSTATIC CONTROL

The lower the pressure of the refrigerant, the lower the temperature. If the pressure in the evaporator is above 30 PSI (220 kPa) for R-12 or 28 PSI (193 kPa) for an R-134a system, the temperature of the evaporator will remain about freezing, 32°F (0°C). Temperature



Figure 48–13 A cutaway of an air-conditioning compressor electromagnetic clutch.

control must be used to prevent the temperature of the evaporator from dropping below 32° F (0°C). At this temperature, the moisture in the air freezes. The resulting ice would clog the airflow through the evaporator. If air cannot flow through the evaporator, the air-conditioning system stops functioning and would be immediately noticed by the driver and any passengers. If the A/C is turned off, heat from the surrounding air will melt the ice and the air-conditioning system will again function until it ices up again.

A commonly used method to control evaporator temperature is to use a thermostat to control the compressor. Air-conditioning compressors use an **electromagnetic clutch.** See Figure 48–13. When the thermostat senses that the temperature is near freezing, 32°F (0°C), the switch opens the electrical circuit to the compressor and the compressor stops circulating refrigerant. This thermostat

switch is also called a **thermo switch, icing switch,** or **defrost switch.**

NOTE: Older vehicles used a system to control evaporator pressure when used with a continuously-operating compressor, including:

POA valve—A POA valve (meaning **pilot operated absolute**)
EPR valve—An **evaporator pressure regulator** valve maintains at least 30 PSI in the evaporator to prevent evaporator freeze up.

REFRIGERANTS

Air-conditioning refrigerant is used to transfer heat from the inside of the vehicle to the condenser located in the front of the vehicle. A refrigerant absorbs heat when it changes state from a liquid to a gas. One of the first refrigerants was **CFC-12,** commonly referred to as **R-12** or by its brand name **Freon,** a registered trade name of the DuPont Corporation. CFC-12 consists of one carbon atom surrounded by two chlorine (CL) and two fluorine (F) atoms and is therefore called a chlorofluorocarbon (CFC) compound. Its chemical name is dichlorodifluoromethane. It is the chlorine atoms that are believed to contribute to the destroying of the ozone layer in our upper atmosphere.

Another refrigerant, **HFC-134a,** also called **R-134a,** has been selected by vehicle manufacturers to replace the ozone-harming CFC. HFC-134a compound contains two carbon atoms and four fluorine atoms plus two hydrogen atoms and is therefore called a hydrofluorocarbon. Its chemical name is tetrafluoroIthene, and Dupont calls it Suva®. See Figure 48–14. The boiling points and therefore the operation characteristics of CFC-12 and HFC-134a are similar.

CFC-12 and HFC-134a Boiling Temperatures at Various Pressures

Temperature °F (°C)	Pressure (PSI) (kPa) CFC-12	Pressure (PSI) (kPa) HFC-134a
0 (–22)	9 (62)	6 (41)
5 (–15)	12 (83)	9 (62)
10 (–12)	15 (103)	12 (83)
15 (–9)	18 (124)	15 (103)
20 (–7)	21 (145)	18 (124)
25 (–4)	25 (172)	22 (152)
30 (–1)	29 (200)	26 (179)
35 (2)	33 (228)	31 (214)
40 (4)	37 (255)	35 (241)
45 (7)	42 (290)	40 (276)
50 (10)	47 (324)	45 (310)
55 (13)	52 (359)	51 (352)
60 (16)	47 (324)	57 (393)
65 (18)	64 (441)	64 (441)
70 (21)	70 (483)	71 (490)
75 (24)	77 (531)	79 (544)
80 (27)	84 (579)	87 (600)
85 (29)	92 (634)	95 (655)
90 (32)	100 (690)	104 (717)
95 (35)	108 (745)	114 (786)
100 (38)	117 (807)	124 (855)
105 (41)	127 (876)	147 (1013)
110 (43)	136 (938)	158 (1089)

HFC-134a is a smaller molecule than CFC-12. However, HFC-134a can more easily leak out through small holes or openings in the system. HFC-134a systems require that the inside layer of the



Figure 48–14 R-134a is available in 12 oz cans as well as larger 30-lb containers.

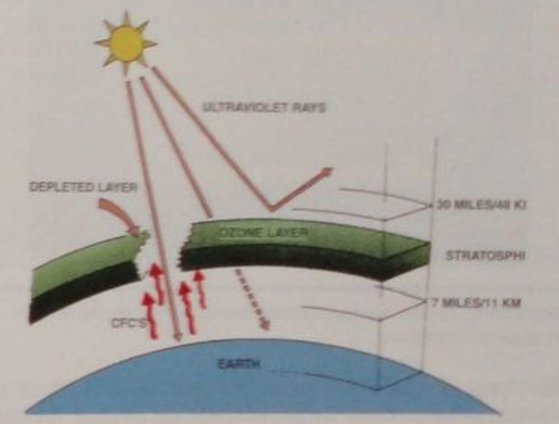


Figure 48–15 A depletion of the ozone layer allows more ultraviolet radiation from the sun to reach Earth's surface.

rubber refrigerant hoses contain a barrier to prevent penetration through the microscopic holes/standard rubber refrigerant holes.

NOTE: Look at the size of a blue HFC-134a 30-pound container compared to a white CFC-12 30-pound container. The blue R-134a container is larger because it requires more HFC-134a to achieve 30 pounds.

NOTE: Many vehicle manufacturers started using barrier-type refrigerant hoses on their vehicles in the late 1980s in anticipation of the conversion from CFC-12 to HFC-134a in future models.

REFRIGERANTS AND THE ENVIRONMENT

Air-conditioning refrigerants have been discovered to be harmful to the ozone layer. The ozone (O_3) layer is in the upper atmosphere and blocks out ultraviolet rays from the sun. See Figure 48–15. It has been discovered that certain chemicals, such as chlorofluorocarbon (CFC), are rapidly destroying this layer of ozone, which is 10 to 30 miles above Earth's surface. See Figure 48–16 for how ozone is destroyed.

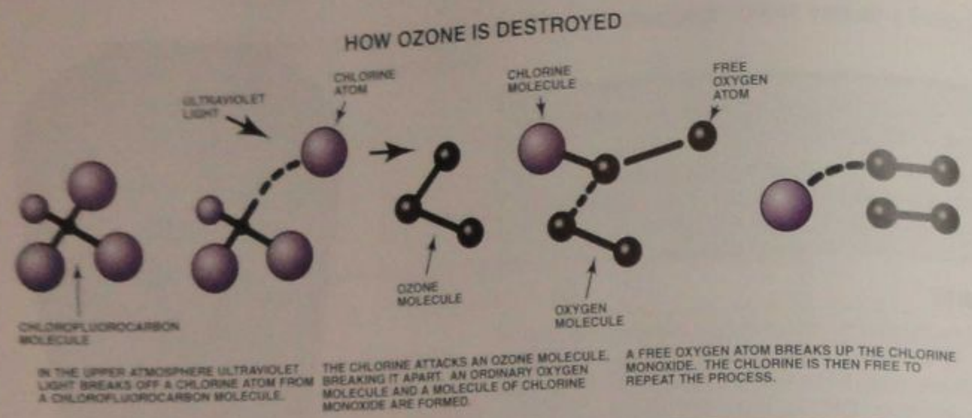


Figure 48–16 Chlorofluorocarbon molecules break apart in the atmosphere.



Figure 48–17 The label on a Toyota Fuel Cell Hybrid Vehicle (FCHV) showing that CO_2 is being used as the refrigerant.



Figure 48–18 PAG oil used in Chrysler vehicles equipped with HFC-134a refrigerant. Notice that different oils are used for different systems depending primarily on the manufacturer of the compressor. Also notice that both PAG oils are in metal cans. PAG oil absorbs moisture so readily that it can even absorb moisture that is in the air through plastic—that is why metal containers are used.

Montreal Protocol A conference was held in Montreal, Canada, in 1987, where the United States and 22 other countries agreed to limit the production of ozone-depleting refrigerants. The Clean Air Act of 1990 specified that the production of R-12 refrigerant would cease at the end of 1995. **Section 609** of the Clean Air Act required the following:

- All technicians who service or repair automotive air-conditioning systems shall be properly trained and certified.
- Recovery and recycling equipment must be properly approved.
- Each shop that performs automotive air-conditioning service should comply to the Environmental Protection Agency (EPA) that it is using approved recycling equipment and that only properly trained and certified technicians are using the equipment.

FREQUENTLY ASKED QUESTION ???

Is Carbon Dioxide the Next Refrigerant?

Not likely. While carbon dioxide (CO_2) (R744) is being used on prototype vehicles, such as the Toyota Fuel Cell Hybrid Vehicle (FCHV), it requires extremely high pressures, up to 2000 PSI and is not as efficient as a refrigerant as R-134a. See Figure 48–17.

REFRIGERANT OILS

The oil carried by the refrigerant through the various components is often the only source of lubrication for the compressor. The oil used must be able to be mixed without separating in the refrigerant. This characteristic of being able to be mixed is called **miscible.** CFC-12 systems must use mineral oil. Mineral oil is not miscible in HFC-134a, and so such systems must use synthetic polyalkyline glycol, usually referred to as PAG oil. There are numerous different PAG oils, and each vehicle manufacturer (or air-conditioning compressor manufacturer) recommends which PAG to use. See Figure 48–18.

Another type of refrigerant oil is called **ester oil.** Ester is a classification of hydrocarbons and is specified for use in air-conditioning systems that have been charged (retrofitted) from CFC-12 to HFC-134a. Ester oil will mix with any remaining mineral oil and will work to lubricate the system even if some CFC-12 is still in the system. See Figure 48–19.

All refrigerant oils have a viscosity rating. Viscosity is the measure of the oil's thickness or resistance to flow. Always use the type and viscosity of oil specified by the manufacturer.

CAUTION: Failure to use the correct refrigerant oil in an air-conditioning system can cause serious (and expensive) damage to the air-conditioning compressor. Always use the refrigerant oil specified by the manufacturer.



Figure 48–19 Ester refrigerant oils are often specified for use when retrofitting an R-12 system to R-134a by companies who supply refit kits. Ester refrigerant oil is not recommended by many vehicle or air-conditioning compressor manufacturers. Always use the recommended refrigerant oil for the vehicle and system being serviced.

CONDENSER

The condenser looks like a cooling system radiator. In fact, a condenser is a radiator because it is designed to radiate heat from the refrigerant to the outside air.

When the refrigerant leaves the compressor it is over 300°F (150°C) as it enters the condenser. Even on a hot 100°F (38°C) day, there is a difference in temperature between the outside air around the condenser and the temperature of the refrigerant inside the condenser. Heat always travels hot to cold. Therefore, the heat in the hot refrigerant has a natural tendency to radiate into the outside air. As the heat travels into the air, the high-pressure gas refrigerant changes state and becomes a high-pressure liquid. This is the reason the condenser is called by that name: as the heat leaves the refrigerant, it **condenses** from a gas (vapor) to a liquid. See Figure 48–20.

To help in the heat transfer, most vehicles are equipped with cooling fans driven either electrically or by the engine through an accessory drive belt. The fan draws air through the condenser and increases the heat transfer rate.

TECH TIP ✓ **Broken Condenser Line?—Check the Engine Mounts!**

Most air-conditioning systems use aluminum and flexible rubber lines between the compressor and the condenser. Because the compressor is mounted on and driven by the engine and the condenser is mounted to the body, these lines can break if the engine mounts are defective. The rubber hoses attached between the aluminum fittings of the compressor and condenser are designed to absorb normal engine movement. Worn engine mounts would allow the engine to move too much. Aluminum lines cannot stand to be flexed without crushing and breaking.

Therefore, the wise technician will carefully inspect and replace any and all worn engine mounts if a broken aluminum condenser line is discovered to prevent a premature failure of a replacement condenser. See Figure 48–21.

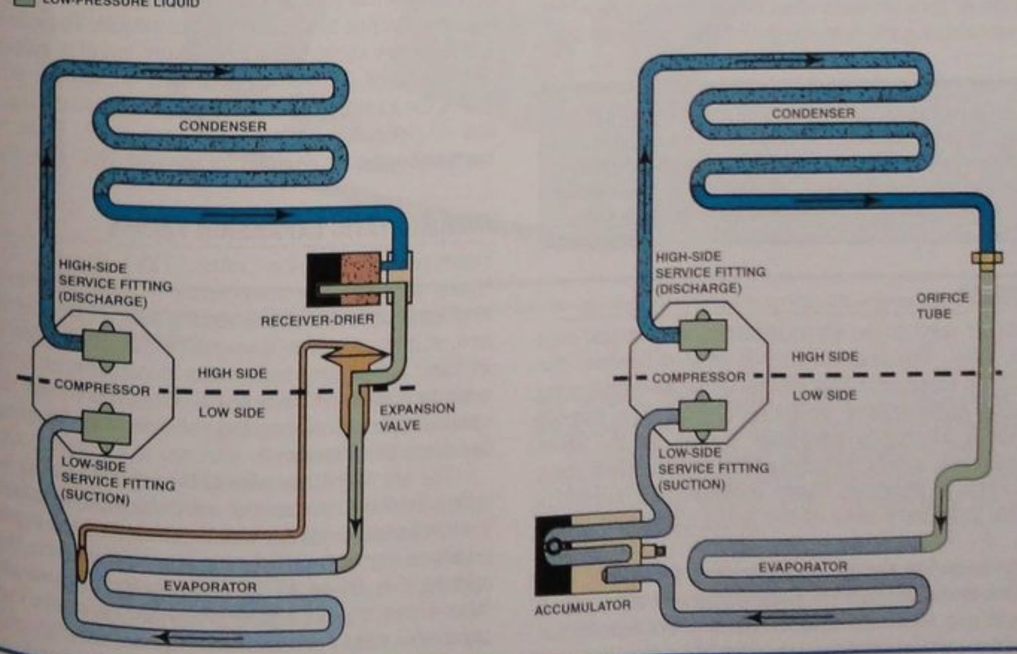


Figure 48–20 The condenser serves the same function for both the orifice-tube and the expansion valve–type air-conditioning system, and that is to remove the heat from the refrigerant and cause the hot refrigerant vapors to condense into a hot liquid.

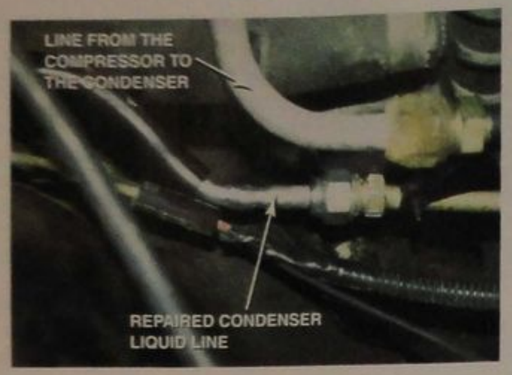


Figure 48–21 A repaired condenser refrigerant line.

EVAPORATOR

The evaporator looks like a small radiator that is located in the evaporator housing on the passenger side of the bulkhead (firewall). The purpose of the evaporator is to transfer heat from the air to the refrigerant flowing through it. Heat from the air causes the low-pressure liquid inside the evaporator to evaporate into a low-pressure gas. As the refrigerant changes state from a liquid to a gas, it absorbs heat. A blower motor equipped with a squirrel cage–type fan circulates air through the evaporator and forces the cooler air into the passenger compartment.

Another benefit of the cooling of the air is a result of what happens to any moisture that may be in the air. Moisture in the air is called relative humidity and represents the percentage of water vapor that could be in the air to the actual amount in the air. High humidity feels uncomfortable. Because the evaporator is cold (usually just above the freezing point of 32°F (0°C), any moisture in the air condenses on its cool surface. This removes the moisture from the air and lowers the relative humidity. The moisture that condenses out of the air then becomes water that is allowed to flow out of the evaporator housing and onto the ground. See Figure 48–22.

NOTE: If the carpet (or floor) of the vehicle is wet on the passenger side, the cause is often a clogged evaporator drain hose. The opening, called the **condensate line,** is frequently clogged with mud, road debris, or leaves. To check the drain opening, hoist the vehicle and insert a wire or screwdriver into the end of the hose opening at the bottom of the evaporator housing.

RECEIVER-DRIER

A receiver-drier is used on an air-conditioning system that uses an expansion valve. The receiver-drier is located between the condenser and the evaporator. This section of the air-conditioning system contains *high-pressure liquid refrigerant.* The purpose of the receiver is to provide temporary storage for the liquid refrigerant and it also usually includes a filter to trap debris and a desiccant to remove moisture. Many receiver-driers contain a sight glass that provides a view of the liquid refrigerant in the system.

A drier is needed to remove moisture from the system. The drier contains a **desiccant** (usually silica alumina or silica gel). A desiccant is a drying agent that absorbs any moisture (water) that gets into the air-conditioning refrigerant system. Moisture can combine with refrigerant to form an acid. Water can also freeze and form ice in the system.

The desiccant is classified as XH-5 for CFC-12 systems and XH-7 or XH-9 for HFC-134a systems. The desiccant used on a CFC-12 system is not compatible with HFC-134a systems. Therefore, whenever a system is changed (retrofitted) from CFC-12 to HFC-134a, the desiccant *must* be replaced.

The desiccant (accumulator or receiver-drier) should also be replaced on any air-conditioning system that has been left open to the atmosphere for any length of time (over 24 hours) or whenever the system has been left in a discharged condition. See Figure 48–23.

ACCUMULATOR

An accumulator is used on systems that use an orifice tube. It is located between the evaporator and the compressor. The refrigerant in this section of the refrigerant cycle is a *low-pressure gas.* The purposes of the accumulator include:

- Preventing liquid refrigerant from reaching the compressor

NOTE: A liquid cannot be compressed. If liquid refrigerant were to enter the compressor, the compressor would lock up and be damaged.

- Holding a reserve of refrigerant
- Holding the desiccant (helping to remove moisture from the system)

See Figure 48–24.

REFRIGERANT LINES AND HOSES

Aluminum tubing is used to connect many stationary items together like the condenser to the receiver-drier and the receiver-drier to the evaporator. Rubber lines are usually used to and from the compressor. Because the compressor is attached to the engine and the engine is mounted on flexible rubber mounts, there is movement between the compressor and the other air-conditioning components that are attached to the body of the vehicle. These flexible refrigerant hoses are constructed from many layers of rubber and fabric. See Figure 48–25. Most hoses used on vehicles since the early 1990s use a nonpermeable inside layer of material that prevents the loss of refrigerant through the hose itself. These hoses, called **barrier hoses,** are required for use with HFC-134a refrigerant.

THERMOSTATIC EXPANSION VALVES

Thermostatic expansion valve (TXV) systems, as shown in Figure 48–26, use a temperature-sensitive bulb located on the evaporator outlet tube. The sensing bulb is insulated with a special tape, so it reacts only to temperature changes it senses from the outlet tube. The sensing bulb works in combination with a pressure-sensitive diaphragm inside the TXV body to control the size of the variable orifice. This regulates the rate at which liquid refrigerant flows into the evaporator.

The key to the operation of the expansion valve is the variable orifice. In these systems, the outlet from the high-pressure side to the low-pressure side is a variable-diameter hole. A **pintle valve** is a ball-and-seat valve used to increase or decrease the size of the opening. See Figure 48–27. The expansion valve uses the pintle valve to control how rapidly refrigerant enters the evaporator. The expansion valve controls the refrigerant flow in response to the temperature of the evaporator outlet, measured by the remotely mounted sensing bulb and **capillary tube.** See Figure 48–28. The sensing bulb may be clamped to the outlet pipe or mounted inside

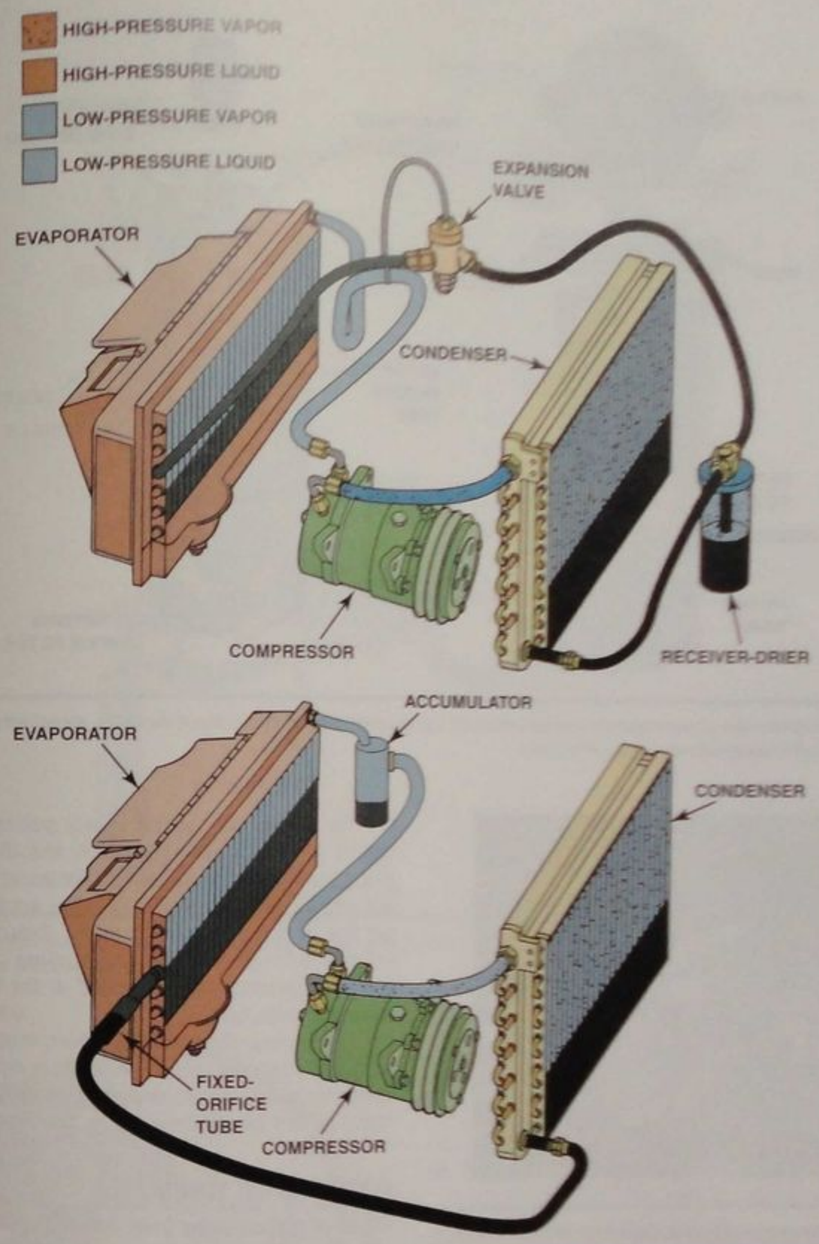


Figure 48–22 The evaporator serves the same function for both the orifice-tube and the expansion valve–type air-conditioning system, and that is to allow the liquid refrigerant to evaporate and absorb heat from the passenger compartment.

a passage near the outlet of the evaporator. The bulb and tube contain refrigerant. The rise or fall of the evaporator outlet temperature causes the refrigerant in the bulb to expand or contract, resulting in a rise or fall of pressure inside the capillary.

This outlet-temperature-sensitive pressure is applied to one side of the spring-loaded diaphragm inside the expansion valve. See Figure 48–29. As the capillary tube warms, the refrigerant inside expands, forcing the diaphragm downward. The diaphragm magnifies this pressure and uses it to open the valve by pushing the pintle and ball away from its seat. This increases the size of the orifice and allows more refrigerant into the evaporator, increasing the cooling capacity.

When the evaporator cools in response to the boiling of the added refrigerant, the refrigerant in the capillary tube contracts. This relieves the pressure on the expansion valve diaphragm, which closes the pintle and ball, and reduces refrigerant flow.

Pressure on the top of the diaphragm is applied through the capillary tube. The equalizing pressure on the underside of the diaphragm can be internal (from the evaporator inlet) or external (from the evaporator outlet):

- An internally equalized expansion valve has a passage that permits evaporator inlet pressure to reach the underside of the diaphragm.
- An externally equalized expansion valve has an extra line mounted to the underside of the diaphragm housing. This line monitors the outlet pressure of the evaporator. The connection can be either at

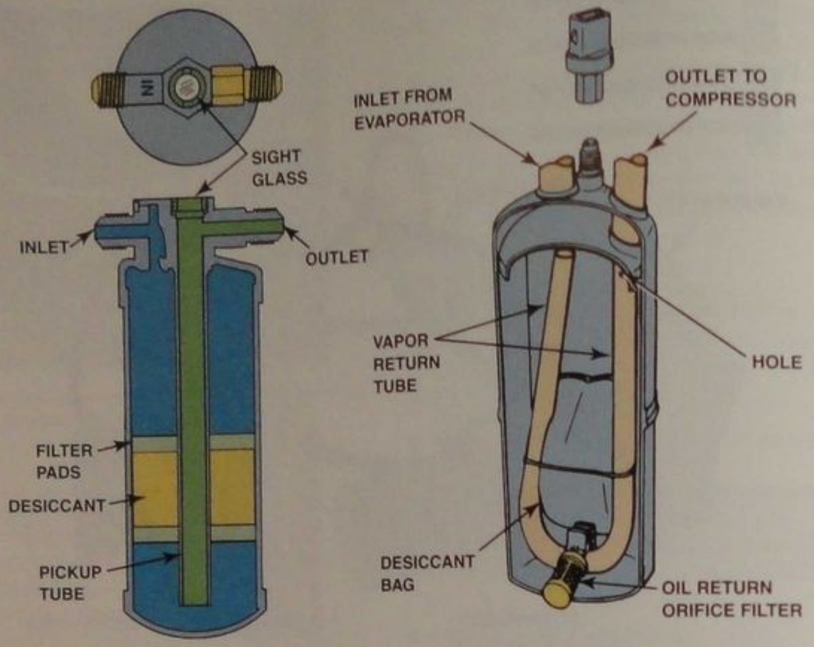


Figure 48–23 Expansion-valve systems store excess refrigerant in a receiver-drier, which is located in the high-side liquid section of the system, whereas orifice-tube systems store excess refrigerant in an accumulator located in the low-side vapor section of the system.



Figure 48–24 A typical accumulator used on a cycling clutch orifice-tube (CCOT) system.

the outlet of the evaporator or at the outlet of the evaporator pressure control device.

In an expansion-valve system, the refrigerant vapor that leaves the evaporator is warmer than the liquid refrigerant that entered it. The heat that warms the refrigerant is referred to as **superheat.** Superheat is usually measured as the actual temperature difference between the boiling point of the refrigerant at the inlet and at the outlet of the evaporator. Typical values for superheat in an evaporator are between 4° and 16°F (3° and 10°C).

Superheat is important because it ensures that all (or almost all) of the refrigerant vaporizes before leaving the evaporator.

DaimlerChrysler uses a valve called an **H-valve.** It includes both the temperature-sensing and pressure-sensing functions of the expansion valve, but does not have any external tubes.

The H-valve has two refrigerant passages that form the legs of the "H" as shown in Figures 48–30 and 48–31. The lower passage is the refrigerant line from the condenser to the evaporator, and contains the ball and spring valve. The upper passage is the refrigerant line from the evaporator to the compressor, and contains the temperature-sensing element. A pushrod connects the diaphragm of the temperature sensor located at the top of the block to the valve ball at the bottom.

The cycling-clutch switch, which senses the suction line, detects the evaporator outlet temperature and cycles the compressor clutch to control system cooling. This capillary device does not directly control the metering orifice. See Figure 48–32.

FIXED-ORIFICE TUBES

Liquid refrigerant flows from the condenser to the orifice tube. As with expansion valves, fixed-orifice tubes provide a restriction that separates the high-pressure from the low-pressure side of the system. See Figure 48–33. When it reaches the fixed-orifice tube, the refrigerant undergoes rapid expansion and changes from a warm, high-pressure liquid to a cold, low-pressure liquid and vapor mixture.

As it passes through the restriction to the low side, the refrigerant changes state from a liquid to a vapor because the pressure in the evaporator is so much lower than in the refrigerant line upstream from the orifice tube. The refrigerant begins to vaporize as quickly as it absorbs the heat from the evaporator.

The orifice tube, located between the condenser and the evaporator inlet, may be inserted in the refrigerant line or may be part of the inlet refrigerant line assembly.

COMPRESSORS

The air-conditioning compressor is driven by the engine with an accessory drive belt. A magnetic clutch is usually used to connect

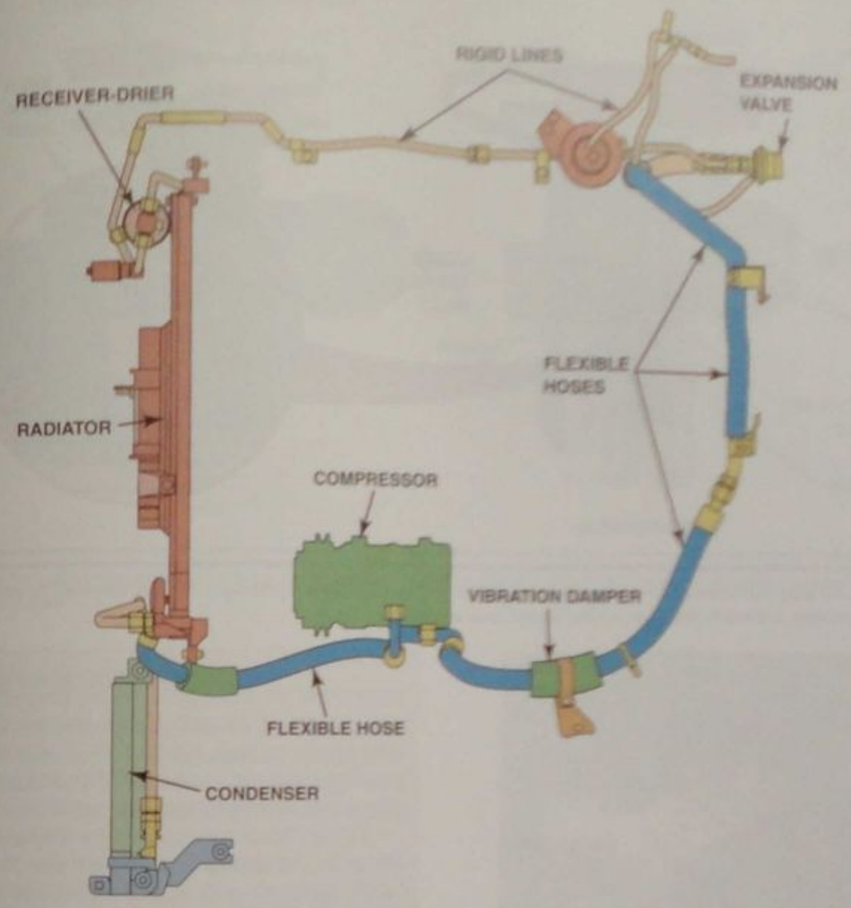


Figure 48–25 Rigid lines and flexible hoses are used throughout the air-conditioning system. The line to and from the compressor must be flexible because it is attached to the engine, which moves on its mounts during normal vehicle operation.

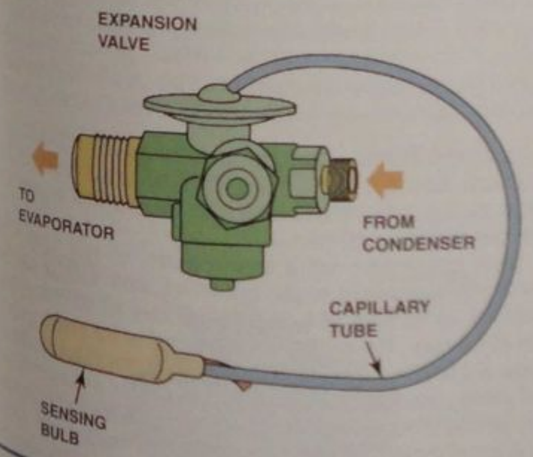


Figure 48–26 A typical expansion valve which uses an inlet and outlet attachment for the evaporator, and a temperature-sensing bulb that is attached to the evaporator outlet tube.

and disconnect the drive pulley to the compressor as needed for cooling or defrosting. The compressor performs the following functions:

- Compresses the low-pressure gas refrigerant from the evaporator into a high-pressure gas that is then sent to the condenser
- Raises the temperature of the gas so that there is a difference in temperature between the outside (ambient) air and the refrigerant in the condenser
- Acts as the pump used to circulate the refrigerant throughout the system
- Often switches on and off (cycles) to control evaporator temperatures
- Is the major reason why there is refrigerant oil in the system. The oil in the refrigerant lubricates the moving parts of the compressor

Positive-Displacement Piston Compressors A **positive-displacement compressor** displaces a constant, uniform volume of refrigerant for each revolution or operating cycle. Most automotive air-conditioner compressors are positive-displacement piston designs. These compressors have from one to 10 cylinders depending on manufacturer and application. Most of these compressors use a piston-in-cylinder arrangement with intake and discharge strokes to draw in, compress, and discharge refrigerant. See Figure 48–34 on page 562.

The compressor intake stroke is also known as the suction stroke. The suction stroke of a positive-displacement compressor is like that of a two-stroke gasoline engine. Just as the intake stroke of an engine's piston creates a low-pressure area that draws the air-fuel mixture in through the cylinder head, the suction stroke of the compressor piston creates a low-pressure area to draw refrigerant vapor into the cylinder. However, the similarity ends here. In a two-stroke engine, the compression stroke compresses the air–fuel mixture inside a sealed cylinder, with both the intake and exhaust valves closed. In the two-stroke piston A/C compressor, the discharge valve

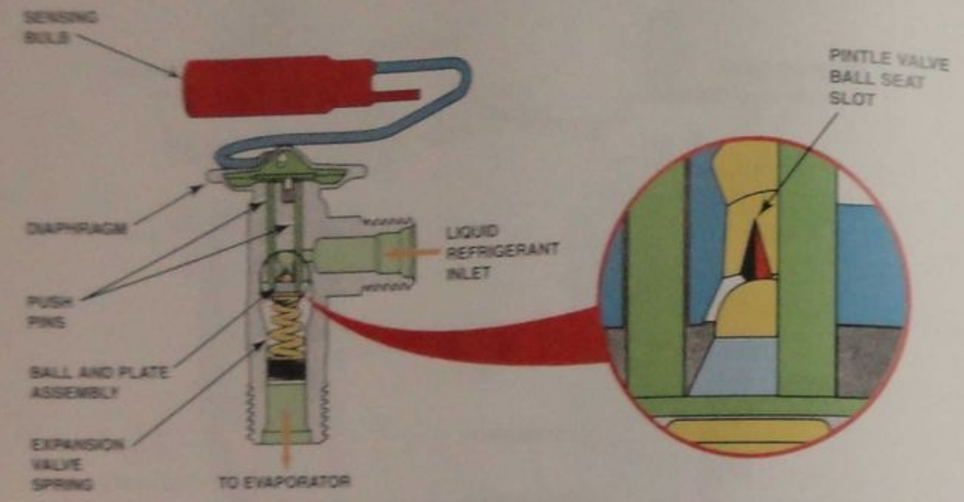


Figure 48–27 A slot cut in the ball seat inside the expansion valve permits a small amount of refrigerant and oil to pass through at all times, even when the valve is closed. This flow of oil through the system is necessary to make sure that the compressor receives the oil it needs for lubrication.

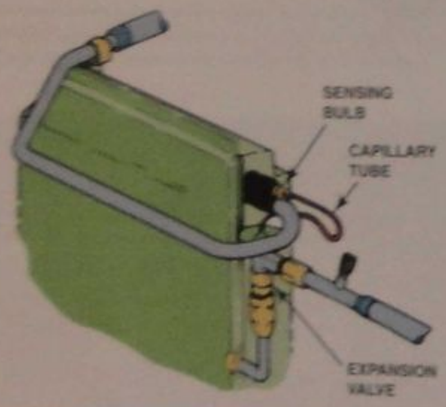


Figure 48–28 The sensing bulb is attached to the evaporator outlet tube. Refrigerant inside the bulb expands or contracts in response to the evaporator temperature.

does not resist the refrigerant flow during the upward piston stroke. As the compressor operates, the maximum possible charge of refrigerant vapor has been drawn in at bottom dead center of the compressor piston's suction stroke. When the piston begins its discharge stroke, the pressure increases, shutting the suction valve and opening the discharge valve at the same time. The charge of refrigerant vapor is pushed out of the compressor into the high-side refrigerant line and travels toward the condenser. Therefore, the refrigerant vapor is compressed simultaneously throughout the entire high side of the air-conditioning system.

All piston compressors use one suction valve and one discharge valve for each piston. The typical valve used in compressors is the **reed valve:** a one-way, flap-type check valve that is built into the valve plate which seals one or more cylinders. See Figure 48–35 on page 565. A reed valve flaps away from the valve plate to open, and toward the valve plate to close. Pressure pushes the valve in one direction or the other. The suction reed valve is located on the underside of the valve plate. When the suction created by the piston's downward stroke becomes strong enough, the suction reed valve bends, or flaps, off its seat. Low-pressure refrigerant vapor then flows into the compressor. The refrigerant vapor fills the partial vacuum created by the moving piston.

The discharge reed valve is on the top side of the valve plate. The partial vacuum in the cylinder also pulls the discharge valve tightly against its seat, sealing off the system's high side from the cylinder during the suction stroke.

The reeds behave in exactly the opposite way during the piston's discharge stroke. The increasing cylinder pressure pushes the suction valve tightly against its seat, sealing off the system's low side. The discharge valve on the opposite side of the valve plate is unseated as the pressure in the cylinder increases as a result of the upward moving piston. The piston pushes the refrigerant through the discharge valve, out of the compressor, and into the air-conditioning system high side.

Pistons and Rings The basic two-stroke cycle depends upon the pistons and their sealing rings to provide an adequate seal against the high-side refrigerant pressure. Most piston compressors have from two to six cylinders.

Some compressors use a **swash plate,** or axial plate. The plate is rigidly mounted to the belt-driven shaft at an angle. See Figure 48–36 on page 564. The pistons may be on one or both sides of the plate. The pistons are connected to the swash plate by means of a large ball bearing. As the pulley turns, the shaft and angled swash plate assembly rotate. This forces the pistons back and forth in their bores. In this way, the swash plate changes the rotating action of the shaft to a reciprocating action that provides driving force for each piston. Compressors that use a swash plate are often called **axial compressors.**

Variable Displacement Compressor Some air-conditioning systems use variable displacement to control the amount of refrigerant flowing through the evaporator. The pressure difference between the high side and the low side causes the swash plate to move inside the compressor. As the swash plate changes its angle, the stroke of the piston is increased for more cooling or decreased to reduce the amount of cooling. See Figure 48–37 on page 564.

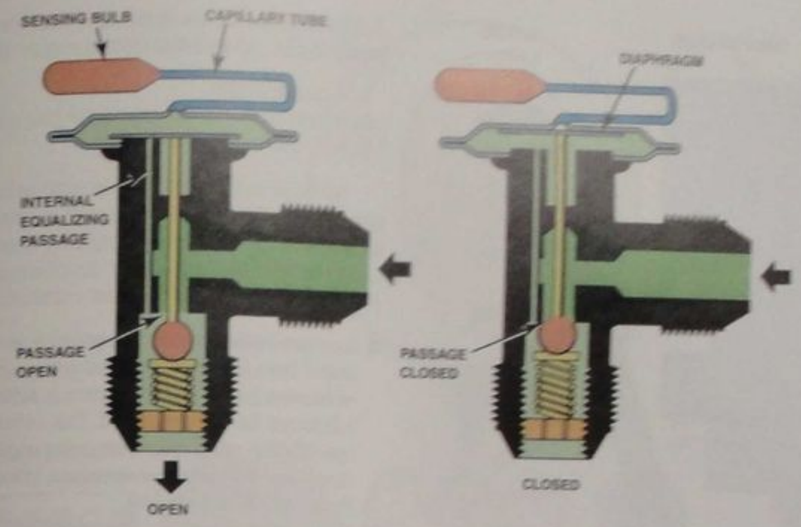


Figure 48–29 Pressure from the capillary tube pushes on the spring-loaded diaphragm to open the expansion valve. As the pressure in the capillary tube contracts, the reduced pressure on the diaphragm allows the valve to close.

TECH TIP ✓ **The Radio "POP" Trick**

Most air-conditioning compressor clutch circuits contain a diode that is used to suppress the high-voltage spike that is generated whenever the compressor clutch coil is disengaged (turned off). If this diode were to fail, a high voltage (up to 400 volts) could damage sensitive electronic components in the vehicle including the electronic air-conditioning compressor clutch control unit (if so equipped).

Another thing that can occur is that the radio will often turn off and then back on whenever the electronics inside the radio detect a high-voltage spike. This can create a "pop" in the radio that is very intermittent because it only occurs when the air-conditioning compressor clutch cycles off. To check this diode, simply tune the radio to a weak AM station near 1400 Hz and cycle the air-conditioning compressor on and off. If a "pop" is heard from the radio speakers, then the diode is defective and must be replaced.

NOTE: While some A/C compressor diodes can be replaced separately, some of these air-conditioning compressor clutch diodes are part of an entire wiring harness assembly.

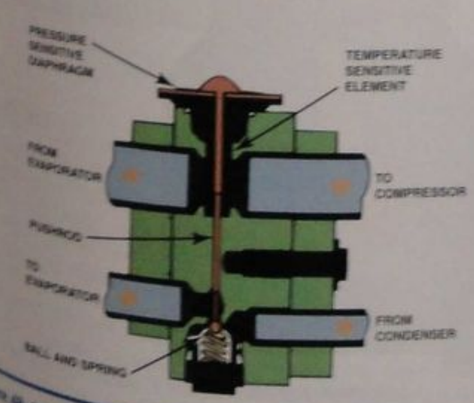


Figure 48–30 An H-valve (H-block) combines the temperature-sensing and pressure-controlling functions into a single assembly.



Figure 48–31 An H-valve as used on a Chrysler minivan.

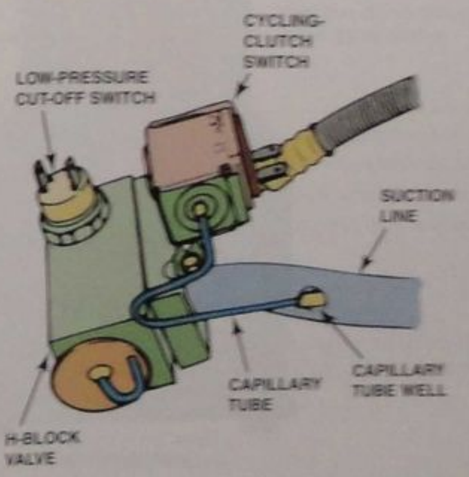


Figure 48–32 In this Chrysler system, a low-pressure cutoff switch and a cycling-clutch switch are mounted on the H-valve.

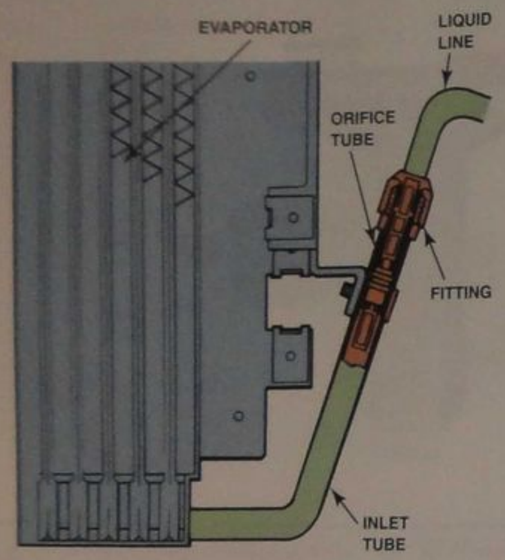


Figure 48–33 The orifice tube is usually located at the inlet tube to the evaporator.

COMPRESSOR CONTROLS

Most air-conditioning compressors use an electromagnetic clutch. A coil of wire inside the clutch creates a strong magnetic field that when activated connects the input shaft of the compressor to the drive pulley. Most electromagnetic coil assemblies have between 3 and 4 ohms of resistance. According to Ohm's law, about 3 to 4 amperes of current are required to energize the air-conditioning compressor clutch. All electrical circuits require three things to operate:

1. A voltage source
2. An electrical load (the air-conditioning compressor clutch)
3. A ground connection

All three of these must be in sync before current (amperes) can flow causing the compressor clutch to engage. Most vehicle manufacturers connect several components in series with the compressor clutch so that all have to be functioning before the compressor clutch can be engaged. The most commonly used switches include:

- **Low-pressure switch:** This pressure switch is electrically closed only if there is at least 25 PSI of refrigerant pressure. This amount of pressure means that the system is sufficiently charged to provide lubrication for the compressor. This switch also prevents the air-conditioning compressor from being engaged when the temperature is low (low temperature means low refrigerant pressures). See Figure 48–38 on page 564.
- **High-pressure switch:** This pressure switch is located in the high-pressure side of the air-conditioning system. If the pressure exceeds a certain level (typically 375 PSI [2,600 kPa]), the pressure switch opens, thereby preventing possible damage to the air-conditioning system due to excessively high pressure.
- **Power steering pressure switch:** This switch is used on many vehicles, especially those with four-cylinder engines. It opens the circuit to the air-conditioning compressor clutch when the driver turns the steering wheel. This reduces the load on the engine at the same time power is needed by the power steering pump. Because the wheel is seldom held in a turning maneuver for a long period of time, this stoppage of the air-conditioning compressor has little, if any, effect on passenger cooling.

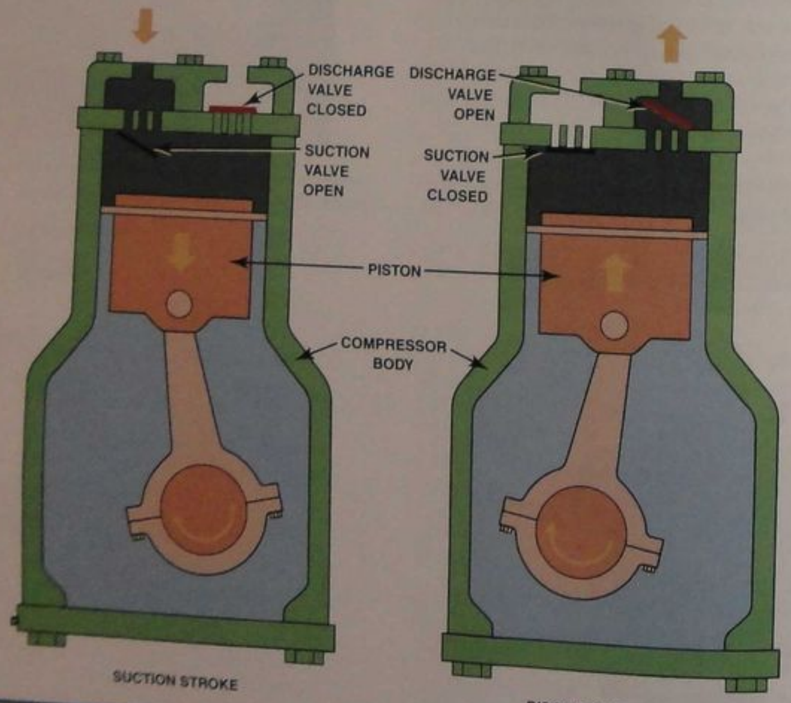


Figure 48–34 In a positive-displacement compressor, the descending piston creates a drop in pressure inside the cylinder. The resulting pressure differential allows low-side pressure to force the suction valve open. Refrigerant then flows into the cylinder. On the piston's discharge stroke, the pressure caused by the ascending piston closes the intake valve and forces the refrigerant out the discharge valve.

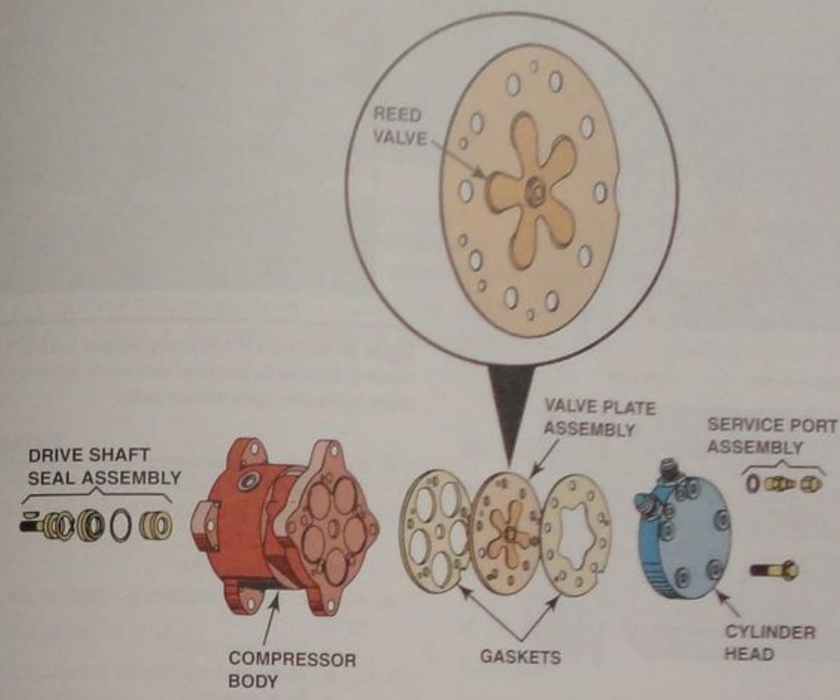


Figure 48–35 A reed valve is a one-way check valve that flaps away from the valve plate to open, and toward the valve plate to close.

REAL WORLD FIX **What Throttle Switch?**

A service technician was tracing the cause of an inoperative air compressor on a Saab. The service manual showed a schematic of the air-conditioning compressor that indicated a number of switches that had to be closed for the compressor clutch to be supplied with battery voltage. Besides the low pressure switch (to assure that the system is charged so as not to damage the compressor), a throttle switch was shown on the schematic. Obviously, someone else had worked on the vehicle because the throttle switch was missing entirely—just two wires remained to indicate that anything had been installed. Connecting the two wires together provided voltage to the air-conditioning compressor clutch. The customer decided not to replace the throttle switch after learning that its purpose was to disconnect (open circuit) the air-conditioning compressor when the throttle was at wide open positive to allow the maximum power for passing.

SUMMARY

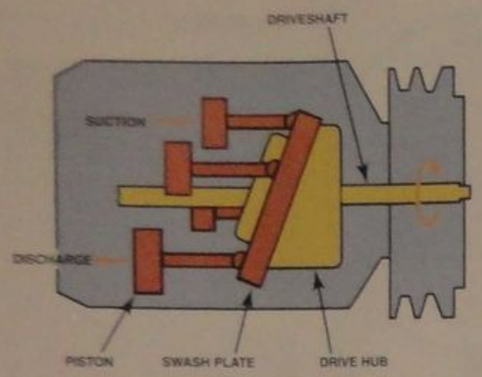
1. Engine coolant flows through heater hoses and through a heater core to provide heat to the inside of the vehicle.
2. The refrigeration cycle uses a compressor to circulate a refrigerant through a closed system.
3. Refrigerant expands in the evaporator. When the refrigerant expands, both its pressure and its temperature drop. The air from inside the vehicle is cooled as it passes through the evaporator.
4. The compressor forces the refrigerant through the closed system and raises the temperature of the refrigerant so that the refrigerant will condense back into a liquid in the condenser.
5. Airflow through the condenser removes heat from the hot refrigerant, which condenses back into a liquid.
6. The expansion valve (or orifice tube) causes the refrigerant to expand. When the refrigerant expands, its pressure and temperature both drop, thereby cooling the evaporator.
7. Temperature (thermostatic) or pressure controls (EPR, POA, or VIR) prevent the freezing of the evaporator by keeping the temperature of the evaporator above freezing (32°F or 0°C).
8. CFC-12 is commonly called Freon and is a chlorofluorocarbon (CFC).
9. HFC-134a is less harmful to the environment because it does not contain any CFCs.
10. A desiccant is used either in the receiver-drier or accumulator to remove any moisture that may get into the system. Moisture and refrigerant combine to form harmful acid.
11. The airflow through the evaporator and heater core help condition the air by removing humidity and directing the airflow where needed.

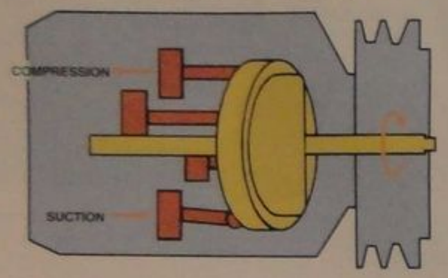
REVIEW QUESTIONS

1. Discuss how the air-conditioning system removes moisture from the air.
2. Describe the operation of the typical automotive air-conditioning system.
3. Explain why a desiccant is needed in automotive air-conditioning systems.
4. List three methods used to prevent the evaporator from becoming too cold and freezing.

CHAPTER QUIZ

1. Technician A says that heat is measured in degrees. Technician B says that temperature is measured in degrees. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. When the defrost setting is selected, the air-conditioning compressor operates.
   a. True
   b. False





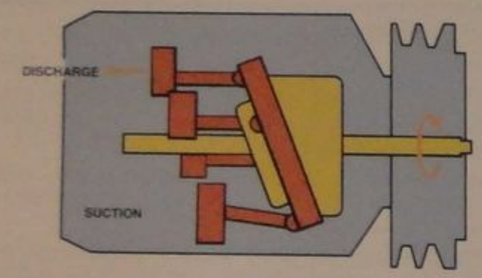


Figure 48–36 The swash plate, attached to the crankshaft at an angle, converts the pulley's rotary motion to axial motion, which drives the pistons in a reciprocating motion.



Figure 48–37 A V-5 variable displacement compressor. Internal pressures act on the swash plate, which changes the stroke of the piston and then displacement based on the pressures in the system.

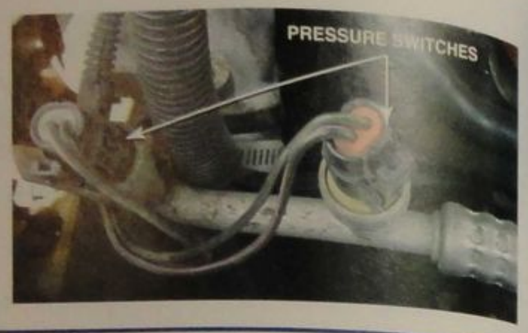


Figure 48–38 Typical air-conditioning pressure switches. A service manual would be needed to determine the function of each switch. One switch could be the low-pressure switch and the other a high-pressure switch.

3. Where in the air-conditioning system is the refrigerant a low-pressure gas?
   a. Condenser outlet
   b. Evaporator outlet
   c. Evaporator inlet
   d. Condenser inlet
4. Where in the air-conditioning system is the refrigerant a high-pressure liquid?
   a. Condenser outlet
   b. Evaporator outlet
   c. Evaporator inlet
   d. Condenser inlet
5. The compressor operates continuously with which type of system control?
   a. Orifice tube
   b. POA/EPR
6. Technician A says that all HFC-134a uses the same refrigerant oil. Technician B says that refrigerant oil, regardless of type, must be kept in a sealed container to keep it from absorbing moisture from the air. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. A front-wheel-drive vehicle has a broken condenser line. What other vehicle component may also be defective that could have caused the condenser line to break?
   a. Shock absorbers
   b. Engine mounts
   c. Cooling fan
   d. Air-conditioning compressor drive belt
8. Clear water is observed dripping out from beneath the evaporator. Technician A says that is normal. Technician B says that the evaporator housing is defective and should be replaced. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. The material used to absorb moisture from inside the air-conditioning system is called:
   a. Drier
   b. Desiccant
   c. Ester
   d. PAG
10. Which position on the climate control panel should the driver select to avoid having the air-conditioning compressor turn on?
    a. Heat
    b. Defrost
    c. A/C
    d. Both a and b

CHAPTER 49 Automatic Air-Conditioning System Operation

OBJECTIVES: **After studying Chapter 49, the reader will be able to:** Prepare for ASE Certification test content area Heating and Air Conditioning (A7), test content area "D," Operating Systems and Related Controls Diagnosis and Repair. • Identify the type of HVAC system being used on a vehicle. • Describe how dual-climate and rear air-conditioning systems work. • Discuss vacuum and electric motor controls.

KEY TERMS: afterblow • ambient air temperature sensor • aspirator tube • automatic temperature control (ATC) system • cabin filter • discharge air temperature (DAT) sensor • dual-position actuator • hybrid electric vehicle (HEV) • photo diode • three-position actuator • variable-position actuator

AIRFLOW MANAGEMENT

All automatic heating, ventilation, and air-conditioning (HVAC) systems use a combination of the following components to control airflow into the passenger compartment:

- Vents
- Ducts
- Air doors (also called flap doors or valves)

The use of these components allows the system to provide airflow under the following conditions:

1. Fresh outside air or recirculated air
2. Air conditioning
3. Defrost
4. Heat

See Figure 49–1.

The following are the typical settings for a manual or automatic air-conditioning system.

Heat

- Temperature set to the desired setting
- Air intake—select outside air (for faster heating, select recirculation for the first few minutes)
- Air conditioning set to off
- Set airflow to flow
- Fan speed to desired speed

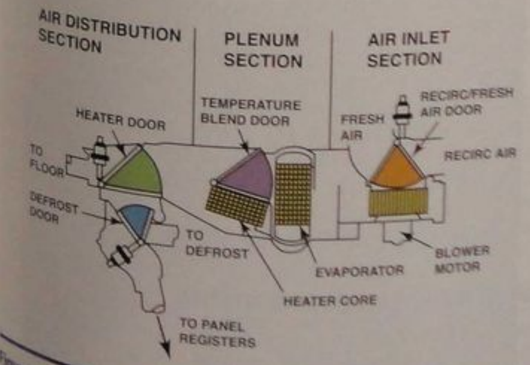


Figure 49–1 The three major portions of the A/C and heat system are air inlet, plenum, and air distribution. The shaded portions show the paths of the four control doors.

Air Conditioning

- Temperature set to the desired setting
- Air intake—set to outside air (for faster cooling, select recirculation for the first few minutes)
- Airflow—select dash vents (also called panel vents)
- Air conditioning set to on
- Fan speed set to desired speed

Ventilation

- Temperature set to lowest temperature
- Air intake—select outside air
- Airflow—set to dash (panel) vents
- Air conditioning set to off
- Fan speed set to desired speed

Defogging or Defrosting the Inside of the Windshield

- Temperature set to high temperature
- Air intake set to outside air
- Airflow set to windshield
- Fan speed set to desired speed

FREQUENTLY ASKED QUESTION ???

What Is "Afterblow"?

Afterblow is a term used to describe the operation of the blower motor after the ignition has been turned off. The purpose of afterblow is to dry the evaporator to help prevent the formation of mold and mildew in the evaporator case. The operation of the blower motor after the ignition is turned off has created some customer complaints. Check service information to be sure that the condition is normal or not on the vehicle being investigated. For example, in a typical General Motors system, the following conditions must be met for afterblow to occur:

1. The engine has been off for 30 minutes.
2. The outside air temperature is 70°F (21°C) or higher.
3. The battery voltage is 12 volts or higher.

If the above conditions exist, the afterblow is commanded to be on for 20 seconds, off for 10 seconds, and then back on for another 20 seconds.

AUTOMATIC AIR CONDITIONING

Automatic air-conditioning systems are usually called **automatic temperature control (ATC) systems.** Automatic systems use many of the same components as a normally adjusted system but with

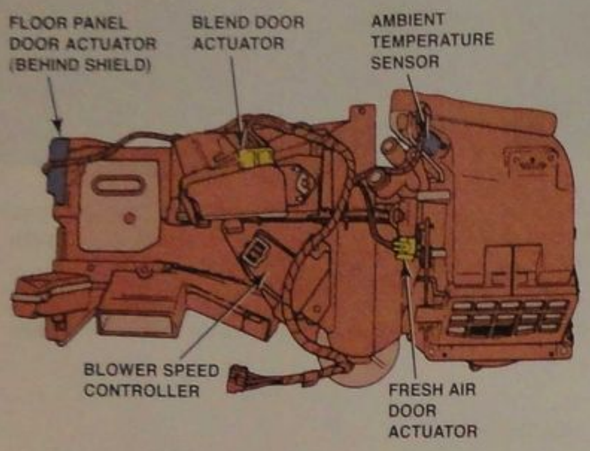


Figure 49–2 The ambient temperature sensor in this system is located in the fresh air intake duct for the HVAC system.

additional sensors. These sensors and their purpose and function include:

Outside Air Temperature (OAT) Sensor This sensor is usually located at the front of the vehicle behind the grille but in front of the radiator. The purpose of this sensor is to detect the temperature of the outside air. This sensor is commonly called the **ambient air temperature sensor** and is also used to supply temperature information for the driver on a display. See Figure 49–2.

Inside Vehicle Temperature Sensor Many older ATC systems used a temperature sensor located behind the instrument panel. Air to the sensor was forced to flow past the sensor by using an **aspirator tube,** which was connected to the blower motor case.

Discharge Air Temperature Sensor The **discharge air temperature (DAT) sensor** is located at the outlet of the vents. The purpose of this sensor is to inform the controller of the actual temperature at the discharge ducts.

Evaporator Outlet Temperature Sensor This sensor is used to control the AC compressor to keep the evaporative temperature within the specified temperature range for most efficient operation.

Sunload Sensor Sunload sensors are mounted on the top of the dash so that they can adjust the temperature and the fan speed to match the increased heating through the windows from the sun. The most common type of sunload sensor is a **photo diode.** This type of sensor produces a voltage which is directly related to the amount of light received. The voltage varies from 0.3 volt (dash) to 3.0 volts (light).

NOTE: Some vehicles are equipped with a dual-zone sunload sensor that has two sensors included. This sensor allows the system to automatically adjust the airflow and air temperature based on the actual sun intensity experienced by both the driver and the passenger.

ACTUATORS

An actuator is a part that moves the vanes or valves. Actuators used in air-conditioning systems are either electric or vacuum operated and include three different types.

Dual-Position Actuator A **dual-position actuator** is able to move either open or closed. An example of this type of actuator is the recirculation door, which can be either open or closed.

Three-Position Actuator A **three-position actuator** is able to provide three air door positions, such as the bi-level door, which could allow defrost only, floor only, or a mixture of the two.

Variable-Position Actuator A **variable-position actuator** is capable of positioning a valve in any position. All variable-position actuators use a feedback potentiometer, which is used by the controller to detect the actual position of the door or valve. See Figure 49–3.

CABIN FILTERS

Most late-model air-conditioning systems include a **cabin filter,** which is an air filter in the outside air inlet. The purpose of the cabin filter is to filter dirt and dust from the air before it enters the interior of the vehicle. Cabin air filters can be accessed either in the dash, usually behind the glove box, or from under the hood. Cabin air filters should be replaced regularly, usually every two years during normal service and more often if the vehicle is driven in dusty areas. See Figure 49–4.

NOTE: Some cabin filters contain activated charcoal which absorbs hydrocarbons and helps to deodorize the air as it enters the interior. For best results, use the designated replacement filter.

VACUUM CONTROL CIRCUITS

Vacuum control circuits use vacuum created in the intake manifold of the engine. Because vacuum decreases to close to zero during heavy acceleration, a vacuum accumulator is used to store vacuum during the short periods of acceleration. See Figure 49–5.

ELECTRIC SERVOMOTOR CIRCUITS

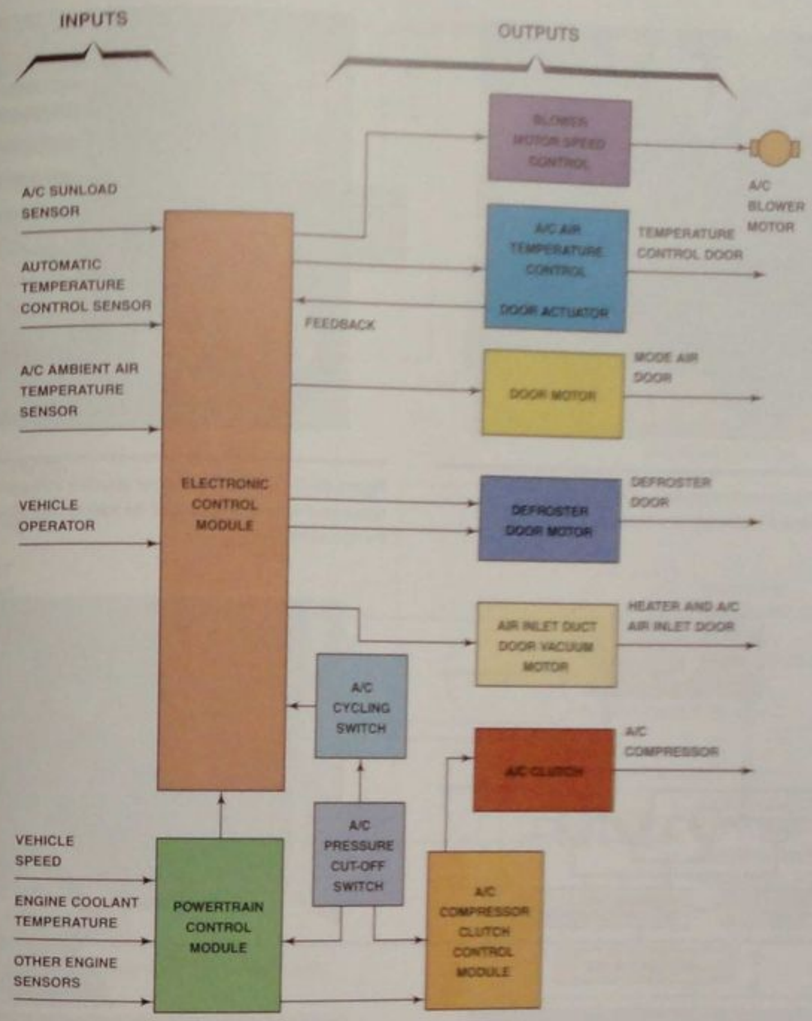
Most HVAC systems use electric motors to move valves and doors. See Figure 49–6 on page 568. Each servomotor contains a feedback potentiometer, which is used by the air conditioning control unit to indicate the actual position of the valve or door. If the commanded position and the actual position are not the same, then most systems are designed to store a diagnostic trouble code indicating which door is out of calibration. See Figure 49–7 on page 568.

BLOWER MOTOR CONTROL

Blower motors are used to move air. The air is directed by the doors of the HVAC system. Most blower motors use resistors to control the speed of the motors by dropping the amount of current flow through the motor at the lower speed. The resistor lowers the voltage and the current to the motor. The control then allows full system voltage to be applied to the motor during high-speed operation. The blower motor resistor is always located in the plenum near the blower motor so that airflow past the resistor can help keep it cool. See Figures 49–8 and 49–9 on page 568.

DUAL-ZONE AIR CLIMATE CONTROLS

Dual-zone climate controls allow the driver and the passenger to select different temperatures, as much as a 30°F (17°C) difference. In a dual-zone climate control system, the ducts and airflow are split and two air mix doors are used, with each door being controlled by its own actuator. See Figure 49–10 on page 569.



ATC SYSTEM BLOCK DIAGRAM

Figure 49–3 A block diagram showing the inputs to the electronic control assembly and the outputs; note that some of the outputs have feedback to the ECM.



Figure 49–4 A typical cabin filter being removed from behind the glove compartment.

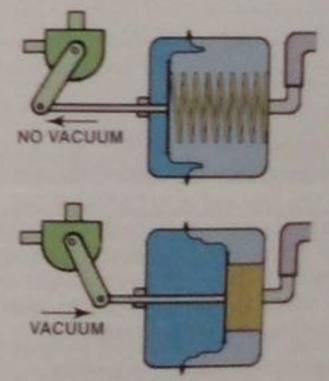


Figure 49–5 With no vacuum signal, the spring extends the actuator shaft to place the door in a certain position (top). A vacuum signal pulls the shaft inward and moves the door to the other position (bottom).



Figure 49–6 Three electric actuators can be easily seen on this demonstration unit. However, accessing these actuators in a vehicle can be difficult.

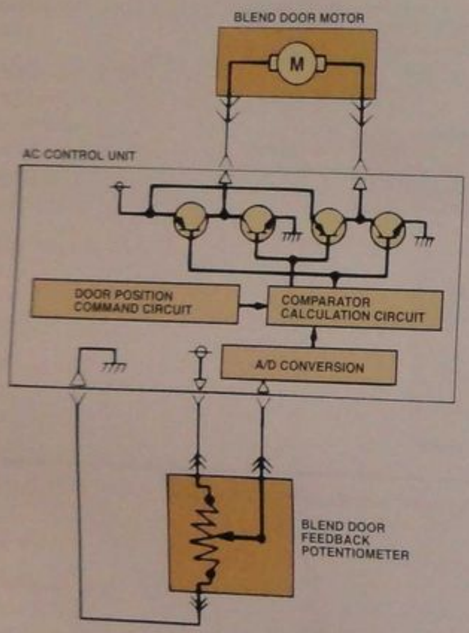


Figure 49–7 The feedback circuit signals the AC control unit with the blend door position.

REAR AIR-CONDITIONING SYSTEM

Many larger trucks, vans, and sport utility vehicles (SUVs) are equipped with rear heat and air-conditioning units. Many vehicles are equipped with ducts that route heated or cooled air to rear-seat passengers. See Figure 49–11. However, many larger vehicles require a separate heater core and air-conditioner evaporator in the rear to provide adequate heating and cooling. Most rear HVAC systems include the following components:

- A larger capacity air-conditioning compressor
- A second evaporator located at the rear of the vehicle
- A second heater core located at the rear of the vehicle
- A second blower motor and blower motor control at the rear of the vehicle

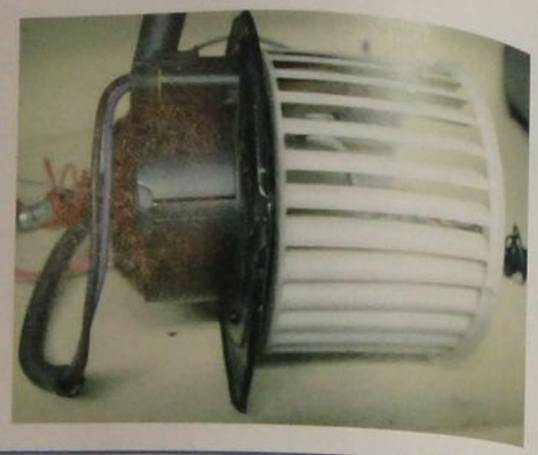


Figure 49–8 A typical blower motor assembly with attached squirrel cage blower. A replacement motor does not include the squirrel cage blower so it needs to be switched to the replacement motor.



Figure 49–9 A "credit card" resistor used in the rear blower assembly in a Dodge minivan

- Lines and fittings connecting the front heater and air-conditioning components to the rear system.
- Rear controls for speed and temperature on some models

See Figure 49–12.

RECIRCULATION OPERATION

When recirculation is selected, about 90% of the air is drawn from the passenger compartment and the other 10% is drawn from outside air. The purpose is to speed up the cooling of the inside of the vehicle.

However, the body control module may also select recirculation operation if the high-side air-conditioning system pressures exceed 320 PSI (2,200 kPa) to help lower the high-side pressure using cooler inside air through the evaporator. This condition should not normally occur, but if it does, this could cause a customer concern because the blower noise is greatly increased in the recirculation position.

HYBRID ELECTRIC VEHICLE HEATING AND COOLING SYSTEMS

Hybrid electric vehicle (HEV) systems need to be different than conventional systems because the engine stops when at idle if the

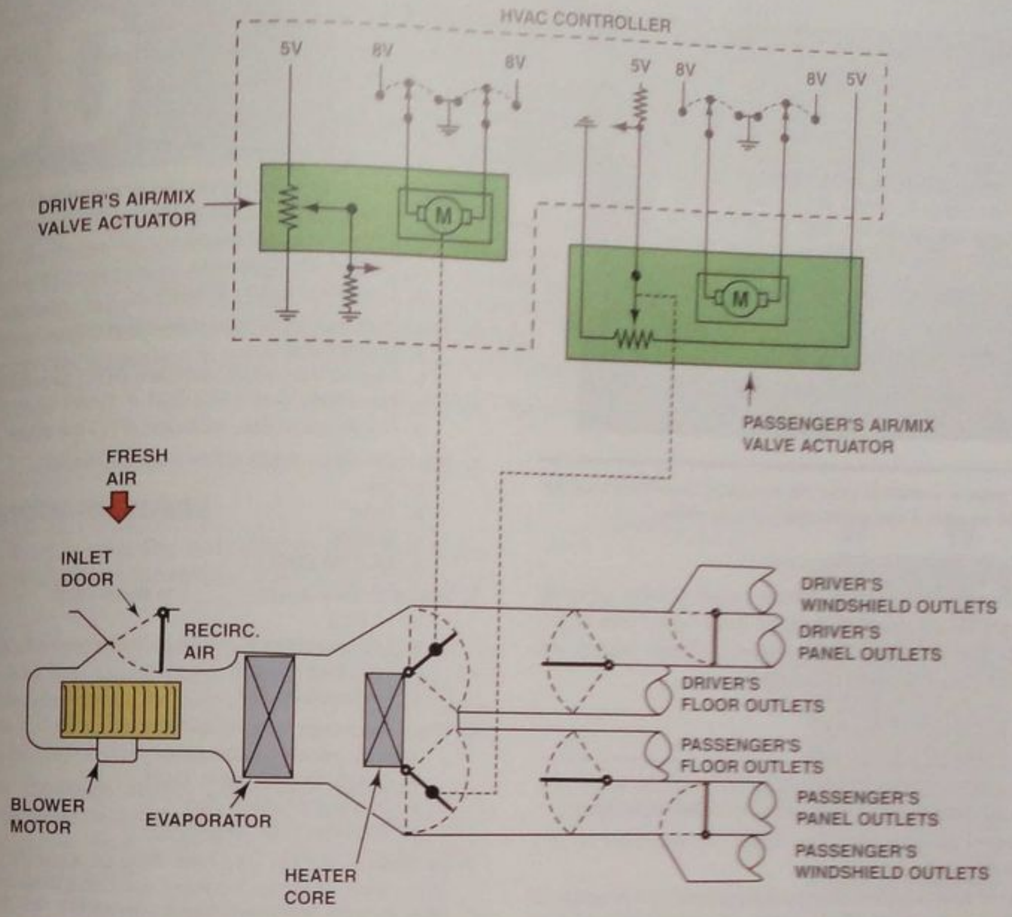


Figure 49–10 A dual climate control system showing the airflow and how it splits.



Figure 49–11 A typical dual-zone climate control panel showing left and right side temperature control levers.



Figure 49–12 Heated or cooled air is supplied to the rear seat passengers of most vehicles through ducts that run under the front seats.

engine is warm. As a result, the engine-driven air-conditioning compressor will also stop. To allow idle-stop mode and still provide air conditioning, several methods are used depending on the exact vehicle. These methods include:

1. Idle-stop mode is disabled if max cooling is selected.
2. Honda uses a hybrid compressor which has a smaller capacity part of the compressor being operated by an electric motor, which is powered by the high-voltage (HV) batteries. See Figure 49–13.
3. Toyota uses an air-conditioning compressor that is entirely driven by the high-voltage batteries and is therefore capable of providing cooling under all conditions, including when the engine is not operating.

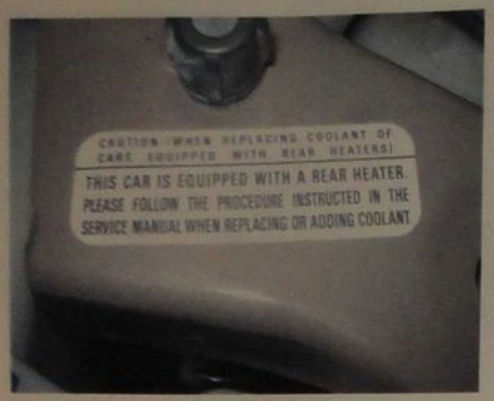


Figure 49–13 A sticker on a vehicle equipped with rear heat and air-conditioning warning that a special service procedure is needed when replacing engine coolant.

Toyota uses electric heating devices called positive temperature coefficient (PTC) thermistor installed in the heater core to provide heat to the passenger compartment. These heaters are powered by the high-voltage electric system.

SUMMARY

1. HVAC systems are designed to be able to deliver airflow to the windshield for defogging or defrosting as well as to the floor or dash vents.
2. HVAC systems are designed to use outside air, recirculated air, or a combination of the two.
3. Sensors used in automotive air-conditioning systems include outside air temperature (OAT), inside vehicle temperature, discharge air temperature (DAT), evaporator outlet temperature, and sunload sensors.
4. Actuators include dual-position, three-position, and variable-position actuators.
5. Most valves and airflow doors are electrically driven by motors and a feedback potentiometer.
6. Rear air-conditioning systems use a second heater core and evaporator at the rear of the vehicle.
7. Hybrid electric vehicles use a variety of components and systems to be able to provide air conditioning under idle-stop conditions.

REVIEW QUESTIONS

1. What are the four airflow locations?
2. Automatic air-conditioning systems include which sensors?
3. Why is a feedback potentiometer used on an electric actuator?
4. What components are needed for rear air conditioning and heat?

CHAPTER QUIZ

1. In heating mode, where is the airflow directed?
   a. Dash vents
   b. Floor
   c. Windshield
   d. Both b and c
2. Which sensor is also called the ambient air temperature sensor?
   a. Outside air temperature (OAT)
   b. Inside vehicle temperature
   c. Discharge air temperature
   d. Evaporator outlet temperature
3. What is the most common type of sunload sensor?
   a. Potentiometer
   b. Negative temperature coefficient (NTC) thermistor
   c. Photo diode
   d. Positive temperature coefficient (PTC) thermistor
4. An actuator can be capable of how many position(s)?
   a. Two
   b. Three
   c. Variable
   d. All of the above
5. Some cabin filters contain _____ to absorb odors.
   a. Perfume
   b. Activated charcoal
   c. Paper filter material
   d. Synthetic fibers
6. Which sensor might use an aspirator tube?
   a. Inside vehicle temperature
   b. Outside air-temperature (OAT)
   c. Discharge air temperature
   d. Evaporator outlet temperature
7. Technician A says that some cabin filters are accessible behind the glove compartment. Technician B says that some cabin filters are accessible from under the hood. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. The blower motor resistors are used to limit _____ to the motor.
   a. Voltage
   b. Current
   c. Airflow
   d. Both a and b
9. Which is *not* part of a rear air-conditioning system?
   a. Rear evaporator
   b. Rear heater core
   c. Rear AC compressor
   d. Rear blower motor
10. What components in the air-conditioning system may be different on a hybrid electric vehicle?
    a. Evaporator
    b. Compressor
    c. Condenser
    d. Blower motor

CHAPTER 50

Heating and Air-Conditioning System Diagnosis

OBJECTIVES: **After studying Chapter 50, the reader will be able to:** Prepare for ASE Heating and Air Conditioning (A7) certification test content area "A" (Air Conditioning System Diagnosis and Repair), content area "B" (Refrigeration System Component Diagnosis and Repair), content area "C" (Heating and Engine Cooling Systems Diagnosis and Repair), content area "D" (Operating Systems and Related Controls Diagnosis and Repair), and content area "E" (Refrigeration, Recovery, Recycling, and Handling). • Diagnose lack of heat problems. • List the air-conditioning system performance check procedures. • Discuss methods used to locate the source of an air-conditioning system leak. • Describe how to recover, evacuate, and recharge an air-conditioning system. • Discuss what is necessary to retrofit a CFC-12 system to be able to use HFC-134a refrigerant.

KEY TERMS: bleeder valves • high-side pressure • low coolant level • low-side pressure

HVAC DIAGNOSTIC PROCEDURE

When diagnosing a heating and air-conditioning system problem, most vehicle manufacturers recommend that the following steps be performed.

Step #1 **Verify the customer complaint (concern).** Sometimes the customer does not understand how the system is supposed to work or does not explain the fault clearly. Verifying the fault also means that the technician can verify that the problem has been corrected after the service procedure has been performed.

Step #2 **Do a thorough visual inspection.** Heating and air-conditioning problems are often found by looking carefully at all of the components, checking for obvious faults or damage due to an accident or road debris.

Step #3 **Check for diagnostic trouble codes.** Many heating and air-conditioning systems use sensors and actuators, which are computer controlled.

Step #4 **Check for related technical service bulletins (TSBs).** If there has been a bulletin released to solve a known problem, it saves a lot of time to know what to do rather than spend a lot of time trying to find and correct a problem.

Step #5 **Determine the root cause.** Be sure to find and correct the root cause of the problem. A low refrigerant level means that there was a leak in the system. Finding and correcting the leak that caused the low refrigerant level is correcting the root cause.

Step #6 **Verify the repair.** Drive the vehicle under similar conditions which caused the customer to complain and verify that the concern has been corrected.

HEATER DIAGNOSIS

Most of the heat absorbed from the engine by the cooling system is wasted. Some of this heat, however, is recovered by the vehicle heater. Heated coolant is passed through tubes in the small core of the heater. Air is passed across the heater fins and is then sent to the passenger compartment. In some vehicles, the heater and air conditioning work in series to maintain vehicle compartment temperature. See Figure 50–1.

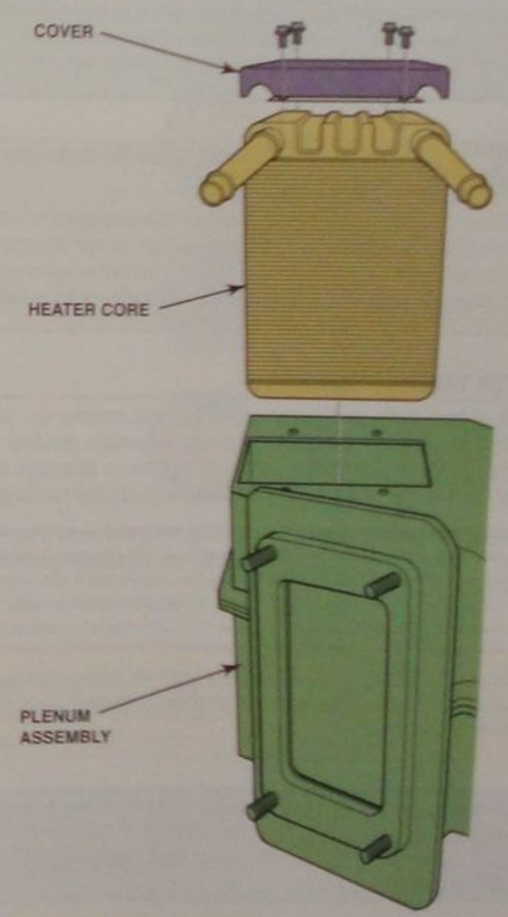


Figure 50–1 The heater core is mounted inside a heater plenum chamber where air passes over it to absorb heat from the warmed engine coolant.

HEATER PROBLEM DIAGNOSIS

When the vehicle's heater does not produce the desired amount of heat, many owners and technicians replace the thermostat before doing any other troubleshooting. It is true that a defective thermostat is the reason for the *engine* not to reach normal operating temperature. Many other causes besides a defective thermostat can result in lack of heat from the heater. To determine the exact cause, follow this procedure:

Step #1 After the engine has been operated, feel the upper radiator hose. If the engine is up to proper operating temperature, the

upper radiator hose should be too hot for you to keep your hand on it. The hose should also be pressurized.

a. If the hose is not hot enough, replace the thermostat.
b. If the hose is not pressurized, test it. Replace the radiator pressure cap if it will not hold the specified pressure.
c. If okay, see step 2.

Step #2 With the engine running, feel both heater hoses. (The heater should be set to the maximum heat position.) Both hoses should be too hot to hold. If both hoses are warm (not hot) or cool, check the heater control valve for proper operation. If one hose is hot and the other (return) is just warm or cool, remove both hoses from the heater core or engine and flush the heater core with water from a garden hose.

HINT: Heat from the heater that "comes and goes" is most likely the result of low coolant level. Usually with the engine at idle, there is enough coolant flow through the heater at higher engine speeds, however, the circulation of coolant through the heads and block prevents sufficient flow through the heater.

TECH TIP ✔ **Water on the Carpet? Check the Evaporator Water Drain**

If the evaporator water drip tube becomes clogged with mud, leaves, or debris, water will build up inside the evaporator housing and spill out onto the carpet on the passenger side. Customers often think that the windshield or door seals are leaking. Most evaporator water drains are not visible unless the vehicle is hoisted.

HEATER TROUBLE DIAGNOSIS

A lack of heat from the heater or having heat coming out of the wrong vents can be a dangerous and uncomfortable problem. The first step in the diagnostic process is to perform a thorough visual inspection and perform simple tests. This includes the following:

- **Check the coolant level.** Low coolant level can cause a lack of heat from the heater. Low coolant level can also cause occasional loss of heat.

CAUTION: Do not remove the radiator cap when the engine is hot. Allow the vehicle to sit several hours before removing the pressure cap to check the radiator coolant level.

- **Carefully touch the upper radiator hose with the engine running.** On most vehicles, the temperature of the hose should be so hot that you cannot keep your hand on it (between 190° to 220°F [88° to 104°C]).

NOTE: An infrared pyrometer can be used to measure the temperature of the upper radiator hose and the area around the thermostat housing.

Results: If the upper radiator hose is not too hot to hold, then the engine thermostat is defective. If the radiator hose is too hot to handle, then the lack of heat from the heater is not due to a lack of hot water in the engine.

- **Carefully touch the heater hoses.** Both heater hoses should also be too hot to keep your hands on the hoses. This test confirms that



Figure 50–2 A heater control valve. This valve is normally open, allowing engine coolant to flow through the heater core. When the air conditioning is switched to maximum cooling, the valve shuts off the flow of coolant to the heater.

engine coolant is able to flow from the engine to and through the heater core and return to the engine. See Figure 50–2.

Results: (a) If neither heater hose is hot to the touch, it is likely there is an air pocket in the heater that is preventing the flow of coolant into the heater core. (b) If only one heater hose is hot to the touch, then the heater core is likely to be clogged or partially clogged. A clogged heater core would prevent enough hot coolant from circulating through the heater core to provide adequate heat to the passenger compartment.

TECH TIP ✔ **Defrost All the Time? Check the Vacuum**

A common problem involves airflow from the defroster ducts even though the selector lever is in other positions. The defrost setting is the default position in the event of a failure with the vacuum supply. The defrost position is used because it is the safest position. For safety, the windshield must remain free from frost. Heat is also supplied to the passenger compartments not only through defrost ducts but also through the heater vents at floor level.

If the airflow is mostly directed to the windshield, check under the hood for a broken, disconnected, or missing vacuum hose. Check the vacuum reserve container for cracks or rust (if metal) that could prevent the container from holding vacuum. Check all vacuum hose connections at the intake manifold and trace each carefully, inspecting for cracks, splits, or softened areas that may indicate a problem.

HINT: This problem of incorrect airflow inside the vehicle often occurs after another service procedure has been performed, such as spark plug replacement. The movement of the technician's body and arms can cause a hose to be pulled loose or a vacuum fitting to break without the service technician being aware that anything wrong has occurred.

Visual Inspection The diagnosis of a heater problem or concern should start with a visual inspection. The following items should be checked or tested:

- Verify that the upper radiator hose is hot and pressurized. The upper radiator hose should be too hot to let you keep your hand tightly around the hose due to the high temperature. If the radiator hose is not too hot to hold, the thermostat may be defective.

Next, grasp the two heater hoses. Both heater hoses should be hot to the touch. If the return hose is cold or much cooler than the heater inlet hose, the heater core may be clogged or restricted.

NOTE: An air bubble could be lodged in the heater core. This is a common occurrence especially if the coolant (antifreeze) has been recently replaced. Failure to properly "burp" the air from the cooling system can cause a pocket of air to remain trapped in the heater core, preventing coolant from flowing through. See Frequently Asked Question "How Can You Easily Burp Air from the Cooling System?"

TECH TIP ✔ **The Hand Test**

To check a radiator or condenser for possible clogged or restricted areas, simply touch the outside of the unit with your hand. Any cool spots indicate that the radiator or condenser is clogged in that cool area.

FREQUENTLY ASKED QUESTION ???

How Can You Easily Burp Air from the Cooling System?

The first step in being certain there is no air in the cooling system is to try to avoid getting air into the system in the first place during cooling system service. If the engine is equipped with **bleeder valves** near the high spots of the cooling system, these valves should be open when refilling the radiator. See Figure 50–3. Any trapped air will always travel to the highest portion of the cooling system and escape out of these bleeder openings. Close the valves as soon as coolant is observed coming out of the valve opening.

If the cooling system is not equipped with bleeder valves, fill the cooling system as full as possible and then start the engine. With the radiator cap removed, the coolant level will often rise as the trapped air is expanding, then drop down as the trapped air escapes out of the radiator neck opening. Air can still remain trapped. To help speed up the process, try installing the radiator cap just to the first notch. (In this position the radiator cap is closed, but will not seal enough to allow pressure to build in the cooling system.) To help force any trapped air from the cooling system, simply drive the vehicle normally for several miles. By driving the vehicle under load, the engine will warm up faster and the thermostat will open allowing the coolant to flow from the engine and through the radiator. Any trapped air is then released into the radiator where it can easily escape through the unsealed radiator cap. After filling the radiator, securely tighten the radiator cap and test-drive the vehicle to verify proper operation.

TECH TIP ✔ **Hot/Cold/Hot/Cold Heater Diagnosis**

A common customer complaint is a lack of heat from the heater but only while driving, even though there seems to be plenty of heat when the engine is at idle speed and the vehicle is stopped. This is a classic symptom of **low coolant level.** The lower than normal coolant level in the radiator prevents enough flow to supply the heater core. When the engine speed is reduced, the water pump turns slower and coolant can more easily flow through the heater core resulting in heat from the heater. As the engine speed increases, the water pump speed also increases. Because there is less than the proper amount of coolant in the system, the water pump will only be able to supply coolant through the engine (a path of lower resistance).

CHECKING A/C SYSTEM PERFORMANCE

The first step in the diagnosis of any cooling system problem is to verify the complaint (concern).

Step #1 Start the engine and turn the A/C system to maximum with the engine operating between 1500 and 2000 RPM with the doors open. Operate the system for 5 to 10 minutes.



Figure 50–3 Many engines are equipped with a bleeder valve to permit a technician to bleed any trapped air from the cooling system. The valve is loosened as coolant is poured into the system. Because air is lighter than coolant, the air tends to float toward the highest part of the cooling system.

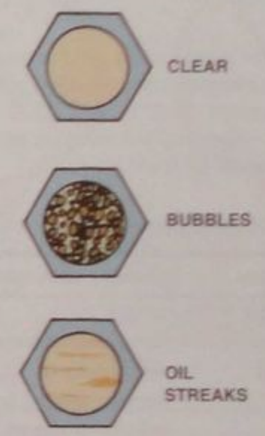


Figure 50–4 Many older CFC-12 systems are equipped with a sight glass either on or near the receiver-drier. A fully-charged (or completely empty) system is indicated by a clear sight glass. Bubbles or foam indicate that the system is not fully charged. An empty system may have oil streaks on the sight glass being moved by the vapor remaining in the system.

Step #2 Verify by visual inspection that the A/C compressor clutch is engaged. Check the sight glass if the vehicle is so equipped, as shown in Figure 50–4.

HINT: If the A/C compressor clutch cannot be observed, have an assistant turn the air conditioning on and then off and listen for the "click" of the A/C compressor clutch.

Step #3 Place an air-conditioning thermometer in the A/C vent near the center of the vehicle. Wait several minutes to allow the system to reach maximum output and observe the thermometer.

- *If 35° to 45°F (2° to 7°C),* the system is functioning okay. Continue a thorough visual inspection looking for any faults that may cause an intermittent problem.
- *If over 45°F (7°C),* continue with pressure gauge testing (Step 4).

Step #4 *Identify the refrigerant.* Before connecting the pressure gauges or performing any other service to an automotive air-conditioning system, verify the refrigerant that is presently in the system. Connect a refrigerant identification machine to the system. See Figure 50–5.



Figure 50–5 A typical refrigerant identification machine. The readout indicates what kind of refrigerant is in the system. If a blend or some other contaminated refrigerant is discovered, it should be recovered and stored in a separate container to keep it from contaminating fresh refrigerant.

Step #5 *Connect both high-pressure and low-pressure gauges to the service ports.* The low-side pressure should be about 25 to 35 PSI. The high-side pressure should be about 150 to 200 PSI. Compare your readings to the normal and abnormal readings in the following chart. See Figures 50–6 and 50–7.

A/C Pressure Gauge Chart

Low Side	High Side	Condition (Possible Cause)
25–35 PSI	170–200	Normal
Low	Low	Low refrigerant charge level
Low	High	Defective compressor
High	High	System is overcharged. Expansion valve stuck open
High	Low	Restriction in the low-side line

TEMPERATURE AND PRESSURE MEASUREMENTS

Temperature and pressure are directly related in AC systems. As the ambient temperature increases, the high-side pressure must also increase to have a heat transfer at the condenser. The temperature of the vapor must be higher than the ambient temperature to allow enough heat to be removed for condensation. Also, higher ambient temperatures, and high humidity, usually mean a higher heat load on the evaporator. This means a larger quantity of heat has to be removed at the condenser.

The **high-side pressure** is directly related to the amount of heat that needs to be removed, and the heat transfer at the condenser. **Low-side pressure** indicates the boiling point, or temperature of the evaporator. If the pressure is too high, the boiling point and temperature of the evaporator are too high. Low-side pressure that is too low indicates the evaporator is too cold and may ice, or that there is not enough boiling refrigerant in the evaporator to remove an adequate amount of heat. See Figure 50–8.

The heat transfer at the condenser is usually the cause of high-side pressure that is too high. The number one cause of poor heat transfer is lack of airflow across the condenser. The vehicle is dependent upon fans to move enough air when you are testing in a stall. It may be necessary to drive the vehicle at 30 mph to get the ram air necessary to determine if lack of airflow is the reason for the poor heat transfer.



(a)



(b)

Figure 50–6 (a) Both high-pressure (red) and low-pressure (blue) hoses have been attached to the vehicle. (b) High-side pressure can be compared to the temperature of the outlet from the compressor. Here a service technician is using an infrared pyrometer to measure the temperature.

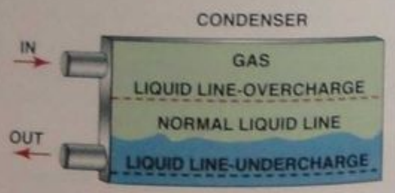


Figure 50–7 Hot refrigerant condenses in the condenser when it loses its heat to the outside air. Note how the level of the liquid line changes when undercharged or overcharged.

Another cause of excessive high-side pressure is contamination with a different refrigerant. Mixing R-12 and R-134a raises the condensing pressure of the mixture. The pressures go really high with R-22. At 150°F, the pressure of R-12 is 235 PSI (1,620 kPa), R-134a is 263 PSI (1,813 kPa), and R-22 is 381 PSI (2,627 kPa). This is an important reason to use a refrigerant identifier.

As compressor efficiency is reduced, the high side decreases and the low side increases. The function of the compressor is to pull down the low side and push up the high side. When the compressor is failing, it does not do either job well. Always look at both the high- and low-side pressures when diagnosing a problem. See Figures 50–9 through 50–11.

R134a PRESSURE-TEMPERATURE CHART

AMBIENT AIR TEMPERATURE (°F)	HUMIDITY	LOW-SIDE PRESSURE (PSI)	HIGH-SIDE PRESSURE (PSI)
70	Low	25 to 30	140 to 190
	High	28 to 35	165 to 220
80	Low	26 to 33	150 to 200
	High	30 to 36	190 to 260
90	Low	31 to 37	170 to 220
	High	37 to 45	210 to 290
100	Low	35 to 44	195 to 245
	High	38 to 48	230 to 320
100	Low	40 to 50	235 to 285
	High	42 to 52	260 to 350

Figure 50–8 The average R-134a pressure–temperature readings during a performance test. The high-side pressure of R-12 systems will be lower at higher temperatures.

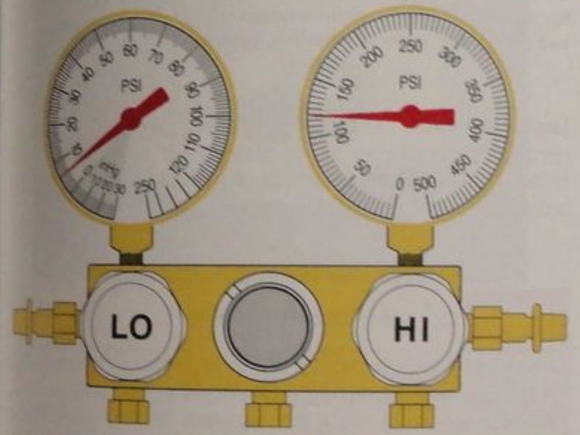


Figure 50–9 When both low- and high-side pressures are low, the system is undercharged with refrigerant.

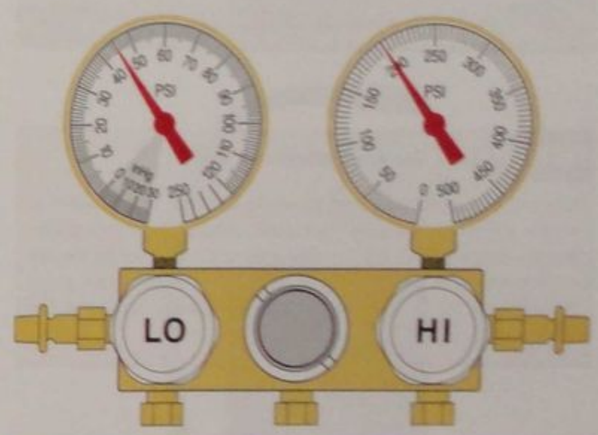


Figure 50–10 Both low- and high-side pressures higher than normal indicate that the system is overcharged with refrigerant.

FREQUENTLY ASKED QUESTION ???

What's Wrong When the A/C Compressor Clutch Cycles On and Off Rapidly?

This is a common occurrence on a vehicle equipped with a cycling clutch orifice tube (CCOT) system that is low on refrigerant charge. With a normal charge, the low-side pressure should be 15 to 35 PSI and the clutch should be on for 45 to 60 seconds and be off for only about 15 to 30 seconds.

TECH TIP

High-Side Pressure Tip

A quick and easy way to determine the correct high-side pressure is to add 100 to the ambient air temperature in Fahrenheit.

For example: 85°F outside air temperature
+100
185 PSI = typical normal high-side pressure

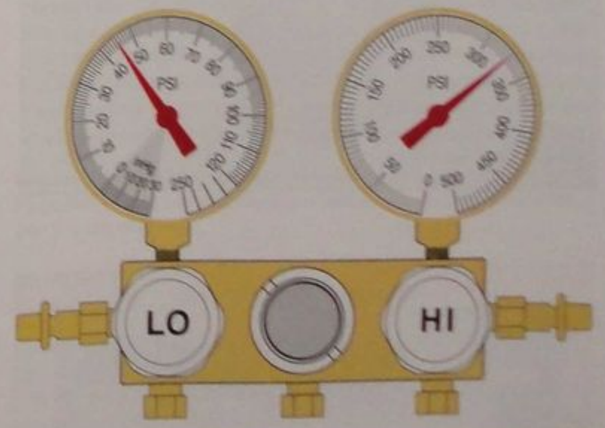


Figure 50–11 Lack of proper airflow across the condenser is usually the cause of this condition.

TECH TIP **Clogged Orifice Tube Test**

A clogged orifice tube is a common air-conditioning system failure. When the orifice tube becomes clogged, it blocks the flow of refrigerant through the evaporator, which causes a reduced cooling of the passenger compartment. To check for a possible restriction in the system, follow these easy steps:

Step #1 Connect the A/C pressure gauge to both low- and high-side pressure fittings.

Step #2 Operate the A/C system for 5 to 10 minutes.

Step #3 Shut off the A/C system and watch the pressure gauges. If the pressures do not equalize quickly, then there is a restriction in the system. See Figures 50–12 and 50–13.

NOTE: To locate a restriction anywhere in the system, feel along the system lines. The restriction exists at the point of greatest temperature difference.

TECH TIP **The Fire Extinguisher Test**

To test the expansion valve, start the engine and allow the A/C system to function with the control set to "recirculate." Using a CO_2 fire extinguisher, blast the expansion valve with CO_2. The valve should close and the low-side pressure should go into a vacuum. If the low-side pressure does not go into a vacuum, the expansion valve is faulty and should be replaced. See Figure 50–14.

REAL WORLD FIX **The Clogged Evaporator Problem**

The owner of an older Buick complained that the blower motor must be defective because the air no longer flowed from the air-conditioning vents as it should. A check of the blower motor circuit revealed that the blower motor was working. To confirm the operation of the blower, the resistor pack was removed and air flowed out of the opening. Then the technician discovered the cause of the lack of airflow—the evaporator was covered with oily dirt. The technician recovered the refrigerant and removed the evaporator. Apparently, the evaporator had a small refrigerant leak that allowed the refrigerant oil to coat the fins of the evaporator. Any dirt in the air stuck to the evaporator until the dirt almost completely blocked the airflow. Replacing the evaporator and recharging the system fixed the blower motor problem. See Figure 50–15.



Figure 50–12 A clogged orifice tube.



Figure 50–13 Assortment of orifice tubes. Note that each is color coded and identified on the lid of the assortment. Even though some technicians have purposely installed an orifice tube with a larger opening in an attempt to increase cooling, it is always safe to use the exact orifice tube specified for the vehicle being serviced.

Leak Detection If the A/C system is low on a charge of refrigerant, the sources of the leak should be found and corrected. Several different methods of leak detection are available including:

TECH TIP **The Touch, Feel Test**

A quick-and-easy test to check the state of charge of an orifice tube system is to use one hand and touch the evaporator side of the orifice tube. Touch your other hand to the inlet to the accumulator. The following conditions can be determined by noticing the temperature of these two locations. See Figure 50–16.

Normal operation—both temperatures about the same

Undercharged condition—accumulator temperature higher (warmer) than the orifice tube temperature

Just remember: High pressure means that the temperature of the component or line will also be high (hot). Low pressure means that the temperature of the component or line will also be low (cold).

- **Visual inspection.** Look for oily areas that are formed when refrigerant leaks and some refrigerant oil is lost. It is this oil that indicates a refrigerant leak.
- **Electronic leak detector.** Many of these units can detect both CFC-12 and HFC-134a. The detector will sound a tone if a leak is detected. See Figure 50–17.
- **Dye in the refrigerant.** A dye is added to some refrigerant to help the technician visually spot a leak in the refrigerant system. This method works well except for leaks in the evaporator, which are usually not visible. See Figure 50–18.
- **Soap solution.** Mix a few drops of liquid soap or detergent into a small glass of water. Using a small brush or a small spray bottle, apply the soapy solution to all fittings and other areas such as the condenser and compressor, which often are sources of leaks. If the system is empty, pressurize the system with dry nitrogen.



(a)



(b)

Figure 50–14 (a) A CO_2 fire extinguisher equipped with the fittings necessary to test the operation of an expansion valve. (b) The size of the opening at the end of the hose determines how much CO_2 is released to cool the expansion valve temperature sensor bulb.



Figure 50–15 A partially clogged evaporator.

TECH TIP **The Smell Test**

Many air-conditioning systems form mildew inside the evaporator housing due to the moist condition that exists in this area. If a "wet" smell is noticed, the mold and mildew may be the cause and a biocide will need to be used to correct the problem.

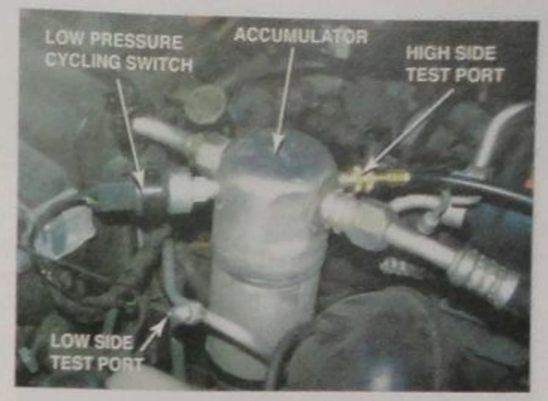


Figure 50–16 If the system is fully charged, the outlet temperature of the line leaving the evaporator should be about the same as the temperature of the line entering the evaporator after the expansion valve. The low-pressure cycling switch usually has to be disconnected and a jumper wire used to connect the two electrical terminals allowing the compressor to run if the system is low on charge.



Figure 50–17 Typical electronic refrigerant leak detector. Many are capable of detecting either CFC-12 or HFC-134a.

TECH TIP **Leak-Testing the Evaporator**

A quick-and-easy test to check whether the evaporator is leaking refrigerant is to remove the blower motor resistor pack. The blower motor resistor pack is almost always located directly "downstream" and near the blower motor. Removing the blower motor resistor pack gives access to the area near the evaporator. Inserting the probe of a leak detector into this open area allows the detector to test the air close to the evaporator.



Figure 50–18 A black light being used to look for refrigerant leaks after a fluorescent dye was installed in the system.

SUMMARY

1. The upper radiator hose and both heater hoses should be hot to the touch on a warm engine.
2. Failure to properly "burp" air from the cooling system after servicing can cause a lack of heat from the heater.
3. A sight glass is found on many older-model vehicles equipped with CFC-12. If the sight glass is cloudy, then the system charge is low.
4. Normal air-vent temperature for a properly operating air-conditioning system is 35° to 45°F (2° to 7°C).
5. An expansion valve or orifice tube is used to allow the liquid refrigerant to expand into a gas inside the evaporator. Heat is absorbed by the refrigerant as it changes state from a liquid to a gas and the evaporator becomes cold. The outlet of the evaporator should be about the same temperature as the evaporator side of the orifice tube if the system is operating properly.
6. Refrigerant leaks can be detected by visual inspection, an electronic leak detector, dye, or a soap solution.
7. A partially clogged evaporator can cause a lack of cooling.
8. A CO_2 fire extinguisher can be used to check the operation of an expansion valve.
9. The temperatures of the inlet and outlet lines to and from the evaporator should be about the same if the system is fully charged.
10. If the compressor clutch is cycling on and off rapidly on a cycling clutch-type system, the most common cause is low on refrigerant.
11. Typical high side pressure can be estimated by adding 100 to the outside temperature.

REVIEW QUESTIONS

1. Discuss how to diagnose the lack of heat from the heater.
2. Explain how the sight glass can be used to determine the state of charge.
3. List the various methods that can be used to detect refrigerant leaks.
4. Describe how to recover refrigerant from and evacuate an air-conditioning system.
5. List the components that may have to be replaced when retrofitting an air-conditioning system from CFC-12 to HFC-134a.

CHAPTER QUIZ

1. A customer complains that the heater works sometimes, but sometimes only cold air comes out while driving. Technician A says that the water pump is defective. Technician B says that the cooling system could be low on coolant. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Airflow through a typical HVAC system is being discussed. Technician A says that outside air is always used in all heating and cooling positions. Technician B says that the temperature is controlled by blending airflow through the evaporator and heater core. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. The first step in the diagnostic procedure when attempting to solve an HVAC customer problem is _____.
   a. Visual inspection
   b. Check for diagnostic trouble codes
   c. Check for technical service bulletins
   d. Verify customer concern
4. The last step in the diagnostic procedure is _____.
   a. Determine the root cause
   b. Verify the repair
   c. Recharge the system
   d. Perform a visual inspection
5. Technician A says that one heater hose should be hot and the other hose cool if the heater is functioning okay. Technician B says that both hoses should be hot to the touch. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Nothing is seen in the sight glass. Technician A says that the system may be completely empty of refrigerant. Technician B says that the system may be completely charged. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Technician A says that evaporator leaks can be detected by installing dye into the system and looking for yellowish-green dye stains. Technician B says that a leak at the evaporator can be detected by removing the blower motor resistor pack and inserting an electronic leak detector probe into the air stream. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Technician A says that with a properly operating air-conditioning system, the inlet to the compressor should be cold and the outlet from the compressor hot. Technician B says that the condenser should be hot and the evaporator cold. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A clogged orifice tube can cause a lack of cooling.
   a. True
   b. False
10. What must the technician do before checking an air-conditioning system for refrigerant leaks using a black light?
    a. Evacuate the system
    b. Install dye in the system
    c. Overcharge the system by 10 oz
    d. Turn the system off and allow the pressure to equalize

CHAPTER 51 Heating and Air-Conditioning System Service

OBJECTIVES: After studying Chapter 51, the reader will be able to: Prepare for the ASE A/C system service, diagnosis and repair (A7) certification test content area "A". • Perform heating, ventilation, and air-conditioning (HVAC) system service procedures. • Identify precautions that should be adhered to during HVAC system service. • Discuss proper evacuation and refrigerant recovery procedures. • List the steps needed to be performed to retrofit an older R-12 system to R-134a. • Describe air-conditioning parts replacement and service procedures.

KEY TERMS: air dam • fin comb • noncondensable gas • O-ring seal • quick-disconnect valve • schrader valve • service cap

BLOWER MOTOR SERVICE

Heater-related services include the following components and operation:

- **Blower motor and construction.** If the blower motor is not functioning, the switch, resistors, or blower motor itself may need to be replaced. If the resistors are found to be defective, then double-check that the current draw of the blower motor is within factory specifications. One of the most common reasons for a defective blower motor resistor is a defective blower motor that has worn bushings and draws more than normal current (amperes).
- **Relays and switches.** Switches and relays can be tested by proper operation and replaced if needed. Always follow the vehicle manufacturer's recommended replacement procedures.
- **Mechanical, electrical, and vacuum components.** Electrical wiring or terminals can often be repaired. Check service information for the recommended procedures to follow. If a component has been found to be defective, follow the vehicle manufacturer's recommended component replacement procedures.

COOLING SYSTEM SERVICE

Cooling System Thermostat Replacement A defective (stuck open) thermostat can cause a lack of heat from the heater. If heat "comes and goes," check for proper coolant level in the radiator before replacing the thermostat. When replacing the thermostat, always follow the vehicle manufacturer's recommended procedures and use the designated coolant.

Heater Hose Replacement Check heater hoses for signs of deterioration and replace as needed. See Figure 51–1. Follow the vehicle manufacturer's recommended procedures.

TECH TIP ✓ Use the Same Length Heater Hoses

Heater hoses are designed to supply warm coolant from the engine's cooling system to the small radiator called the heater core inside the vehicle. Because the heater hoses attach to the engine and the engine moves on its mounts during operation, the heater hoses are long enough to allow the engine to move without causing stress to be applied to the heater core. The extra length also helps to prevent engine vibration from being transmitted to the heater core and the interior of the vehicle. When replacing heater hoses, always use the old hoses as a guide and use the same length hoses. Also, route the replacement hoses in the same manner as originally designed, again, to help reduce the stress to the heater core.



Figure 51–1 Some heater hoses are best inspected by hoisting the vehicle and inspecting them from underneath the vehicle as shown.

Cooling Fan Inspect the cooling fan for dents, nicks, or other faults that can cause a vibration or reduce airflow through the radiator. Check the viscous fan clutch for leakage of silicone fluid and replace if needed.

TECH TIP ✓ Check the Air Dam If Overheating Occurs

The **air dam** under the front of the vehicle is designed to force air to flow upward and through the radiator rather than travel underneath the vehicle. If this air dam is broken or damaged due to contact with a parking block or other object, the engine may overheat.

REFRIGERANT RECOVERY PROCEDURES

Leak Repair Procedures After a leak has been found, the refrigerant should be recovered and the faulty part repaired or replaced. Leaks at joints may need a replacement O-ring. Often, the leak is at a component such as the evaporator, condenser, or refrigerant line. Leaking components are usually replaced rather than repaired.

Refrigerant should be recovered and not allowed to be discharged into the atmosphere. A refrigerant recovery unit should be



(a)



(b)

Figure 51–2 (a) A typical automotive air-conditioning service machine that is capable of handling both CFC-12 and HFC-134a systems. (b) HFC-134a systems use quick-disconnect fittings that are larger than those used for CFC-12 systems.

used to remove the refrigerant from the vehicle, and it should be stored in a container until it can be recycled. See Figures 51–2 and 51–3.

Most recovery units are capable of drawing a slight vacuum on the system (about 5 in. Hg) to assure that all refrigerant is removed from the system. During the recovery process, any refrigerant oil removed is separated from the refrigerant and allowed to flow into a container where it can be measured. This is important because the correct total amount of lubricating refrigerant oil must be added to the system when recharged to protect the compressor.

Repairs or Replacement of Components After all refrigerant has been removed from the system, repairs can be accomplished. For example, the evaporator can now be removed from the vehicle and replaced. If the system has been opened to the atmosphere for a length of time (over 24 hours), most experts recommend replacing the drier to help prevent the possibility of damaging moisture being trapped in the system. After all repairs are completed, the system should then be evacuated.

NOTE: Be sure to follow all instructions regarding the amount of oil that needs to be added to the system if components have been replaced.



(a)



(b)

Figure 51–3 (a) Refrigerant oil must be retrieved and measured when the refrigerant is recovered from the system. (b) A rubber O-ring is used to indicate the level of refrigerant oil already in the container. The exact same amount of refrigerant oil must be installed as was removed when the system is recharged.

Refrigerant Line Connections Refrigerant lines have connections at each end so they can be removed during system repair. Refrigerant line connections must meet three requirements:

- The connection must be vapor tight.
- The connection must be easy to disconnect and reconnect.
- The seals must withstand rapid and extreme temperature changes.

The **O-ring seal,** Figure 51–4, is part of a fitting that holds the ends of two refrigerant lines or hoses together inside a connector. The O-ring forms the seal between the lines or hoses and the connector. The O-rings usually are made of highly saturated nitriles (HSN) or neoprene rubber and remain flexible over a wide range of temperatures. The O-ring must be lubricated with clean refrigerant oil before assembly to ensure a good seal. Be careful not to crimp the O-ring during installation.

Replace the O-ring seals at all connections when you retrofit a system to R-134a. This ensures any traces of R-12 or its oil absorbed in the O-ring cannot enter the new system. Replace all gaskets as well.

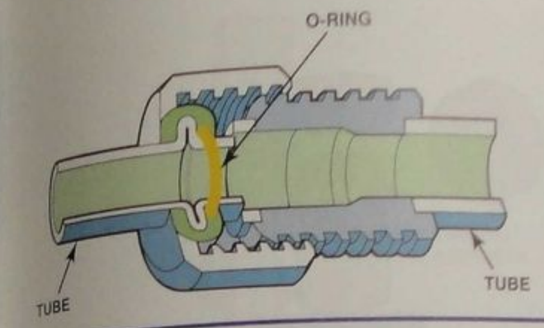


Figure 51–4 O-rings are usually made of neoprene rubber or highly saturated nitriles (HSN) to withstand high temperatures and flexing. O-rings should be changed during a retrofit procedure.

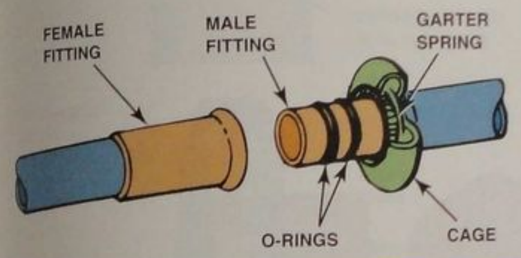


Figure 51–5 A Ford spring-lock coupling.

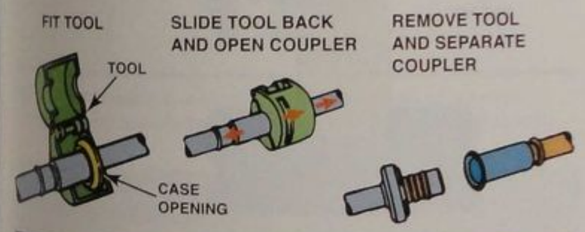


Figure 51–6 A special tool is needed to remove and install the Ford spring-lock coupling.

A variation on the O-ring seal is Ford's spring-lock coupling. See Figure 51–5. It uses two O-rings mounted on the small end of the refrigeration line. The end of the joining refrigeration line is flared to slide over the two O-rings. A circular garter spring holds the connection together. You need a special tool to disconnect the coupling. See Figure 51–6.

SAFETY TIP **Refrigerant Can Be Hazardous**

Always wear safety glasses and protective gloves when servicing any automotive air-conditioning system. If any refrigerant escapes, it can cause skin to freeze or cause blindness if liquid refrigerant were to get into the eyes.

Service Valves Service valves provide entry to the system when it is necessary to add or discharge refrigerant. The Schrader valve is used on R-12 systems. **Quick-disconnect valves** are used on R-134a systems. Each type of refrigerant has its own unique fitting. This prevents accidental use of the wrong service equipment and/or the introduction of the wrong refrigerant. Service valves are found almost anywhere on the system. They may be located on the receiver-drier, accumulator, compressor, muffler, or in the lines themselves.

All service valves have plastic coverings called **service caps.** See Figure 51–7. Along with preventing dirt from entering the system, service valve caps have O-rings which become the primary seal if a valve leaks. Always reattach the caps after any service has been performed, and replace them if you come across a system with missing service caps. Another built-in precaution is the refrigerant cut-off valve, which keeps the refrigerant in the service hose instead of allowing it to vent to the atmosphere. All service equipment hoses are required to have a cut-off valve within 12 inches of the end of the hose.

Schrader Valves For years, R-12 systems have used the **Schrader valve.** A Schrader valve is similar to a tire valve. Internal pressure holds Schrader valves closed. There is also a small spring to keep the valve seated if the internal pressure becomes insufficient. When the service connection is made, the depressor in the end of the service hose or service coupling, presses on a small pin inside the valve, forcing the valve open. See Figure 51–8. The valve opens only when the service line connection is nearly complete, preventing contamination of the system or the unnecessary release of refrigerant.

The high-side service valve on R-12 systems is smaller and has different threads than the low-side service valve. This prevents incorrect connections that may result in damage to the system and to your service equipment. Some Ford systems use different sizes of quick-disconnect fittings, similar to an air-hose coupling. Adapters are available for use with standard manifold gauge sets.

EVACUATION PROCEDURES

Evacuation means that a vacuum will be applied to the system to vaporize any moisture that may be in the system. Although water boils at 212°F (100°C) at sea level, it can boil at much lower temperatures when the pressure is reduced. In other words, if a vacuum is applied to the air-conditioning system, the low pressure will cause any trapped moisture in the system to vaporize (boil). This water vapor is then removed from the system through the vacuum pump and released into the atmosphere. It is important to evacuate the system to at least 26 in. Hg of vacuum for at least 45 minutes to be assured that all of the moisture has been removed. For best results, the vacuum should be higher than 29 in. Hg. Just remember, the higher the vacuum and the longer that it is allowed to evacuate, the better.

TECH TIP **Use a Micron Vacuum Gauge for Best Results**

A typical vacuum gauge reads in inches of Mercury (in. Hg) and the recommended vacuum level needed to remove moisture from the system is considered to be 27 in. Hg or less. However, many experts recommend using a vacuum gauge that measures the amount of air remaining in the system. This type of gauge measures vacuum in microns. A micron is one millimeter of a meter and there are about 760,000 microns of air at atmospheric pressure. A vacuum reading of 29.72 in. Hg is about 5,000 microns. Many experts recommend that the micron level be 500 or less for best results. This is particularly important when evacuating a dual-climate control system where two evaporators are used and there are long lengths of refrigerant lines. See Figure 51–9 on page 583.

NONCONDENSABLE GASES

Refrigerant should be checked for the presence of air, which is called a **noncondensable gas.** This means that the air will not

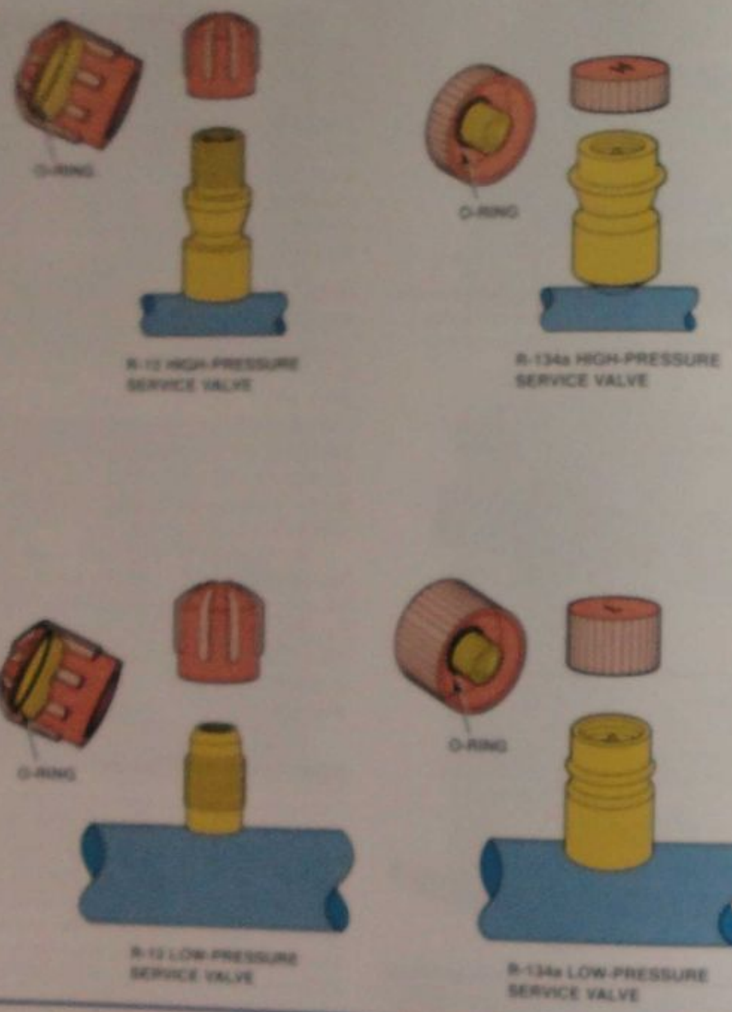


Figure 51–8 The service cap O-ring becomes the primary seal if the service valve leaks.

condense into a liquid when pressurized like refrigerant. If air is present in the container of refrigerant, it is considered to be a contaminant and will reduce the cooling efficiency if installed into an air-conditioning system. There are two ways to determine if there is air (noncondensable gas) in the refrigerant, including:

- **Use a refrigerant identifier.** Most refrigerant identifiers will display the amount of air present.
- **Measure the temperature and pressure of the refrigerant.** Compare the measurement to a temperature/pressure chart.

If the only contaminant is air, it can be purged from the refrigerant. Always follow the instructions on the recycling machine for the procedure to follow.

REFRIGERANT RECYCLING

After refrigerant has been recovered, it needs to be recycled for further use. Most air-conditioning machines include the ability to recycle the refrigerant to the following SAE J1991 specification:

- **Moisture**—A maximum of 15 parts per million (ppm) by weight
- **Refrigerant oil**—A maximum of 4,000 parts per million (ppm) by weight
- **Noncondensable gases (air)**—A maximum of 330 parts per million (ppm) by weight

RECHARGING A SYSTEM

After the system has been evacuated, it can be recharged with refrigerant. Most vehicles have a placard or sticker that indicates the correct amount of refrigerant to use. See Figures 51–10 and 51–11. Follow the operating instructions for the equipment you are using.

NOTE: Always use the specified amount of refrigerant. Reduced cooling can occur if the system is either undercharged or overcharged, so air conditioning service is definitely not a situation where "more is better."

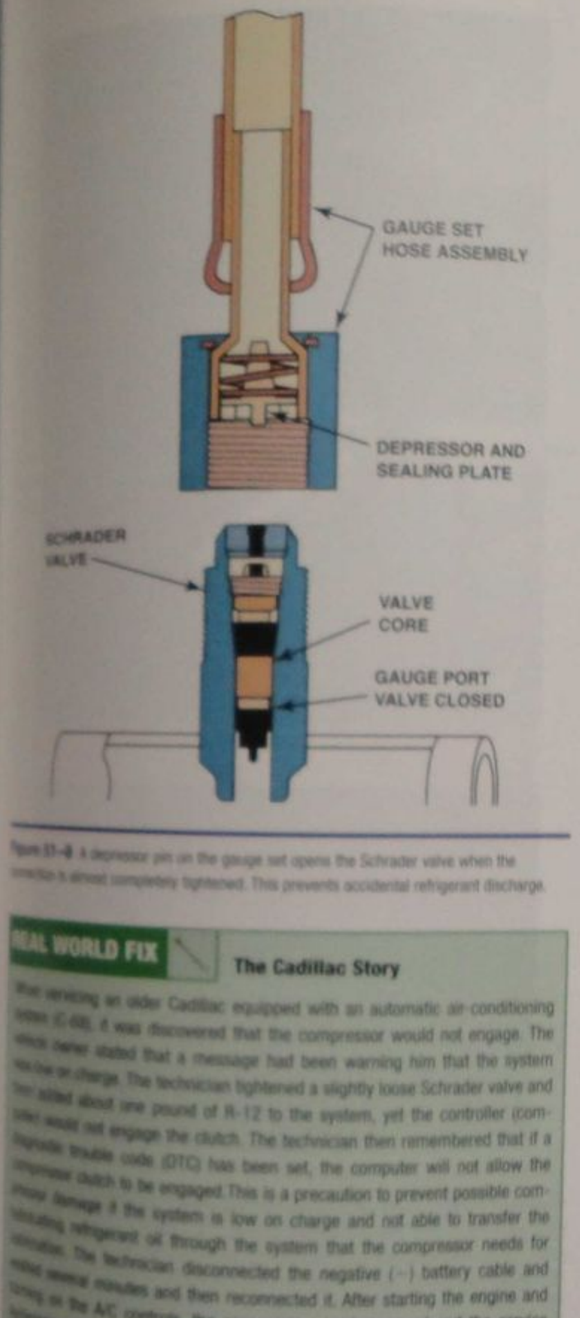


Figure 51–9 A depressor pin on the gauge set opens the Schrader valve when the coupler is almost completely tightened. This prevents accidental refrigerant discharge.

REAL WORLD FIX

The Cadillac Story

While servicing an older Cadillac equipped with an automatic air-conditioning system (C-68), it was discovered that the compressor would not engage. The vehicle owner stated that a message had been warning him that the system was low on charge. The technician tightened a slightly loose Schrader valve and then added about one pound of R-12 to the system, yet the controller (computer) would not engage the clutch. The technician then remembered that if a diagnostic trouble code (DTC) has been set, the computer will not allow the compressor clutch to be engaged. This is a precaution to prevent possible compressor damage if the system is low on charge and not able to transfer the lubricating refrigerant oil through the system that the compressor needs for lubrication. The technician disconnected the negative (−) battery cable and waited several minutes and then reconnected it. After starting the engine and turning on the A/C controls, the compressor clutch engaged and the service technician was able to complete charging the system.

RETROFITTING A CFC-12 SYSTEM TO A HFC-134A SYSTEM

Due to environmental and cost concerns, many service technicians are retrofitting (adapting) CFC-12 systems to HFC-134a systems. Whenever making the change, several tasks have to be performed, including:

- Specific service fittings must be installed.
- Service labels must be attached to the vehicle in a visible location.



Figure 51–9 An air-conditioning vacuum gauge that reads in microns.

TECH TIP ✓ **Because It Fits, Does Not Mean It Is Correct!**

Many air-conditioning systems use orifice tubes that look similar if not identical. They are usually color coded for identification. Always use the recommended orifice tube for the vehicle you are servicing. Some examples of the various colors and sizes available include:

Make	Color	Orifice Size (Inches)
Chrysler	purple	0.0605
Ford	red	0.0605
Ford	orange	0.0560
Ford	brown	0.0470
Ford	green	0.0505
GM	yellow	0.0605



Figure 51–10 A typical under-hood sticker that identifies the refrigerant and the amount needed to change the system in kilograms (0.96 kg is equal to 0.44 pounds).

- PAG or ester oil must be used instead of the mineral oil in a CFC-12 system.
- A high-pressure shutoff switch must be installed that opens the compressor clutch circuit if the pressure exceeds 410 PSI.

Other changes that may or may not be necessary include:

- Replacing hoses
- Replacing O-rings



Figure 51–11 A temperature and humidity gauge is a useful tool for air-conditioning work. The higher the relative humidity, the more difficult it is for the air-conditioning system to lower the temperature inside the vehicle.

- Replacing the receiver-drier or accumulator
- Replacing pressure switches and calibrating them for use with an HFC-134a system
- Replacing the condenser or compressor as required by some vehicle manufacturers

All of the required parts necessary to retrofit a particular vehicle are often included in a kit for easy use. See Figure 51–12. When the system is recharged, the amount of HFC-134a is usually 90% of the CFC-12 amount minus 4 ounces. In other words, if 30 ounces is the normal charge of CFC-12, then 23 ounces of HFC-134a should be used (30 ounces × 90% = 27 ounces minus 4 ounces = 23 ounces).

COMPRESSOR SERVICE

Compressor Drive Belt Always check the compressor drive belt(s) whenever servicing the air-conditioning system and replace as needed. If some chunks are missing from the belt ribs or pieces of rubber are embedded in the pulleys, a noise that is often misinterpreted as coming from a defective compressor can occur.

Compressor Clutch Service If the compressor clutch has been slipping, it will be blue, indicating that excessive heat has been generated by the slipping clutch. Replace the clutch and adjust the air gap according to service information instructions. See Figure 51–13.

If replacement is needed, determine the quantity of oil that may be trapped in the old unit so that the proper amount can be added to the system after the new condenser has been installed.

Compressor Removal If testing indicates that the air-conditioning compressor has failed, it should be removed from the vehicle after all of the refrigerant has been evacuated from the system. The steps specified by service information usually include the following:

Step #1 Remove the refrigerant from the system.

Step #2 Disconnect the compressor drive belt.

Step #3 Disconnect sensors and compressor clutch wiring connectors and label them if needed.

Step #4 Disconnect the suction and discharge hoses.

Step #5 Seal the hoses to help keep moisture and dirt from entering the system.

Step #6 Remove the compressor mounting fasteners.

Step #7 Drain and measure the refrigerant oil from the compressor.



(a)



(b)

Figure 51–12 (a) When a system is retrofitted from CFC-12 to HFC-134a, the proper service fittings have to be used to help assure that cross-contamination does not occur. (b) An under-hood sticker is also installed indicating that the system was retrofitted to HFC-134a and when it was done and by whom.

Step #8 Inspect the hose, lines, fittings, O-rings, seals, muffler, and service valves for proper operation and repair or replace as needed as part of the compressor service.

TECH TIP ✓ **An Additional Filter Is Insurance**

If the air-conditioning compressor is found to be damaged mechanically, many experts recommend that an additional filter be installed in the refrigerant line to trap any debris that may have gotten into the system. This additional filter will help prevent the new compressor from being harmed by the debris as it circulates through the system.

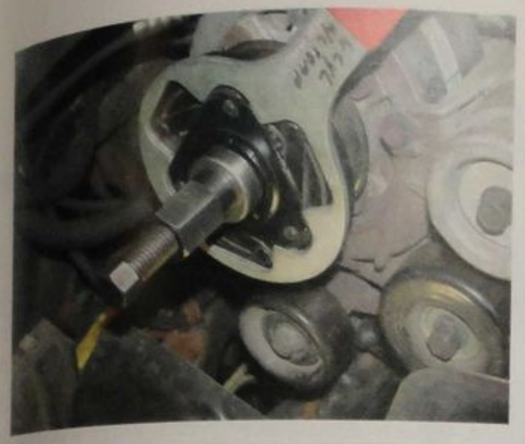


Figure 51–13 A special tool is needed to remove and install the magnetic clutch on the air-conditioning compressor.



Figure 51–14 A fin comb is used to straighten the fins on the condenser to help increase airflow and heat transfer.

CONDENSER SERVICE

Inspect the condenser for airflow restriction and clean as needed. Often a **"fin comb"** is needed to straighten the fins of the condenser, which may have been bent by road debris. See Figure 51–14.

EVAPORATOR SERVICE

If the evaporator has been tested and found to be clogged or leaking, it has to be replaced. In most vehicles this is a major job involving disassembly of the dash.

RECEIVER/DRIER OR ACCUMULATOR/DRIER SERVICE

Most experts recommend that the receiver/drier or accumulator/drier be replaced anytime the refrigerant system is opened and other repairs or services are being performed. Before replacing the receiver/drier or accumulator/drier, determine the quantity of refrigerant oil so that the proper amount can be added to the system when it is recharged. See Figure 51–15. Always follow the vehicle manufacturer's recommended service and repair procedures.



Figure 51–15 Always be sure that the service valves are snug before evacuating the system. They are a common place for small refrigerant leaks.

TECH TIP ✓ **Might as Well Do It Now**

Whenever an evaporator is being replaced, many service technicians also recommend that the heater core also be replaced. This is especially true if the vehicle had a neglected cooling system. Most heater cores are close to or even have to be removed to replace an evaporator. The only additional cost to the vehicle owner is the cost of the heater core itself.

ORIFICE TUBE/EXPANSION VALVE SERVICE

If the orifice tube is found to be clogged or the expansion valve has been determined to be not operating correctly, they will require replacement. Always follow the vehicle manufacturer's recommended replacement procedures and adhere to all precautions.

SUMMARY

1. The proper operation of the heater depends on the proper operation of the engine cooling system as well as the blower motor and temperature controls.
2. A serviceable compressor drive belt and clutch are needed for the proper operation of the air-conditioning system.
3. Refrigerant must be checked for contamination before recovery.
4. Check for leaks in the system by drawing a vacuum on the system and checking to see that other systems are able to maintain the vacuum.
5. Always use the specified replacement parts, such as orifice tubes, to be assured of proper operation.
6. Verify that the heating and air-conditioning system is functioning correctly after any repair or service.

REVIEW QUESTIONS

1. What components should be checked if a blower motor resistor is found to be defective?
2. Why could a broken air dam in the front of a vehicle cause an engine to overheat?
3. Why should a refrigerant identifier be used before evacuating the refrigerant?
4. Why should the receiver/drier or accumulator/drier be replaced if the refrigerant system is opened for a repair?
5. What steps and procedures are required to retrofit an older R-12 system to a R-134a system?

CHAPTER QUIZ

1. A customer complains that the heater works sometimes, but sometimes only cold air comes out while driving. Technician A says that the water pump is defective. Technician B says that the cooling system could be low on coolant. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Two technicians are discussing replacing heater hoses. Technician A says that the replacement hoses should be the same length as the original hoses. Technician B says that the replacement hoses should be cut as short as possible to allow more coolant to flow through the heater core faster. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. A defective thermostat can cause the engine to operate _____.
   a. Too cold
   b. Too hot
   c. Either a or b
   d. Neither a nor b
4. O-rings are usually made from _____.
   a. HSN
   b. Natural rubber
   c. Neoprene
   d. Either a or c
5. What type of service valves are used with R-134a?
   a. Schrader valves
   b. Gate valves
   c. Quick-disconnect valves
   d. Saddle valves
6. Which reading represents the lowest vacuum reading?
   a. 27 in. Hg
   b. 28 in. Hg
   c. 29 in. Hg
   d. 500 microns
7. What is a noncondensable gas?
   a. Air
   b. R-12
   c. Ozone
   d. R-134a
8. Technician A says that all orifice tubes on all vehicles use the same orifice size. Technician B says that orifice tubes vary the orifice size by application. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Which part *must* be used when refitting a vehicle from R-12 to R-134a refrigerant?
   a. A new (larger) condenser
   b. A new service fitting and a retrofit label
   c. A high-pressure cut-off switch
   d. Both a and b
10. When replacing a compressor clutch, what is the critical measurement?
    a. Air gap
    b. Current (ampere) draw
    c. Voltage drop
    d. High-pressure pressure

SECTION IX Engine Performance



52 Gasoline and Alternative Fuels
53 Computer and Network Fundamentals
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55 Computer Sensors
56 Ignition System Components and Operation
57 Ignition System Diagnosis and Service
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63 Scan Tools and Engine Performance Diagnosis

CHAPTER 52

Gasoline and Alternative Fuels

OBJECTIVES: After studying Chapter 52, the reader will be able to: Prepare for the ASE fuel, air induction and exhaust systems diagnosis and repair (A8) certification test content area "C". • Describe how the proper grade of gasoline affects engine performance. • List gasoline purchasing hints. • Discuss how volatility affects driveability. • Explain how oxygenated fuels can reduce CO exhaust emissions. • Discuss the advantages and disadvantages of various alternative fuels.

KEY TERMS: air–fuel ratio • alternative fuel vehicle (AFV) • American Petroleum Institute (API) gravity • American Society for Testing and Materials (ASTM) • antiknock index (AKI) • B20 • biodiesel • biomass • British thermal unit (BTU) • catalytic cracking • cellulose ethanol • cellulosic biomass • cetane rating • coal to liquid (CTL) • compressed natural gas (CNG) • cracking • detonation • diesohol • distillation • distillation curve • E-10 • E-85 • E-diesel • ethanol • ethyl alcohol • ethyl tertiary butyl ether (ETBE) • Fischer-Tropsch diesel (FTD) • flex fuel • flexible fuel vehicle (FFV) • formaldehyde • fuel compensation sensor • gas to liquid (GTL) • gasoline • grain alcohol • GTL diesel • hydrocracking • liquified petroleum gas (LPG) • LP-gas • M-85 • methanol • methanol-to-gasoline (MTG) • methyl alcohol • methyl tertiary butyl ether (MTBE) • MTHF • natural gas vehicle (NGV) • octane rating • organic • oxygenated fuels • petrodiesel • petroleum • ping • propane • pure plant oil (PPO) • reformulated gasoline (RFG) • Reid vapor pressure (RVP) • spark knock • stoichiometric ratio • straight vegetable oil (SVO) • switchgrass • syncrude • synthetic fuel • syn-gas (synthesis gas) • tertiary-amyl methyl ether (TAME) • tetraethyl lead (TEL) • underground coal gasification (UCG) • used cooking oil (UCO) • vapor lock • variable fuel sensor • virtual-flexible fuel vehicle (V-FFV) • volatility • waste vegetable oil (WVO) • wood alcohol • world wide fuel charter (WWFC)

The quality of the fuel any engine uses is important to its proper operation and long life. If the fuel is not right for the air temperature or if the tendency of the fuel to evaporate is incorrect, severe driveability problems can result. An engine burns about 15 pounds of air for every pound of gasoline.

AUTOMOTIVE FUEL REFINING

As it comes out of the ground, **petroleum** (meaning "rock oil") crude can be as thin and light colored as apple cider or as thick and black as melted tar. Thin crude oil has a high **American Petroleum Institute (API) gravity,** and therefore, is called *high-gravity* crude, and thick crude oil is called *low-gravity* crude. High-gravity-type crude contains more natural gasoline and its lower sulfur and nitrogen content makes it easier to refine.

NOTE: Low-sulfur crude oil is also known as "sweet" crude and high-sulfur crude oil is also known as "sour" crude.

Processes Refining is a complex combination of interdependent processing units, and it all starts with the simple physical separation process called **distillation.**

Distillation In the late 1800s, crude was separated into different products by boiling. Distillation works because crude is composed of hydrocarbons with a wide range of molecular weights, and therefore a broad range of boiling points. Each product was assigned a temperature range and the product was obtained by condensing the vapor that boiled off in this range at atmospheric pressure (atmospheric distillation). The earliest crude stills were simple pot stills consisting of a container where crude was heated and a condenser to condense the vapor. Later, distillation became a continuous process with a pump to provide crude flow, a furnace to heat the crude, and a distillation column to separate the different boiling cuts.

In a distillation column, the vapor of the lowest-boiling hydrocarbons, propane and butane, rises to the top. The straight-run gasoline (also called naphtha), kerosene, and diesel fuel cuts are drawn off at successively lower positions in the column.

Cracking The discovery that hydrocarbons with higher boiling points could be broken down (**cracked**) into lower-boiling hydrocarbons by subjecting them to very high temperatures offered a way to correct the mismatch between supply and demand. This process, called thermal cracking, was used to increase gasoline production starting in 1913. It is the nature of thermal cracking to make a lot of olefins, which have higher octane numbers but may cause engine deposits. By today's standards, the quality and performance of this early cracked gasoline was low, but it was sufficient for the engines of the day.

Eventually heat was supplemented by a catalyst, transforming thermal cracking into **catalytic cracking.** A catalyst is a material that speeds up or otherwise facilitates a chemical reaction without undergoing a permanent chemical change itself. Catalytic cracking produces gasoline of higher quality than thermal cracking.

Hydrocracking is similar to catalytic cracking in that it uses a catalyst, but the catalyst is in a hydrogen atmosphere. Hydrocracking can break down hydrocarbons that are resistant to catalytic cracking alone. More commonly it is used to produce diesel fuel rather than gasoline.

Other types of refining processes include:

- Reforming
- Alkylation
- Isomerization
- Hydrotreating
- Desulfurization

See Figure 52–1.

Shipping The gasoline is transported to regional storage facilities by tank railway car or by pipeline. In the pipeline method, gasoline from many refineries is often sent through the same pipeline and can become mixed. All gasoline is said to be miscible, meaning that it is capable of being mixed because each grade is created to specification so there is no reason to keep the different gasoline brands separated except for grade. Regular grade, midgrade, and premium grades are separated in the pipeline and the additives are added at the regional storage facilities and then shipped by truck to individual gas stations.

GASOLINE

Gasoline is a term used to describe a complex mixture of various hydrocarbons refined from crude petroleum oil for use as a fuel in engines. Most gasoline is "blended" to meet the needs of the local climates and altitudes.

FREQUENTLY ASKED QUESTION ???

What Is a California Gas Can?

When researching for ways to reduce hydrocarbon emissions in California, it was discovered that leakage from small gasoline containers used to refill small lawn mowers and other power equipment was a major source of unburned gasoline entering the atmosphere. As a result of this discovery, a new design for a gas can (container) was developed that is kept closed by a spring and uses O-rings to seal the opening. To use this container, the nozzle release lever is held against the side of the fuel opening and, when depressed, allows air to enter the container and fuel to flow. The flow of fuel stops automatically when the tank is full, eliminating any spillage. See Figure 52–2.

VOLATILITY

Volatility describes how easily the gasoline evaporates (forms a vapor). The definition of volatility assumes that the vapors will remain in the fuel tank or fuel line and will cause a certain pressure based on the temperature of the fuel.

Winter Blend **Reid vapor pressure (RVP)** is the pressure of the vapor above the fuel when the fuel is at 100°F (38°C). Increased vapor pressure permits the engine to start in cold weather. Gasoline without air will not burn. Gasoline must be vaporized (mixed with air) to burn in an engine. Cold temperatures reduce the normal vaporization of gasoline; therefore, winter-blended gasoline is specially formulated to vaporize at lower temperatures for proper starting and driveability at low ambient temperatures. The **American Society for Testing and Materials (ASTM)** standards for winter-blend gasoline allow volatility of up to 15 pounds per square inch (PSI) RVP.

Summer Blend At warm ambient temperatures, gasoline vaporizes easily. However, the fuel system (fuel pump, carburetor, fuel-injector nozzles, etc.) is designed to operate with liquid gasoline. The volatility of summer-grade gasoline should be about 7.0 PSI RVP. According to ASTM standards, the maximum RVP should be 10.5 PSI for summer-blend gasoline.

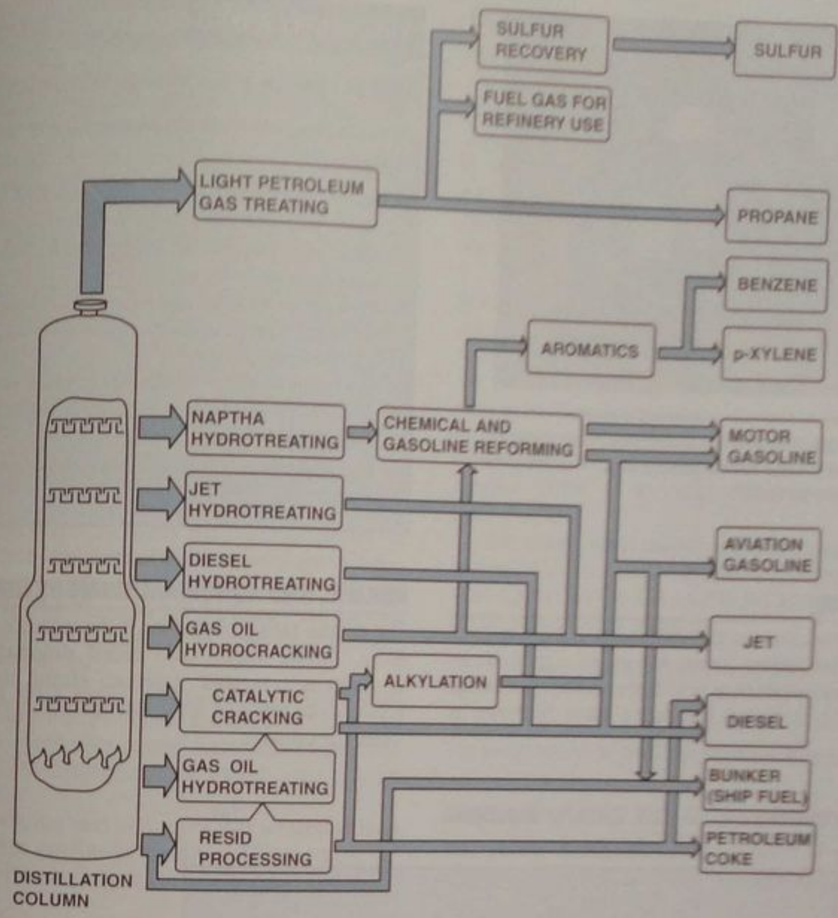


Figure 52–1 The crude oil refining process showing most of the major steps and processes.



Figure 52–2 A gas can that meets the California Resources Board (CARB) approval uses a spring loaded sealed nozzle that eliminates gasoline spillage and leaks into the atmosphere.

Volatility Problems At higher temperatures, liquid gasoline can easily vaporize, which can cause **vapor lock.** Vapor lock is a *lean* condition caused by vaporized fuel in the fuel system. This vaporized fuel takes up space normally occupied by liquid fuel. Vapor lock is caused by bubbles that form in the fuel, preventing proper operation of the fuel-injection system.

Bubbles in the fuel can be caused by heat or by sharp bends in the fuel system. Heat causes some fuel to evaporate, thereby causing bubbles. Sharp bends cause the fuel to be restricted at the bend. When the fuel flows past the bend, the fuel can expand to fill the space after the bend. This expansion drops the pressure, and bubbles form in the fuel lines. When the fuel is full of bubbles, the engine is not being supplied with enough fuel and the engine runs lean. A lean engine will stumble during acceleration, will run rough, and may stall. Warm weather and alcohol-blended fuels both tend to increase vapor lock and engine performance problems.

If winter-blend gasoline (or high-RVP fuel) is used in an engine during warm weather, the following problems may occur:

1. Rough idle
2. Stalling
3. Hesitation on acceleration
4. Surging

The RVP can be tested using the test kit shown in Figure 52–3.



Figure 52–3 A gasoline testing kit. Included is an insulated container where water at 100°F is used to heat a container holding a small sample of gasoline. The reading on the pressure gauge is the Reid vapor pressure (RVP).

DISTILLATION CURVE

Besides Reid vapor pressure, another method of classifying gasoline volatility is the **distillation curve.** A curve on a graph is created by plotting the temperature at which the various percentage of the fuel evaporates. A typical distillation curve is shown in Figure 52–4.

FREQUENTLY ASKED QUESTION ???

Why Do I Get Lower Gas Mileage in the Winter?

Several factors cause the engine to use more fuel in the winter than in the summer, including:

- Gasoline that is blended for use in cold climates is designed for ease of starting and contains fewer heavy molecules, which contribute to fuel economy. The heat content of winter gasoline is lower than summer-blended gasoline.
- In cold temperatures, all lubricants are stiff, causing more resistance. These lubricants include the engine oil, as well as the transmission and differential gear lubricants.
- Heat from the engine is radiated into the outside air more rapidly when the temperature is cold, resulting in longer run time until the engine has reached normal operating temperature.
- Road conditions, such as ice and snow, can cause tire slippage or additional drag on the vehicle.

NORMAL AND ABNORMAL COMBUSTION

The **octane rating** of gasoline is the measure of its antiknock properties. *Engine knock* (also called **detonation, spark knock,** or **ping**) is a metallic noise an engine makes, usually during acceleration, resulting from abnormal or uncontrolled combustion inside the cylinder.

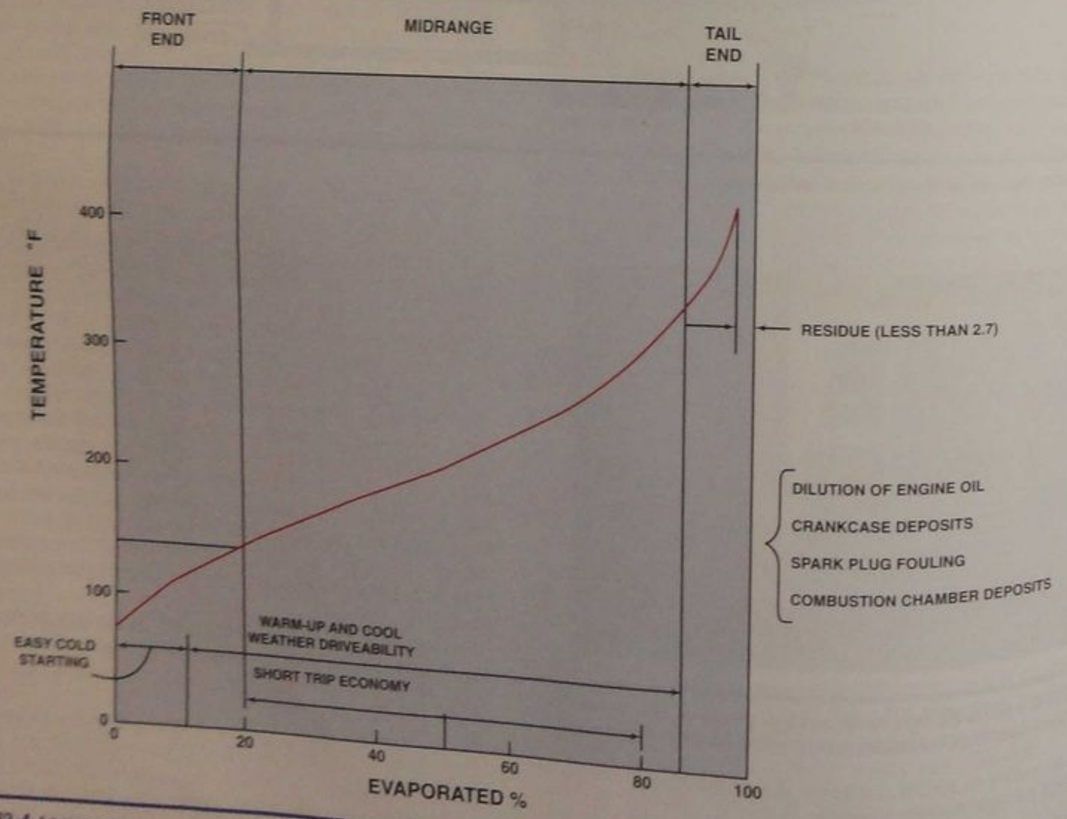


Figure 52–4 A typical distillation curve. Heavier molecules evaporate at higher temperatures and contain more heat energy for power, whereas the lighter molecules evaporate easier for starting.

TECH TIP ✓ The Sniff Test

Problems can occur with stale gasoline from which the lighter parts of the gasoline have evaporated. Stale gasoline usually results in a no-start situation. If stale gasoline is suspected, sniff it. If it smells rancid, replace it with fresh gasoline.

NOTE: If storing a vehicle, boat, or lawn mower over the winter, put some gasoline stabilizer into the gasoline to reduce the evaporation and separation that can occur during storage. Gasoline stabilizer is frequently available at lawn mower repair shops or marinas.

Some experts recommend that a diesel fuel additive be used to kill bacteria and fungi growth that occurs in fuels when moisture is present. To kill algae and stop bacterial growth, use from 0.25 to 0.50 fl oz of additive in each 20 gallons. While algae growth is usually associated with diesel fuel when water collects at the bottom of the tank, gasoline tanks can still be a source of algae, especially when vehicles are stored for long periods of time, usually over 90 days.

Normal combustion occurs smoothly and progresses across the combustion chamber from the point of ignition. See Figure 52–5.

Normal flame-front combustion travels between 45 and 90 mph (72 and 145 km/h). The speed of the flame front depends on air–fuel ratio, combustion chamber design (determining amount of turbulence), and temperature.

During periods of spark knock (detonation), the combustion speed increases by up to 10 times to near the speed of sound. The increased combustion speed also causes increased temperatures and pressures, which can damage pistons, gaskets, and cylinder heads. See Figure 52–6.

One of the first additives used in gasoline was **tetraethyl lead (TEL).** TEL was added to gasoline in the early 1920s to reduce the tendency to knock. It was often called ethyl or high-test gasoline.

OCTANE RATING

The antiknock standard or basis of comparison was the knock-resistant hydrocarbon isooctane, chemically called trimethylpentane (C_8H_{18}), also known as 2-2-4 trimethylpentane. If a gasoline tested had the exact same antiknock characteristics as isooctane, it was rated as 100-octane gasoline. If the gasoline tested had only 85% of the antiknock properties of isooctane, it was rated as 85 octane. Remember, octane rating is only a comparison test.

The two basic methods used to rate gasoline for antiknock properties (octane rating) are the *research method* and the *motor method.* Each uses a model of the special cooperative fuel research (CFR) single-cylinder engine. The research method and the motor method vary as to temperature of air, spark advance, and other parameters. The research method typically results in readings that are 6 to 10 points higher than those of the motor method. For example, a fuel with a research octane number (RON) of 93 might have a motor octane number (MON) of 85.

The octane rating posted on pumps in the United States is the average of the two methods and is referred to as (R + M) ÷ 2, meaning that, for the fuel used in the previous example, the rating posted on the pumps would be

$$\frac{\text{RON} + \text{MON}}{2} = \frac{93 + 85}{2} = 89$$

The pump octane is called the **antiknock index (AKI).**

GASOLINE GRADES AND OCTANE NUMBER

The posted octane rating on gasoline pumps is the rating achieved by the average of the research and the motor methods.

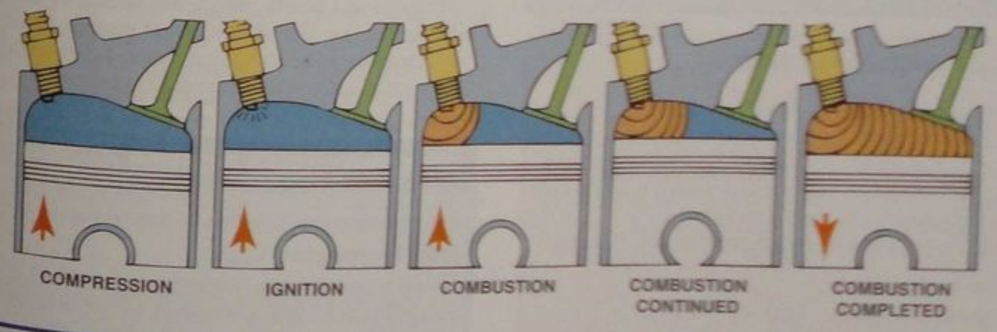


Figure 52–5 Normal combustion is a smooth, controlled burning of the air–fuel mixture.

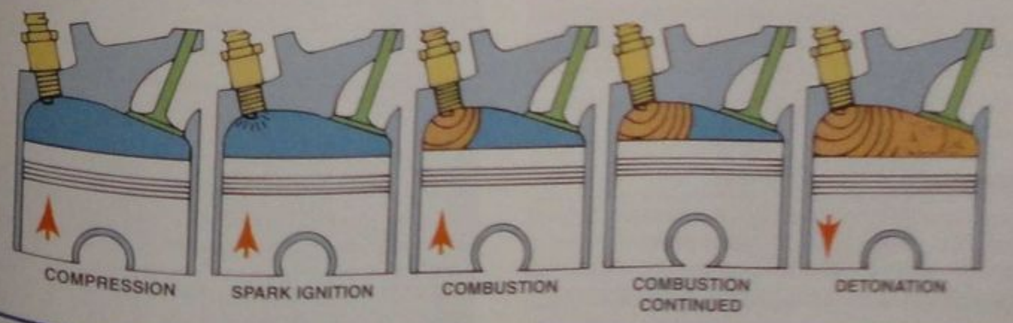


Figure 52–6 Detonation is a secondary ignition of the air–fuel mixture. It is also called spark knock or pinging.



Figure 52–7 A fuel pump showing regular (87 octane), plus (88.5 octane), and premium (90 octane). These ratings can vary with brand as well as in different parts of the country, especially in high-altitude areas where the ratings are lower as shown here.

Grades	Octane Rating
Regular	87
Midgrade (also called Plus)	89
Premium	91 or higher

FREQUENTLY ASKED QUESTION ???

What Grade of Gasoline Does the EPA Use When Testing Engines?

Due to the various grades and additives used in commercial fuel, the government (EPA) uses a liquid called indolene. Indolene has a research octane number of 96.5 and a motor method octane rating of 88, which results in an R + M ÷ 2 rating of 92.25.

TECH TIP ✓ **Horsepower and Fuel Flow**

To produce 1 hp, the engine must be supplied with 0.50 lb of fuel per hour (lb/hr). Fuel injectors are rated in pounds per hour. For example, a V-8 engine equipped with 25 lb/hr fuel injectors could produce 50 hp per cylinder (per injector) or 400 hp. Even if the cylinder head or block is modified to produce more horsepower, the limiting factor may be the injector flow rate.

The following are flow rates and resulting horsepower for a V-8 engine:

30 lb/hr: 60 hp per cylinder or 480 hp

35 lb/hr: 70 hp per cylinder or 560 hp

40 lb/hr: 80 hp per cylinder or 640 hp

Of course, injector flow rate is only one of many variables that affect power output. Installing larger injectors without other major engine modification could decrease engine output and drastically increase exhaust emissions.

See Figure 52–7. Except in high-altitude areas, the grades and octane ratings are as follows:

OCTANE IMPROVERS

When gasoline companies, under federal EPA regulations, removed tetraethyl lead from gasoline, other methods were developed to help maintain the antiknock properties of gasoline. Octane improvers (enhancers) can be grouped into three broad categories:

1. Aromatic hydrocarbons (hydrocarbons containing the benzene ring) such as xylene and toluene

REAL WORLD FIX **The Stalling Honda**

On a warm day in March, a customer walked into an automotive repair shop and asked for help. The car was parked on the street just outside the shop. A service technician accompanied the owner to check out the situation. The owner complained that the engine would start, then immediately stall. The engine would again start, and then stall during another attempt.

The service technician slid into the driver's seat and turned the ignition key. When the engine started, the technician depressed the accelerator slightly and the engine continued to run without any apparent problem. The car owner had never depressed the accelerator pedal and had never had any previous engine trouble.

The technician suspected winter-grade (high-RVP) gasoline was the problem. The owner replied that the present tank of fuel had been purchased during the last week in February. The technician explained that the uncommonly warm weather caused the fuel to vaporize in the fuel rail. Enough condensed fuel was available to start the engine, but the fuel injectors were designed to handle liquid fuel—not vapor—so the engine stalled.

The technician was probably lucky because by the third start enough of the remaining vapor had been drawn into the engine that all that remained was liquid gasoline.

2. Alcohols such as ethanol (ethyl alcohol), methanol (methyl alcohol), and tertiary butyl alcohol (TBA)
3. Metallic compounds such as methylcyclopentadienyl manganese tricarbonyl (MMT)

NOTE: MMT has been proven to be harmful to catalytic converters and can cause spark plug fouling. However, MMT is currently one of the active ingredients commonly found in octane improvers available to the public and in some gasoline sold in Canada. If an octane boost additive has been used that contains MMT, the spark plug porcelain will be rust colored around the tip.

Propane and butane, which are volatile by-products of the refinery process, are also often added to gasoline as octane improvers. The increase in volatility caused by the added propane and butane often leads to hot-weather driveability problems.

FREQUENTLY ASKED QUESTION ???

Can Regular-Grade Gasoline Be Used If Premium Is the Recommended Grade?

Yes. It is usually possible to use regular-grade or midgrade (plus) gasoline in most newer vehicles without danger of damage to the engine. Most vehicles built since the 1990s are equipped with at least one knock sensor. If a lower octane gasoline than specified is used, the engine ignition timing setting will usually cause the engine to spark knock, also called detonation or ping. This spark knock is detected by the knock sensor(s), which sends a signal to the computer. The computer then retards the ignition timing until the spark knock stops.

NOTE: Some scan tools will show the "estimated octane rating" of the fuel being used, which is based on knock sensor activity.

As a result of this spark timing retardation, the engine torque is reduced. While this reduction in power is seldom noticed, it will reduce fuel economy, often by 4 to 5 miles per gallon. If premium gasoline is then used, the PCM will gradually permit the engine to operate at the more advanced ignition timing setting. Therefore, it may take several tanks of premium gasoline to restore normal fuel economy. For best overall performance, use the grade of gasoline recommended by the vehicle manufacturer.

OXYGENATED FUELS

Oxygenated fuels contain oxygen in the molecule of the fuel itself. Examples of oxygenated fuels include methanol, ethanol, methyl tertiary butyl ether (MTBE), tertiary amyl methyl ether (TAME), and ethyl tertiary butyl ether (ETBE).

Oxygenated fuels are commonly used in high-altitude areas to reduce carbon monoxide (CO) emissions. The extra oxygen in the fuel itself is used to convert harmful CO into carbon dioxide (CO_2). The extra oxygen in the fuel helps ensure that there is enough oxygen to convert all the CO into CO_2 during the combustion process in the engine or catalytic converter.

Methyl Tertiary Butyl Ether (MTBE) MTBE is manufactured by means of the chemical reaction of methanol and isobutylene. Unlike methanol, MTBE does not increase the volatility of the fuel, and is not as sensitive to water as are other alcohols. The maximum allowable volume level, according to the EPA, is 15% but it is currently being phased out due to health concerns, as well as MTBE contamination of drinking water if spilled from storage tanks.

Tertiary-Amyl Methyl Ether Tertiary-amyl methyl ether (TAME) is an oxygenate added to gasoline and is flammable and can form explosive mixtures with air. It is slightly soluble in water, very soluble in ethers and alcohol, and soluble in most organic solvents including hydrocarbons. TAME is an ether, which contains an oxygen atom bonded to two carbon atoms.

Ethyl Tertiary Butyl Ether ETBE is derived from ethanol. The maximum allowable volume level is 17.2%. The use of ETBE is the cause of much of the odor from the exhaust of vehicles using reformulated gasoline.

Ethanol Ethyl alcohol is drinkable alcohol and is usually made from grain. Adding 10% ethanol (ethyl alcohol or grain alcohol) increases the (R + M) ÷ 2 octane rating by three points. The alcohol added to the base gasoline, however, also raises the volatility of the fuel about 0.5 PSI. Most automobile manufacturers permit up to 10% ethanol if driveability problems are not experienced. The oxygen content of a 10% blend of ethanol in gasoline, called **E-10,** is 3.5% oxygen by weight. See Figure 52–8.

Methanol Methyl alcohol is made from wood (wood alcohol), natural gas, or coal. **Methanol** is poisonous if ingested and tends to be more harmful to the materials in the fuel system and to separate when combined with gasoline unless used with a co-solvent. A co-solvent is another substance (usually another alcohol) that is soluble in both methanol and gasoline and is used to reduce the tendency of the liquids to separate.

Methanol can damage fuel system parts. Methanol is corrosive to lead (used as a coating of fuel tanks), aluminum, magnesium, and some plastics and rubber. Methanol can also cause rubber products (elastomers) to swell and soften. Methanol contains oxygen, and gasoline containing 5% methanol would have an oxygen content of 2.5% by weight.



Figure 52–8 This fuel tank indicates that the gasoline is blended with 10% ethanol (ethyl alcohol) and can be used in any gasoline vehicle. E-85 contains 85% ethanol and can only be used in vehicles specifically designed to use it.

CAUTION: All alcohols absorb water, and the alcohol–water mixture can separate from the gasoline and sink to the bottom of the fuel tank. This process is called *phase separation*. To help avoid engine performance problems, try to keep at least a quarter tank of fuel at all times, especially during seasons when there is a wide temperature span between daytime highs and nighttime lows. These conditions can cause moisture to accumulate in the fuel tank as a result of condensation of the moisture in the air. Keeping the fuel tank full reduces the amount of air and moisture in the tank. See Figure 52–9.

ALCOHOL ADDITIVES—ADVANTAGES AND DISADVANTAGES

The advantages and disadvantages of using alcohol as an additive to gasoline can be summarized as follows:

Advantages

1. Alcohol absorbs moisture in the fuel tank.
2. Ten percent alcohol added to gasoline raises the octane rating, (R + M) ÷ 2, by three points.
3. Alcohol cleans the fuel system.
4. Alcohol reduces CO emissions because it contains oxygen.

Disadvantages

1. The use of alcohol can result in the clogging of fuel filters with dirt and other debris cleaned from the fuel tank, pump, and lines.
2. Alcohol raises the volatility of fuel about 0.5 PSI; this can cause hot-weather driveability problems.
3. Alcohol reduces the heat content of the resulting fuel mixture (it has about one-half of the energy content of gasoline); 60,000 to 75,000 **British thermal units (BTUs)** per gallon for alcohol versus about 130,000 BTUs per gallon for gasoline.



Figure 52–9 A container with gasoline containing alcohol. Notice the separation line where the alcohol–water mixture separated from the gasoline and sank to the bottom.

4. Alcohol absorbs water and then separates from the gasoline, especially as temperature drops. Separated alcohol and water on the bottom of the tank can cause hard starting during cold weather. Alcohol does not vaporize easily at low temperatures.

FREQUENTLY ASKED QUESTION ???

Is Water Heavier Than Gasoline?

Yes. Water weighs about 7 pounds per gallon whereas gasoline weighs about 6 pounds per gallon. The density as measured by specific gravity includes:

Water = 1.000 (the baseline for specific gravity)

Gasoline = 0.730 to 0.760

This means that any water that gets into the fuel tank will sink to the bottom.

TESTING GASOLINE FOR ALCOHOL CONTENT

Take the following steps when testing gasoline for alcohol content:

1. Pour suspect gasoline into a small clean beaker or glass container.

WARNING: Do not smoke or run the test around sources of ignition!

2. Carefully fill the graduated cylinder to the 10-mL mark.
3. Add 2 mL of water to the graduated cylinder by counting the number of drops from an eyedropper. (Before performing the test, the eyedropper must be calibrated to determine how many drops equal 2.0 mL.)
4. Put the stopper in the cylinder and shake vigorously for 1 minute. Relieve built-up pressure by occasionally removing the stopper. Alcohol dissolves in water and will drop to the bottom of the cylinder.
5. Place the cylinder on a flat surface and let it stand for 2 minutes.
6. Take a reading near the bottom of the cylinder at the boundary between the two liquids.
7. For percent of alcohol in gasoline, subtract 2 from the reading and multiply by 10. For example,

The reading is 3.1 mL: $3.1 - 2 = 1.1 \times 10 = 11\%$ alcohol

The reading is 2.0 mL: $2 - 2 = 0 \times 10 = 0\%$ alcohol (no alcohol)

If the increase in volume is 0.2% or less, it may be assumed that the test gasoline contains no alcohol. Alcohol content can also be checked using an electronic tester. See the photo sequence at the end of the chapter.

FREQUENTLY ASKED QUESTION ???

How Does Alcohol Content in the Gasoline Affect Engine Operation?

In most cases, the use of gasoline containing 10% or less of ethanol (ethyl alcohol) has little or no effect on engine operation. However, because the addition of 10% ethanol raises the volatility of the fuel slightly, occasional rough idle or stalling may be noticed, especially during warm weather. The rough idle and stalling may also be noticeable after the engine is started, driven, then stopped for a short time. Engine heat can vaporize the alcohol-enhanced fuel causing bubbles to form in the fuel system. These bubbles in the fuel prevent the proper operation of the fuel injection system and result in a hesitation during acceleration, rough idle, or in severe cases, repeated stalling until all the bubbles have been forced through the fuel system, replaced by cooler fuel from the fuel tank.

COMBUSTION CHEMISTRY

Internal combustion engines burn an organic fuel to produce power. The term **organic** refers to a product (gasoline) from a source that originally was alive. Because crude oil originally came from living plants and animals, all products of petroleum are considered organic fuels and are composed primarily of hydrogen (H) and carbon (C).

The combustion process involves the chemical combination of oxygen (O_2) from the air (about 21% of the atmosphere) with the hydrogen and carbon from the fuel. In a gasoline engine, a spark starts the combustion process, which takes about 3 ms (0.003 sec) to be completed inside the cylinder of an engine. The chemical reaction that takes place can be summarized as follows: hydrogen (H) plus carbon (C) plus oxygen (O_2) plus nitrogen (N) plus spark equals heat plus water (H_2O) plus carbon monoxide (CO) (if incomplete combustion) plus carbon dioxide (CO_2) plus hydrocarbons (HC) plus oxides of nitrogen (NO_X) plus many other chemicals.

AIR–FUEL RATIOS

Fuel burns best when the intake system turns it into a fine spray and mixes it with air before sending it into the cylinders. In fuel-injected engines, the fuel becomes a spray and mixes with the air in the intake manifold. There is a direct relationship between engine airflow and fuel requirements; this is called the **air–fuel ratio.**

The air–fuel ratio is the proportion by weight of air and gasoline that the injection system mixes as needed for engine combustion. The mixtures, with which an engine can operate without stalling, range from 8 to 1 to 18.5 to 1. See Figure 52–10. These ratios are usually stated by weight, such as:

- 8 parts of air by weight combined with 1 part of gasoline by weight (8:1), which is the richest mixture that an engine can tolerate and still fire reliably.
- 18.5 parts of air mixed with 1 part of gasoline (18.5:1), which is the leanest practical ratio. Richer or leaner air–fuel ratios cause the engine to misfire badly or not run at all.

Stoichiometric Air–Fuel Ratio The ideal mixture or ratio at which all of the fuel combines with all of the oxygen in the air and burns completely is called the **stoichiometric ratio,** a chemically perfect combination. In theory, this ratio is an air–fuel mixture of 14.7 to 1. See Figure 52–11.

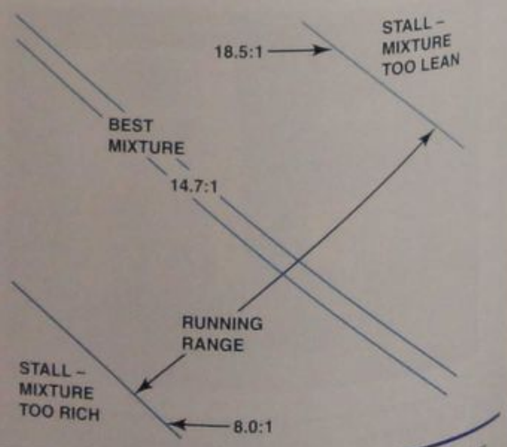


Figure 52–10 An engine will not run if the air–fuel mixture is either too rich or too lean.

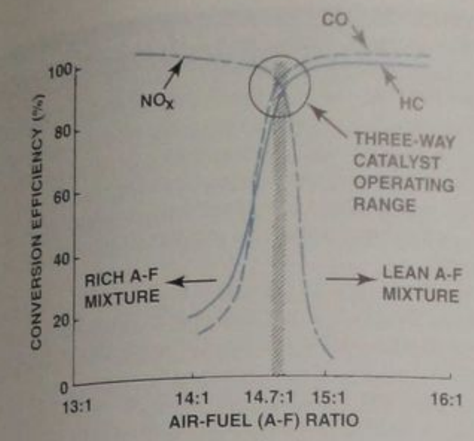


Figure 52–11 With a three-way catalytic converter, emission control is most efficient with an air-fuel ration between 14.65:1 and 14.75:1.

In reality, the exact ratio at which perfect mixture and combustion occurs depends on the molecular structure of gasoline, which can vary. The stoichiometric ratio is a compromise between maximum power and maximum economy.

Stoichiometric Air–Fuel Ratio for Various Fuels If the combustion process is complete, all gasoline or HCs will be completely combined with all the available oxygen. This total combination of all components of the fuel is called *stoichiometric air-fuel ratio.* The stoichiometric quantities for gasoline are 14.7 parts air for 1 part gasoline by weight. Different fuels have different stoichiometric proportions. See the accompanying table comparing the heat and stoichiometric ratio for alcohol versus gasoline.

Fuel	Heat Energy (BTU/gal)	Stoichiometric Ratio
Gasoline	About 130,000	14.7:1
Ethyl (ethanol) alcohol	About 76,000	9.0:1
Methyl (methanol) alcohol	About 60,000	6.4:1

The heat produced by the combustion process is measured in BTUs. One BTU is the amount of heat required to raise one pound of water one Fahrenheit degree. The metric unit of heat is the calorie (cal). One calorie is the amount of heat required to raise the temperature of one gram (g) of water one Celsius degree.

HIGH-ALTITUDE OCTANE REQUIREMENTS

As the altitude increases, atmospheric pressure drops. The air is less dense because a pound of air takes more volume. The octane rating of fuel does not need to be as high because the engine cannot take in as much air. This process will reduce the combustion (compression) pressures inside the engine. In mountainous areas, gasoline octane ratings are two or more numbers lower than $(R + M) \div 2$ octane ratings are two or more numbers lower than normal (according to the SAE, about one octane number lower per 1,000 ft or 300 m in altitude). See Figure 52–12.

A secondary reason for the lowered octane requirement of engines running at higher altitudes is the normal enrichment of the air-fuel ratio and lower engine vacuum with the decreased air density. Some problems, therefore, may occur when driving out of high-altitude areas into lower-altitude areas where the octane rating must be higher. Most computerized engine control systems can compensate for changes in altitude and modify air–fuel ratio and ignition timing for best operation.



Figure 52–12 Photo of gasoline pump taken in a high-altitude area. Note the lower than normal octane ratings. The "ethanol" sticker reads that all grades contain 10% ethanol from November 1 through February 28 each year to help reduce CO exhaust emissions.

Because the combustion burn rate slows at high altitude, the ignition (spark) timing can be advanced to improve power. The amount of timing advance can be about 1 degree per 1,000 ft over 5,000 ft. Therefore, if driving at 8,000 ft of altitude, the ignition timing can be advanced 3 degrees.

High altitude also allows fuel to evaporate more easily. The volatility of fuel should be reduced at higher altitudes to prevent vapor from forming in sections of the fuel system, which can cause driveability and stalling problems. The extra heat generated in climbing to higher altitudes plus the lower atmospheric pressure at higher altitudes combine to cause vapor lock problems as the vehicle goes to higher altitudes.

REFORMULATED GASOLINE

Reformulated gasoline (RFG) is manufactured by refiners to help reduce emissions. The gasoline refiners reformulate gasoline by using additives that contain at least 2% oxygen by weight and reducing the additive benzene to a maximum of 1% by volume. Two other major changes done at the refineries are as follows:

1. **Reduce light compounds.** Refineries eliminate butane, pentane, and propane, which have a low boiling point and evaporate easily. These unburned hydrocarbons are released into the atmosphere during refueling and through the fuel tank vent system, contributing to smog formation. Therefore, reducing the light compounds from gasoline helps reduce evaporative emissions.
2. **Reduce heavy compounds.** Refineries eliminate heavy compounds with high boiling points such as aromatics and olefins. The purpose of this reduction is to reduce the amount of unburned hydrocarbons that enter the catalytic converter, which makes the converter more efficient, thereby reducing emissions.

Because many of the heavy compounds are eliminated, a drop in fuel economy of about 1 mpg has been reported in areas where reformulated gasoline is being used. Formaldehyde is formed when RFG is burned, and the vehicle exhaust has a unique smell when reformulated gasoline is used.

FREQUENTLY ASKED QUESTION ???

What Is "Top-Tier" Gasoline?

Top-tier gasoline is gasoline that has specific standards for quality, including enough detergent to keep all intake valves clean. The standards were developed by the four automobile manufacturers, including BMW, General Motors, Honda, and Toyota. Top-tier gasoline exceeds the quality standards developed by the **World Wide Fuel Charter (WWFC)** that was established in 2002 by vehicle and engine manufacturers. The gasoline companies that agreed to make fuel that matches or exceeds the standards as a top-tier fuel include Chevron Texaco and Conoco Phillips. Ford has specified that BP fuel, sold in many parts of the country, is the recommended fuel to use in Ford vehicles. See Figure 52–13.



Figure 52–13 The gas cap on a Ford vehicle notes that BP fuel is recommended.

GENERAL GASOLINE RECOMMENDATIONS

The fuel used by an engine is a major expense in the operation cost of the vehicle. The proper operation of the engine depends on clean fuel of the proper octane rating and vapor pressure for the atmospheric conditions.

To help ensure proper engine operation and keep fuel costs to a minimum, follow these guidelines:

1. Purchase fuel from a busy station to help ensure that it is fresh and less likely to be contaminated with water or moisture.
2. Keep the fuel tank above one-quarter full, especially during seasons in which the temperature rises and falls by more than 20°F between daytime highs and nighttime lows. This helps to reduce condensed moisture in the fuel tank and could prevent gas line freeze-up in cold weather.

NOTE: Gas line freeze-up occurs when the water in the gasoline freezes and forms an ice blockage in the fuel line.

3. Do not purchase fuel with a higher octane rating than is necessary. Try using premium high-octane fuel to check for operating differences. Most newer engines are equipped with a detonation (knock) sensor that signals the vehicle computer to retard the ignition timing when spark knock occurs. Therefore, an operating difference may not be noticeable to the driver when using a low-octane fuel, except for a decrease in power and fuel economy. In other words, the engine with a knock sensor will tend to operate knock free on regular fuel, even if premium, higher-octane fuel is specified. Using premium fuel may result in more power and greater fuel economy. The increase in fuel economy, however, would have to be substantial to justify the increased cost of high-octane premium fuel. Some drivers find a good compromise by using midgrade (plus) fuel to benefit from the engine power and fuel economy gains without the cost of using premium fuel all the time.
4. Avoid using gasoline with alcohol in warm weather, even though many alcohol blends do not affect engine driveability. If warm-engine stumble, stalling, or rough idle occurs, change brands of gasoline.
5. Do not purchase fuel from a retail outlet when a tanker truck is filling the underground tanks. During the refilling procedure, dirt, rust, and water may be stirred up in the underground tanks. This undesirable material may be pumped into your vehicle's fuel tank.
6. Do not overfill the gas tank. After the nozzle clicks off, add just enough fuel to round up to the next dime. Adding additional gasoline will cause the excess to be drawn into the charcoal canister. This can lead to engine flooding and excessive exhaust emissions.
7. Be careful when filling gasoline containers. Always fill a gas can on the ground to help prevent the possibility of static electricity build-up during the refueling process. See Figure 52–14.



Figure 52–14 Many gasoline service stations have signs posted warning customers to place plastic fuel containers on the ground while filling. If placed in a trunk or pickup truck bed equipped with a plastic liner, static electricity could build up during fueling and discharge from the container to the metal nozzle, creating a spark and possible explosion. Some service stations have warning signs not to use cell phones while fueling to help avoid the possibility of an accidental spark creating a fire hazard.

FREQUENTLY ASKED QUESTION ???

Why Should I Keep the Fuel Gauge above One-Quarter Tank?

The fuel pickup inside the fuel tank can help keep water from being drawn into the fuel system unless water is all that is left at the bottom of the tank. Over time, moisture in the air inside the fuel tank can condense, causing liquid water to drop to the bottom of the fuel tank (water is heavier than gasoline—about 8 lb per gallon for water and about 6 lb per gallon for gasoline). If alcohol-blended gasoline is used, the alcohol can absorb the water and the alcohol–water combination can be burned inside the engine. However, when water combines with alcohol, a separation layer occurs between the gasoline at the top of the tank and the alcohol–water combination at the bottom. When the fuel level is low, the fuel pump will draw from this concentrated level of alcohol and water. Because alcohol and water do not burn as well as pure gasoline, severe driveability problems can occur such as stalling, rough idle, hard starting, and missing.

TECH TIP ✓ **Do Not Overfill the Fuel Tank**

Gasoline fuel tanks have an expansion volume area at the top. The volume of this expansion area is equal to 10% to 15% of the volume of the tank. This area is normally not filled with gasoline, but rather is designed to provide a place for the gasoline to expand into, if the vehicle is parked in the hot sun and the gasoline expands. This prevents raw gasoline from escaping from the fuel system. A small restriction is usually present to control the amount of air and vapors that can escape the tank and flow to the charcoal canister.

This volume area could be filled with gasoline if the fuel is slowly pumped into the tank. Since it can hold an extra 10% (2 gallons in a 20-gallon tank), some people deliberately try to fill the tank completely. When this expansion volume is filled, liquid fuel (rather than vapors) can be drawn into the charcoal canister. When the purge valve opens, liquid fuel can be drawn into the engine, causing an excessively rich air–fuel mixture. Not only can this liquid fuel harm vapor recovery parts, but overfilling the gas tank could also cause the vehicle to fail an exhaust emission test, particularly during an enhanced test when the tank could be purged while on the rollers.

ALTERNATIVE FUELS

Alternative fuels include a number of fuels besides gasoline for use in passenger vehicles. See Figure 52–15.



Figure 52–15 Some retail stations offer a variety of fuel choices, such as this station in Ohio where biodiesel, E-10, and E-85 are available.

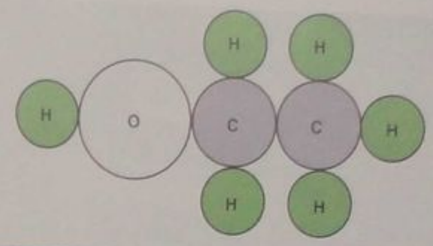


Figure 52–16 The ethanol molecular structure showing two carbon atoms, six hydrogen atoms, and one oxygen atom.

Ethanol Ethanol is also called **ethyl alcohol** or **grain alcohol,** because it is usually made from grain and is the type of alcohol found in alcoholic drinks such as beer, wine, and distilled spirits like whiskey. Ethanol is composed of two carbon atoms and six hydrogen atoms with one added oxygen atom. See Figure 52–16.

Conventional ethanol and **cellulose ethanol** are the same product, but cellulose ethanol is produced using the nonfood portion of the feedstock. Conventional ethanol is derived from grains, such as corn, wheat, or soybeans. Corn, for example, is converted to ethanol in either a dry or wet milling process. In dry milling operations, liquefied cornstarch is produced by heating cornmeal with water and enzymes. A second enzyme converts the liquefied starch to sugars, which are fermented by yeast into ethanol and carbon dioxide. Wet milling operations separate the fiber, germ (oil), and protein from the starch before it is fermented into ethanol.

Cellulose ethanol can be produced from a wide variety of cellulose biomass feedstock, including agricultural plant wastes (corn stalks, cereal straws), plant wastes from industrial processes (sawdust, paper pulp), and energy crops grown specifically for fuel production. These nongrain products are often referred to as **cellulosic biomass.** Cellulosic biomass is composed of cellulose and lignin, with smaller amounts of proteins, lipids (fats, waxes, and oils), and ash. About two-thirds of cellulosic materials are present as cellulose, with lignin making up the bulk of the remaining dry mass.

As with grains, processing cellulose biomass strives to extract fermentable sugars from the feedstock. But the sugars in cellulose are locked in complex carbohydrates called polysaccharides (long chains of simple sugars). Separating these complex structures into fermentable sugars is needed to achieve the efficient and economic production of cellulose ethanol.

Two processing options are employed to produce fermentable sugars from cellulose biomass:

- Acid hydrolysis is used to break down the complex carbohydrates into simple sugars.
- Enzymes are employed to convert the cellulose biomass to fermentable sugars. The final step involves microbial fermentation, yielding ethanol and carbon dioxide.

NOTE: Grain-based ethanol uses fossil fuels to produce heat during the conversion process, generating substantial greenhouse gas emissions. Cellulose ethanol production substitutes biomass for fossil fuels. The greenhouse gases produced by the combustion of biomass are offset by the CO_2 absorbed by the biomass as it grows in the field.

The majority of the ethanol in the United States is made from:

- Corn
- Grain
- Sorghum
- Wheat
- Barley
- Potatoes

In Brazil, the world's largest ethanol producer, it is made from sugarcane. Ethanol can be made by the dry mill process in which the starch portion of the corn is converted into sugar and then distilled into alcohol.

FREQUENTLY ASKED QUESTION ???

Does Ethanol Production Harm the Environment?

The production of ethanol is claimed to be fairly carbon neutral because the amount of CO_2 released during production is equal to the amount of CO_2 that would be released if the corn or other products were left to decay.

E-85 Vehicle manufacturers have available vehicles that are capable of operating on gasoline plus ethanol in a combination of gasoline and ethanol called **E-85.** E-85 is composed of 85% ethanol and 15% gasoline. Pure ethanol has an octane rating of about 113, whereas E-85, which contains 85% oxygen by weight, has an octane rating of about 100 to 105 compared to a regular unleaded gasoline rating of 87.

NOTE: The octane rating of E-85 depends on the exact percent of ethanol used, which can vary from 45% to 85%, as well as the octane rating of the gasoline used.

E-85 has less heat energy than gasoline.

Gasoline = 114,000 BTUs per gallon
E-85 = 81,000 BTUs per gallon

This means that the fuel economy is reduced by 25% to 30% if E-85 is used instead of gasoline.

For example, a Chevrolet Tahoe 5.3-liter V8, automatic transmission has an EPA rating using gasoline of 15 mpg in the city and 20 mpg on the highway. If that same vehicle was fueled with E-85, the EPA fuel economy rating drops to 11 mpg in the city and 15 mpg on the highway.

The 15% gasoline in this blend helps the engine start, especially in cold weather. Vehicles equipped with this capability are commonly referred to as **alternative fuel vehicles (AFVs), flex fuels,** and **flexible fuel vehicles,** or **FFVs.** See Figure 52–17. Using E-85 in a flex fuel vehicle can result in a power increase of about 5%. For example, an engine rated at 300 hp using gasoline can be rated another 315 hp if using E-85.

NOTE: Fuel economy will be improved even if flex-fuel ethanol is used because it is often blended according to local conditions. A lower percentage of ethanol and a slightly higher percentage of gasoline helps engines start in cold climates.

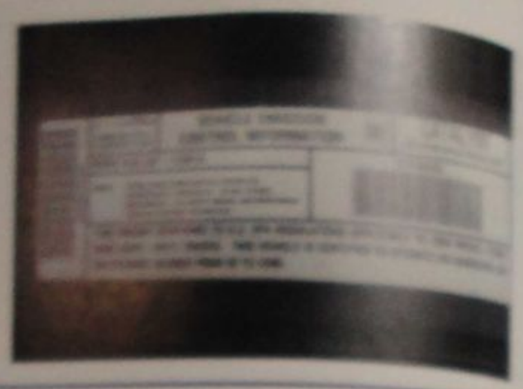


Figure 52–17 A vehicle emission control information (VECI) sticker on a flexible fuel vehicle indicating the percentage of ethanol with which it is able to operate.

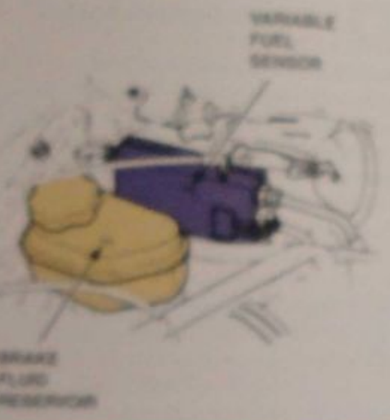


Figure 52–18 The location of the variable fuel sensor can vary, depending on the year and model of vehicle, but it is always in the fuel line between the fuel tank and the fuel injectors.

These vehicles are equipped with an electronic sensor that detects the presence and percentage of ethanol and then adjusts the fuel injector on-time and ignition timing to match the blend of the fuel being used.

E-85 contains less heat energy, and therefore will use more fuel, but the benefits include a lower cost of the fuel and the environmental benefit associated with using an oxygenated fuel.

General Motors, Ford, Chrysler, Mazda, and Honda are a few of the manufacturers offering E-85 compatible vehicles. E-85 vehicles use fuel system parts designed to withstand the additional alcohol content, modified driveability programs that adjust fuel delivery and timing to compensate for the various percentages of ethanol in fuel, and a **fuel compensation sensor** that measures both the percentage of ethanol blend and the temperature of the fuel. The sensor is also called a **variable fuel sensor.** See Figures 52–18 and 52–19.

Most E-85 vehicles are very similar to non-E-85 vehicles. Fuel system components may be redesigned to withstand the effects of higher concentrations of ethanol. In addition, since the stoichiometric point for ethanol is 9:1 instead of 14.7:1 as in gasoline, the air-fuel mixture has to be adjusted for the percentage of ethanol present in the fuel tank. In order to determine this percentage of ethanol in the fuel tank, a compensation

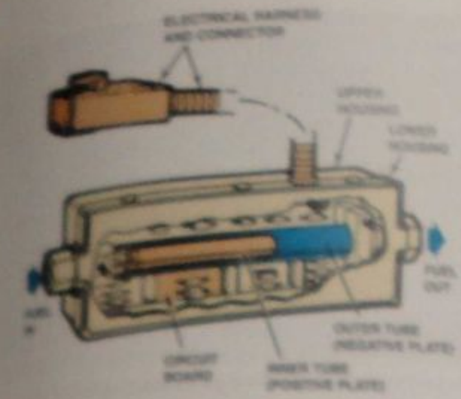


Figure 52–19 A cutaway view of a typical variable fuel sensor.

sor is used. The fuel compensation sensor is the only additional piece of hardware required on some E-85 vehicles. The fuel compensation sensor provides both the ethanol percentage and the fuel temperature to the PCM. The PCM uses this information to adjust both the ignition timing and the quantity of fuel allowed to the engine. The fuel compensation sensor uses a microprocessor to measure both the ethanol percentage and the fuel temperature. This information is sent to the PCM on two signal circuits. The compensation sensor produces a square wave frequency and pulse width signal. The normal frequency range of the fuel compensation sensor is 50 hertz, which represents 0% ethanol and 150 hertz, which represents 100% ethanol. The pulse width of the signal varies from 1 millisecond to 5 milliseconds. One millisecond would represent a fuel temperature of −40°F (−40°C), and 5 milliseconds would represent a fuel temperature of 257°F (125°C). Since the PCM knows both the fuel temperature and the ethanol percentage of the fuel, it can adjust fuel quantity and ignition timing for optimum performance and emissions.

FREQUENTLY ASKED QUESTION ???

How Does a Sensorless Flex Fuel System Work?

General Motors flex fuel vehicles do not use a fuel compensation sensor and instead rely the oxygen sensor to detect the presence of the lean mixture and the extra oxygen in the fuel.

The power train control module (PCM) then adjusts the injector pulse width and the ignition timing to optimize engine operation to the use of E-85. This type of vehicle is called a **virtual-flexible fuel vehicle,** abbreviated **V-FFV.** The virtual-flexible fuel vehicle can operate on pure gasoline, E-10, E-85, or any combination.

The benefits of E-85 vehicles are less pollution, less CO_2 production, and less dependence on oil. See Figure 52–20.

Ethanol-fueled vehicles generally produce the same emissions as gasoline vehicles; however, they produce less NO_x and CO_2 emissions. While CO_2 is not considered a pollutant, it is thought to lead to global warming and is called a greenhouse gas.



Figure 52–20 A pump for E-85 (85% ethanol and 15% gasoline). There are now, if any, of these pumps in many states.

FREQUENTLY ASKED QUESTION ???

What Is Switchgrass?

Switchgrass (*Panicum virgatum*) is a summer perennial grass that is native to North America. It is a natural component of the tall-grass prairie, which covered most of the Great Plains, but was also found on the prairie soils in the Black Belt of Alabama and Mississippi. Switchgrass is resistant to many pests and plant diseases, and is capable of producing high yields with very low applications of fertilizer. This means that the need for agricultural chemicals to grow switchgrass is relatively low. Switchgrass is also very tolerant of poor soils, flooding, and drought, which are widespread agricultural problems in the Southeast.

There are two main types of switchgrass:

- *Upland types* — usually grow 5 to 6 feet tall
- *Lowland types* — grow up to 12 feet tall and are typically found on heavy soils in bottomland sites

Better energy efficiency is gained because less energy is used to produce ethanol from switchgrass.

TECH TIP ✓ **Avoid Resetting Fuel Compensation**

Starting in 2006, General Motors vehicles designed to operate on E-85 do not use a fuel compensation sensor, but instead use the oxygen sensor and refueling information to calculate the percentage of ethanol in the fuel. The PCM uses the fuel level sensor to sense that fuel has been added and starts to determine the resulting ethanol content by using the oxygen sensor. However, if a service technician were to reset fuel compensation by clearing long-term fuel trim, the PCM starts the calculation based on base fuel, which is gasoline with less than or equal to 10% ethanol (E-10). If the fuel tank has E-85, then the fuel compensation cannot be determined unless the tank is drained and refilled with base fuel. Therefore, avoid resetting the fuel compensation setting unless it is known that the fuel tank contains gasoline or E-10 only.

NOTE: For additional information on E-85 and for the location of E-85 stations in your area, go to www.e85fuel.com.

Methanol **Methanol,** also known as *methyl alcohol* or *wood alcohol,* is a chemical compound with a chemical formula that includes one carbon atom, four hydrogen atoms, and one oxygen atom. See Figure 52–21.

Methanol is a light, volatile, colorless, tasteless, flammable, poisonous liquid with a very faint odor. It is used as an antifreeze, solvent, and fuel, and because of its poisonous properties it is also used to denature ethanol. Methanol burns in air, forming CO_2 (carbon dioxide) and H_2O (water). A methanol flame is almost colorless. Methanol is often called **wood alcohol** because it was once produced chiefly as a by-product of the destructive distillation of wood. See Figure 52–22.

The biggest source of methanol in the United States is coal. Using a simple reaction between coal and steam, a gas mixture called **syn-gas (synthesis gas)** is formed. The components of this mixture are carbon monoxide and hydrogen, which, through an additional chemical reaction, are converted to methanol.

Natural gas can also be used to create methanol and is re-formed or converted to synthesis gas, which is later made into methanol.

Biomass can be converted to synthesis gas by a process called partial oxidation, and later converted to methanol. **Biomass** is organic material, such as urban wood wastes, primary mill residues, forest residues, agricultural residues, and dedicated energy crops (e.g., sugarcane and sugar beets) that can be made into fuel.

Electricity can be used to convert water into hydrogen, which is then reacted with carbon dioxide to produce methanol.

Methanol is toxic and can cause blindness and death. It can enter the body by ingestion, inhalation, or absorption through the skin. Dangerous doses will build up if a person is regularly exposed to fumes or handles liquid without skin protection. If methanol has been ingested, a doctor should be contacted immediately. The usual fatal dose is 4 fl oz (100 to 125 mL).

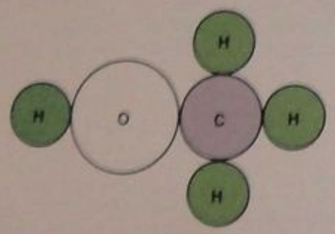


Figure 52–21 The molecular structure of methanol showing the one carbon atom, four hydrogen atoms, and one oxygen atom.

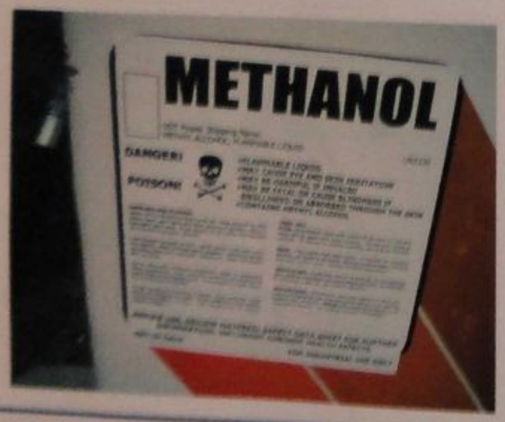


Figure 52–22 This sign on a methanol pump shows that methyl alcohol is a poison and can cause skin irritation and other personal injury. Methanol is used in industry as well as a fuel source.

M-85 Some flexible fuel vehicles are designed to operate on 85% methanol and 15% gasoline. Methanol is very corrosive and requires that the fuel system components be constructed of stainless steel and other alcohol-resistant rubber and plastic components. The heat content of **M-85** is about 60% of that of gasoline.

Propane **Propane** is normally a gas but is easily compressed into a liquid and stored in inexpensive containers. When sold as a fuel, it is also known as **liquefied petroleum gas (LPG)** or **LP-gas** because the propane is often mixed with about 10% of other gases such as butane, propylene, butylenes, and mercaptan to give the colorless and odorless propane a smell. Propane is nontoxic, but if inhaled can cause asphyxiation through lack of oxygen. Propane is heavier than air and lays near the floor if released into the atmosphere. Propane is commonly used in forklifts and other equipment used inside warehouses and factories because the exhaust from the engine using propane is not harmful. Propane comes from a by-product of petroleum refining of natural gas. In order to liquefy the fuel, it is stored in strong tanks at about 300 PSI (2,000 kPa). The heating value of propane is less than that of gasoline; therefore, more is required, which reduces the fuel economy. See Figure 52–23.

Compressed Natural Gas (CNG) Another alternative fuel that is often used in fleet vehicles is **compressed natural gas,** or **CNG,** and vehicles using this fuel are often referred to as **natural gas vehicles (NGVs).** Look for the blue CNG label on vehicles designed to operate on compressed natural gas. See Figure 52–24.

Natural gas has to be compressed to about 3000 PSI (20,000 kPa) or more, so the weight and the cost of the storage container is a major factor when it comes to preparing a vehicle to run on CNG. The tanks needed for CNG are typically constructed of 0.5-inch-thick (3-mm) aluminum reinforced with fiberglass. The octane rating of CNG is about 130 and the cost per gallon is about half of the cost of gasoline. However, the heat value of CNG is also less, and therefore more is required to produce the same power and the miles per gallon is less.

Compressed natural gas is made up of a blend of methane, propane, ethane, N-butane, carbon dioxide, and nitrogen. Once it



Figure 52–23 Propane fuel storage tank in the trunk of a Ford taxi.



Figure 52–24 The blue sticker on the rear of this vehicle indicates that it is designed to use compressed natural gas.



Figure 52–25 The fuel injectors used on this Honda Civic GX CNG engine are designed to flow gaseous fuel instead of liquid fuel and cannot be interchanged with any other type of injector.

is processed, it is at least 93% methane. Natural gas is nontoxic, odorless, and colorless in its natural state. It is odorized during processing, using ethyl mercaptan ("skunk"), to allow for easy leak detection. Natural gas is lighter than air and will rise when released into the air. Since CNG is already a vapor, it does not need heat to vaporize before it will burn, which improves cold start-up and results in lower emissions during cold operation. However, because it is already in a gaseous state, it does displace some of the air charge in the intake manifold. This leads to about a 10% reduction in engine power as compared to an engine operating on gasoline. Natural gas also burns slower than gasoline; therefore, the ignition timing must be advanced more when the vehicle operates on natural gas. Natural gas has an octane rating of about 115 octane. The stoichiometric ratio, the point at which all the air and fuel is used or burned, is 16.5:1 compared to 14.7:1 for gasoline. This means that more air is required to burn one pound of natural gas than is required to burn one pound of gasoline. See Figure 52–25. The CNG engine is designed to include:

- Increased compression ratio
- Strong pistons and connecting rods
- Heat-resistant valves
- Fuel injectors designed for gaseous fuel instead of liquid fuel

When completely filled, the CNG tank has 3600 PSI of pressure in the tank. When the ignition is turned on, the alternate fuel



Figure 52–26 A CNG storage tank from a Honda Civic GX shown with the fixture used to support it while it is being removed or installed in the vehicle. Honda specifies that three technicians be used to remove or install the tank through the rear door of the vehicle due to the size and weight of the tank.

electronic control unit activates the high-pressure lock-off, which allows high-pressure gas to pass to the high-pressure regulator. The high-pressure regulator reduces the high-pressure CNG to approximately 170 PSI, 1172 kPa and sends it to the low-pressure lock-off. The low-pressure lock-off is also controlled by the alternate fuel electronic control unit and is activated at the same time that the high-pressure lock-off is activated. From the low-pressure lock-off, the CNG is directed to the low-pressure regulator. This is a two-stage regulator that first reduces the pressure to approximately 4 to 6 PSI in the first stage and then to 4.5 to 7 inches of water in the second stage. From here, the low-pressure gas is delivered to the gas mass sensor/mixture control valve. This valve controls the air–fuel mixture. The CNG gas distributor adapter then delivers the gas to the intake stream.

CNG vehicles are designed for fleets that usually have their own refueling capabilities. One of the drawbacks to using CNG is the time that it takes to refuel a vehicle. The ideal method of refueling is the slow fill method. The slow filling method compresses the natural gas as the tank is being fueled. This method ensures that the tank will receive a full charge of CNG; however, this method can take three to five hours to accomplish. If more than one vehicle needs filling, the facility will need multiple CNG compressors to refuel the vehicles. There are three commonly used CNG refilling station pressures:

P24—2400 PSI
P30—3000 PSI
P36—3600 PSI

Try to find and use a station with the highest pressure to help ensure a long driving range. Filling at lower pressures will result in less compressed natural gas being installed in the storage tank, thereby reducing the driving range. See Figure 52–26.

The fast fill method uses CNG that is already compressed. However, as the CNG tank is filled rapidly, the internal temperature of the tank will rise, which causes a rise in tank pressure. Once the temperature drops in the CNG tank, the pressure in the tank also drops, resulting in an incomplete charge in the CNG tank. This refueling method may take only about five minutes; however, it will result in an incomplete charge to the CNG tank, reducing the driving range.

P-SERIES FUELS

P-series alternative fuel is patented by Princeton University and is a non-petroleum-based fuel suitable for use in flexible fuel vehicles or any vehicle designed to operate on E-85 (85% ethanol, 15% gasoline). P-series fuels are blends of the following:

- Ethanol (ethyl alcohol)
- Methyltetrahydrofuran, abbreviated **MTHF**
- Natural gas liquids, such as pentanes
- Butane

The ethanol and MTHF are produced from renewable feedstocks, such as corn, waste paper, biomass, agricultural waste, and wood waste (scraps and sawdust). The components used in P-type fuel can be varied to produce regular grade, premium grade, or fuel suitable for cold climates. P-series fuels are not produced in large enough amounts to make this fuel a good alternative at the present time.

Composition of P-Series Fuels (by Volume)

Component	Regular Grade	Premium Grade	Cold Weather
Pentanes plus	32.5%	27.5%	16.0%
MTHF	32.5%	17.5%	26.0%
Ethanol	35.0%	55.0%	47.0%
Butane	0.0%	0.0%	11.0%

See the chart below for a comparison that summarizes the characteristics of the most commonly used fuels.

FREQUENTLY ASKED QUESTION ???

What Is a Tri-Fuel Vehicle?

In Brazil, most vehicles are designed to operate on ethanol or gasoline or any combination of the two. In this South American country, ethanol is made from sugarcane, is commonly available, and is lower in price than gasoline. Compressed natural gas (CNG) is also being made available, so many vehicle manufacturers in Brazil, such as General Motors and Ford, are equipping vehicles to be capable of using gasoline, ethanol, or CNG. These vehicles are called tri-fuel vehicles.

BIODIESEL

Biodiesel is a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant greases. Biodiesel is safe, biodegradable, and reduces serious air pollutants such as particulate matter (PM), carbon monoxide, and hydrocarbons. Biodiesel is defined as mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats which conform to ASTM D6751 specifications for use in diesel engines. Biodiesel refers to the pure fuel before blending with diesel fuel. See Figure 52–27.

Biodiesel blends are denoted as "BXX" with "XX" representing the percentage of biodiesel contained in the blend (i.e., **B20** is 20% biodiesel, 80% petroleum diesel). Blends of 20% biodiesel with 80% petroleum diesel (B20) can generally be used in unmodified diesel engines; however, users should consult their OEM and engine warranty statement. Biodiesel can also be used in its pure form (B100), but it may require certain engine modifications to avoid maintenance and performance problems and may not be suitable for wintertime use. Users should consult their engine warranty statement for more information on fuel blends of greater than 20% biodiesel.

In general, B20 costs 30 to 40 cents more per gallon than conventional diesel. Although biodiesel costs more than regular diesel fuel, often called **petrodiesel,** fleet managers can make the switch to alternative fuels without purchasing new vehicles, acquiring new spare parts inventories, rebuilding refueling stations, or hiring new service technicians. Biodiesel has the following characteristics:

1. Purchasing biodiesel in bulk quantities decreases the cost of fuel.
2. Biodiesel maintains similar horsepower, torque, and fuel economy.
3. Biodiesel has a higher cetane number than conventional diesel, which increases the engine's performance.
4. Biodiesel has a high flash point and low volatility so it does not ignite as easily as petrodiesel, which increases the margin of safety in fuel handling. In fact, it degrades four times faster than petrodiesel and is not particularly soluble in water.
5. It is nontoxic, which makes it safe to handle, transport, and store. Maintenance requirements for B20 vehicles and petrodiesel vehicles are the same. B100 does pose a few concerns, however.
6. Biodiesel acts as a lubricant and this can add to the life of the fuel system components.

Alternate Fuel Comparison Chart

Characteristic	Propane	CNG	Methanol	Ethanol	Regular Unleaded Gas
Octane	104	130	100	100	87–93
BTU per gallon	91,000	NA	70,000	83,000	114,000–125,000
Gallon equivalent	1.15	122 cubic feet—1 gallon of gasoline	1.8	1.5	1
On-board fuel storage	Liquid	Gas	Liquid	Liquid	Liquid
Miles/gallon as compared to gas	85%	NA	55%	70%	100%
Relative tank size required to yield driving range equivalent to gas	Tank is 1.25 times larger	Tank is 3.5 times larger	Tank is 1.8 times larger	Tank is 1.5 times larger	
Pressure	200 PSI	3000–3600 PSI	NA	NA	NA
Cold weather capability	Good	Good	Poor	Poor	Good
Vehicle power	5–10% power loss	10–20% power loss	4% power increase	5% power increase	Standard
Toxicity	Nontoxic	Nontoxic	Highly toxic	Toxic	Toxic
Corrosiveness	Noncorrosive	Noncorrosive	Corrosive	Corrosive	Minimally corrosive
Source	Natural gas/petroleum refining	Natural gas/crude oil	Natural gas/coal	Sugar and starch crops/biomass	Crude oil

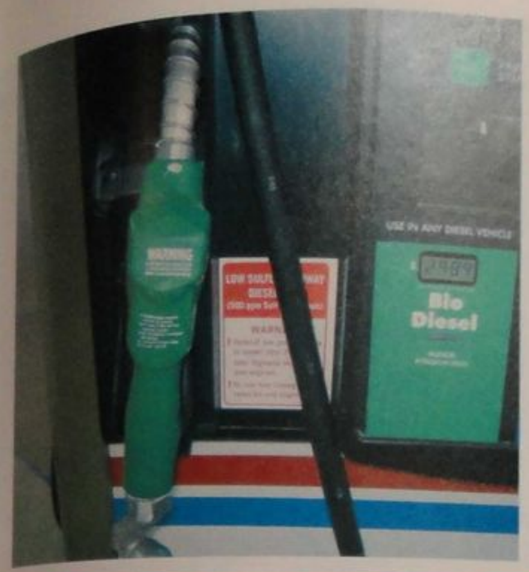


Figure 52–27 Biodiesel is available at few locations.

FREQUENTLY ASKED QUESTION ???

I Thought Biodiesel Was Vegetable Oil?

Biodiesel is vegetable oil with the glycerin component removed by means of reacting the vegetable oil with a catalyst. The resulting hydrocarbon esters are 16 to 18 carbon atoms in length, almost identical to the petroleum diesel fuel atoms. This allows the use of biodiesel fuel in a diesel engine with no modifications needed. Biodiesel-powered vehicles do not *need* a second fuel tank, whereas vegetable-oil-powered vehicles do.

There are three main types of fuel used in diesel engines. These are:

- Petroleum diesel, a fossil hydrocarbon with a carbon chain length of about 16 carbon atoms.
- Biodiesel, a hydrocarbon with a carbon chain length of 16 to 18 carbon atoms.
- Vegetable oil, a triglyceride with a glycerin component joining three hydrocarbon chains of 16 to 18 carbon atoms each, called **straight vegetable oil (SVO).** Other terms used when describing vegetable oil include:
  - **Pure plant oil (PPO)**—a term most often used in Europe to describe SVO
  - **Waste vegetable oil (WVO)**—this oil could include animal or fish oils from cooking
  - **Used cooking oil (UCO)**—a term used when the oil may or may not be pure vegetable oil

Vegetable oil is not liquid enough at common ambient temperatures for use in a diesel engine fuel delivery system designed for the lower-viscosity petroleum diesel fuel. Vegetable oil needs to be heated to obtain a similar viscosity to biodiesel and petroleum diesel. This means that a heat source needs to be provided before the fuel can be used in a diesel engine. This is achieved by starting on petroleum diesel or biodiesel fuel until the engine heat can be used to sufficiently warm a tank containing the vegetable oil. It also requires purging the fuel system of vegetable oil with petroleum diesel or biodiesel fuel prior to stopping the engine to avoid the vegetable oil thickening and solidifying in the fuel system away from the heated tank. The use of vegetable oil in its natural state does, however, eliminate the need to remove the glycerin component. Many vehicle and diesel engine fuel system suppliers permit the use of biodiesel fuel that is certified as meeting testing standards. None permit the use of vegetable oil in its natural state.

NOTE: For additional information on biodiesel and the locations where it can be purchased, go to visit www.biodiesel.org.

E-DIESEL FUEL

E-diesel, also called **diesohol** outside of the United States, is standard No. 2 diesel fuel that contains up to 15% ethanol. While E-diesel can have up to 15% ethanol by volume, typical blend levels are from 8% to 10%.

Cetane Rating The higher the cetane number, the shorter the delay between injection and ignition. Normal diesel fuel has a cetane number of about 50. Adding 15% ethanol lowers the cetane number. To increase the cetane number back to that of conventional diesel fuel, a cetane-enhancing additive is added to E-diesel. The additive used to increase the **cetane rating** of E-diesel is ethylhexylnitrate or ditertbutyl peroxide.

The flash point is the minimum temperature at which the fuel will ignite (flash). E-diesel has a higher flash point compared to conventional diesel fuel and is therefore safer to handle.

E-diesel has better cold-flow properties than conventional diesel. The heat content of E-diesel is about 6% less than conventional diesel, but the particulate matter (PM) emissions are reduced by as much as 40%, 20% less carbon monoxide, and a 5% reduction in oxides of nitrogen (NO_X).

Currently, E-diesel is considered to be experimental and can be used legally in off-road applications or in mass-transit buses with EPA approval. For additional information, go to *www.e-diesel.org.*

FREQUENTLY ASKED QUESTION ???

How Long Can Oxygenated Fuel Be Stored Before All of the Oxygen Escapes?

The oxygen in oxygenated fuels, such as E-10, E-85, and E-diesel, is not in a gaseous state like the CO_2 in soft drinks. The oxygen is part of the molecule of ethanol or other oxygenates and does not bubble out of the fuel. Oxygenated fuels, just like any fuel, have a shelf life of about 90 days.

SYNTHETIC FUELS

Synthetic fuels were first developed using the Fischer-Tropsch method and have been in use since the 1920s to convert coal, natural gas, and other fossil fuel products into a fuel that is high in quality and clean-burning. The process for producing Fischer-Tropsch fuels was patented by two German scientists, Franz Fischer and Hans Tropsch, during World War I. The Fischer-Tropsch method uses carbon monoxide and hydrogen (the same synthesis gas used to produce hydrogen fuel) to convert coal and other hydrocarbons to liquid fuels in a process similar to hydrogenation, another method for hydrocarbon conversion. The process using natural gas, also called **gas-to-liquid (GTL)** technology, uses a catalyst, usually iron or cobalt, and incorporates steam reforming to give off the by-products of carbon dioxide, hydrogen, and carbon monoxide.

Whereas traditional fuels emit environmentally harmful particulates and chemicals, namely sulfur compounds, Fischer-Tropsch fuels combust with no soot or odors and emit only low levels of toxins. Fischer-Tropsch fuels can also be blended with traditional transportation fuels with little equipment modification, as they use the same engine and equipment technology as traditional fuels.

The fuels contain a very low sulfur and aromatic content and they produce virtually no particulate emissions. Researchers also expect reductions in hydrocarbon and carbon monoxide emissions. Fischer-Tropsch fuels do not differ in fuel performance from gasoline and diesel. At present, Fischer-Tropsch fuels are very expensive to produce on a large scale, although research is under way to lower processing costs. Diesel fuel created using the **Fischer-Tropsch diesel (FTD)** process is often called **GTL diesel.** GTL diesel can also be combined with petroleum diesel to produce a GTL blend. This fuel product is currently being sold in Europe and plans are in place to introduce it in North America.

Coal to Liquid (CTL) Coal is very abundant in the United States, and coal can be converted to a liquid fuel through a process called **coal to liquid (CTL).** The main obstacle to these CTL plants is the huge cost. The need to invest $1.4 billion per plant before the product can be made is the reason why no one has built a CTL plant yet in the United States. Investors need to be convinced that the cost of oil is going to remain high in order to get them to commit this kind of money.

A large plant might be able to produce 120,000 barrels of liquid fuel a day and would consume about 50,000 tons of coal per day. However, such a plant would create about 6,000 tons of CO_2 per day. These CO_2 emissions and the cost involved make CTL a new technology that is not likely to expand.

Two procedures can be used to convert coal to a liquid fuel:

1. **Direct**—In the direct method, coal is broken down to create liquid products. First the coal is reacted with hydrogen (H_2) at high temperatures and pressure with a catalyst. This process creates a synthetic crude, called **syncrude,** which is then refined to produce gasoline or diesel fuel.
2. **Indirect**—In the indirect method, coal is first turned into a gas and the molecules are reassembled to create the desired product. This process involves turning coal into a gas called syngas. The syngas is then converted into liquid, using the Fischer-Tropsch (FT) process.

Russia has been using CTL by injecting air into the underground coal seams. Ignition is provided and the resulting gases are trapped and converted to liquid gasoline and diesel fuel through the Fischer-Tropsch process. This underground method is called **underground coal gasification (UCG).** See Figure 52–28.

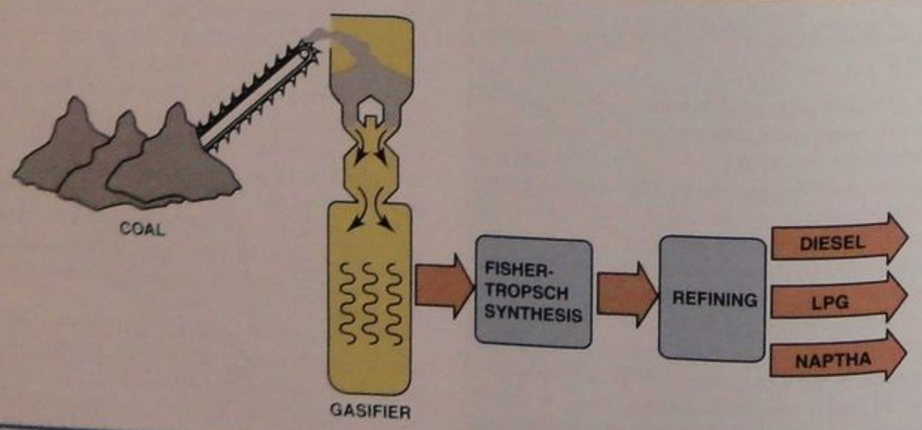


Figure 52–28 A typical coal-to-liquid plant.

Methanol to Gasoline Exxon Mobil has developed a process for converting methanol (methyl alcohol) into gasoline in a process called **methanol-to-gasoline (MTG).** The MTG process was discovered by accident when a gasoline additive made from methanol was being created. The process instead created olefins (alkenes), paraffins (alkenes), and aromatic compounds, which in combination are known as gasoline. The process uses a catalyst and is currently being produced in New Zealand.

Future of Synthetic Fuels Producing gasoline and diesel fuels by other methods besides refining from crude oil has usually been more expensive. With the increasing cost of crude oil, alternative methods are now becoming economically feasible. Whether or not the diesel fuel or gasoline is created from coal, natural gas, or methanol, or created by refining crude oil, the transportation and service pumps are already in place. Compared to using compressed natural gas or other similar alternative fuels, synthetic fuels represent the lowest cost.

SAFETY PROCEDURES WHEN WORKING WITH ALTERNATIVE FUEL VEHICLES

All fuels are flammable and many are explosive under certain conditions. Whenever working around compressed gases of any kind (CNG, LNG, propane, or LPG), always wear personal protective equipment (PPE), including at least the following items:

1. Safety glasses and/or face shield.
2. Protective gloves.
3. Long-sleeved shirt and pants to help protect exposed skin from the freezing effects of gases under pressure in the event that the pressure is lost.
4. If any fuel gets on the skin, the area should be washed immediately.
5. If fuel spills on clothing, change into clean clothing as soon as possible.
6. If fuel spills on a painted surface, flush the surface with water and air-dry. If simply wiped off with a dry cloth, the paint surface could be permanently damaged.
7. As with any fuel-burning vehicle, always vent the exhaust to the outside. If methanol fuel is used, the exhaust contains **formaldehyde,** which has a sharp odor and can cause severe burning of the eyes, nose, and throat.

WARNING: Do not smoke or have an open flame in the area when working around or refueling any vehicle.

PHOTO SEQUENCE Testing for Alcohol Content in Gasoline



P52–1 A fuel composition tester is the recommended tool to use to test the alcohol content of gasoline.



P52–2 This battery-powered tester uses light-emitting diodes (LEDs), meter lead terminals, and two small openings for the fuel sample.



P52–3 The first step is to verify the proper operation of the tester by measuring the air frequency by selecting AC hertz on the meter. The air frequency should be between 35 Hz and 48 Hz.



P52–4 After verifying that the tester is capable of correctly reading the air frequency, gasoline is poured into the testing cell of the tool.



P52–5 Record the AC frequency as shown on the meter and subtract 50 from the reading. (e.g., 60.50 − 50.00 = 10.5). This number (10.5) is the percentage of alcohol in the gasoline sample.



P52–6 Adding additional amounts of ethyl alcohol (ethanol) increases the frequency reading.

SUMMARY

1. Gasoline is a complex blend of hydrocarbons. Gasoline is blended for seasonal usage to achieve the correct volatility for easy starting and maximum fuel economy under all driving conditions.
2. Winter-blend fuel used in a vehicle during warm weather can cause a rough idle and stalling because of its higher Reid vapor pressure (RVP).
3. Abnormal combustion (also called detonation or spark knock) increases both the temperature and the pressure inside the combustion chamber.
4. Most regular-grade gasoline today, using the (R + M) ÷ 2 rating method, is 87 octane; midgrade (plus) is 89 and premium grade is 91 or higher.
5. Oxygenated fuels contain oxygen to lower CO exhaust emissions.
6. Gasoline should always be purchased from a busy station, and the tank should not be overfilled.
7. Flexible fuel vehicles are designed to operate on gasoline or gasoline-ethanol blends up to 85% ethanol.

REVIEW QUESTIONS

1. What is the difference between summer-blend and winter-blend gasoline?
2. What is Reid vapor pressure?
3. What is vapor lock?
4. What does the (R + M) ÷ 2 gasoline pump octane rating indicate?
5. What are five octane improvers that may be used during the refining process?
6. What is the stoichiometric ratio?

CHAPTER QUIZ

1. Winter-blend gasoline _____.
   a. Vaporizes more easily than summer-blend gasoline
   b. Has a higher RVP
   c. Can cause engine driveability problems if used during warm weather
   d. All of the above
2. Vapor lock can occur _____.
   a. As a result of excessive heat near fuel lines
   b. If a fuel line is restricted
   c. During both a and b
   d. During neither a nor b
3. Technician A says that spark knock, ping, and detonation are different names for abnormal combustion. Technician B says that any abnormal combustion raises the temperature and pressure inside the combustion chamber and can cause severe engine damage. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

4. Technician A says that the research octane number is higher than the motor octane number. Technician B says that the octane rating posted on fuel pumps is an average of the two ratings. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that in going to high altitudes, engines produce lower power. Technician B says that most engine control systems can compensate the air–fuel mixture for changes in altitude. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. When refueling a CNG vehicle, why is it recommended that the tank be filled to a high pressure?
   a. The range of the vehicle is increased
   b. The cost of the fuel is lower
   c. Less of the fuel is lost to evaporation
   d. Both a and c
7. The use of premium high-octane gasoline in an engine designed to use regular-grade gasoline will increase engine power.
   a. True
   b. False
8. To avoid problems with the variation of gasoline, all government testing uses _____ as a fuel during testing procedures.
   a. MTBE (methyl tertiary butyl ether)
   b. Indolene
   c. Xylene
   d. TBA (tertiary butyl alcohol)
9. Avoid topping off the fuel tank because _____.
   a. It can saturate the charcoal canister
   b. The extra fuel simply spills onto the ground
   c. The extra fuel increases vehicle weight and reduces performance
   d. The extra fuel goes into the expansion area of the tank and is not used by the engine
10. Using ethanol-enhanced or reformulated gasoline can result in reduced fuel economy.
    a. True
    b. False

CHAPTER 53 Computer and Network Fundamentals

OBJECTIVES: After studying Chapter 53, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain the purpose and function of onboard computers. • List the various parts of an automotive computer. • List five input sensors. • List four devices controlled by the computer (output devices).

KEY TERMS: actuator • analog-to-digital (AD) converter • binary • central processing unit (CPU) • clock generator • controller • controller area network (CAN) • digital • duty cycle • EEPROM • E² PROM • electronic control assembly (ECA) • electronic control module (ECM) • electronic control unit (ECU) • engine mapping • high-side drivers (HSD) • input conditioning • keep-alive memory (KAM) • low-side drivers (LSD) • multiplexing • network • nonvolatile RAM • output drivers • power train control module (PCM) • programmable read-only memory (PROM) • random-access memory (RAM) • read-only memory (ROM) • serial data • splice pack • terminating resistors • volatile

COMPUTER CONTROL

Modern automotive control systems consist of a network of electronic sensors, actuators, and computer modules designed to regulate the power train and vehicle support systems. The **power train control module (PCM)** is the heart of this system. It coordinates engine and transmission operation, processes data, maintains communications, and makes the control decisions needed to keep the vehicle operating.

Automotive computers use voltage to send and receive information. Voltage is electrical pressure and does not flow through circuits, but voltage can be used as a signal. A computer converts input information or data into voltage signal combinations that represent number combinations. The number combinations can represent a variety of information—temperature, speed, or even words and letters. A computer processes the input voltage signals it receives by computing what they represent, and then delivering the data in computed or processed form.

THE FOUR BASIC COMPUTER FUNCTIONS

The operation of every computer can be divided into four basic functions. See Figure 53–1.

- Input
- Processing
- Storage
- Output

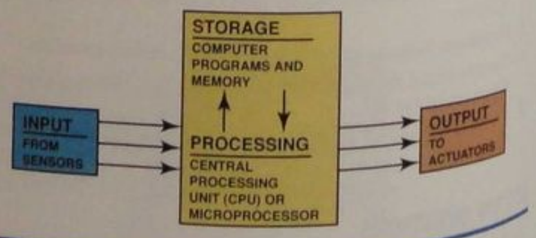


Figure 53–1 All computer systems perform four basic functions: input, processing, storage, and output.

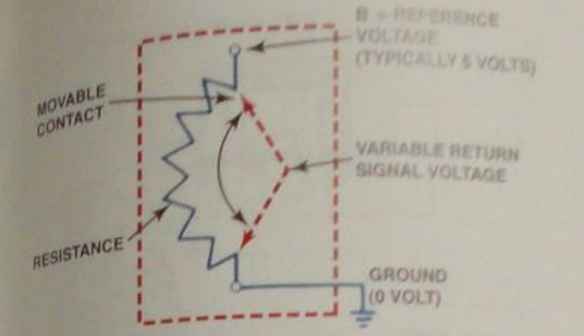


Figure 53–2 A potentiometer uses a movable contact to vary resistance and send an analog voltage right to the PCM.

These basic functions are not unique to computers; they can be found in many noncomputer systems. However, we need to know how the computer handles these functions.

Input First, the computer receives a voltage signal (input) from an input device. The device can be as simple as a button or a switch on an instrument panel, or a sensor on an automotive engine. See Figure 53–2 for a typical type of automotive sensor.

Vehicles use various mechanical, electrical, and magnetic sensors to measure factors such as vehicle speed, engine RPM, air pressure, oxygen content of exhaust gas, airflow, and engine coolant temperature. Each sensor transmits its information in the form of voltage signals. The computer receives these voltage signals, but before it can use them, the signals must undergo a process called **input conditioning.** This process includes amplifying voltage signals that are too small for the computer circuitry to handle. Input conditioners generally are located inside the computer, but a few sensors have their own input-conditioning circuitry.

Processing Input voltage signals received by a computer are processed through a series of electronic logic circuits maintained in its programmed instructions. These logic circuits change the input voltage signals, or data, into output voltage signals or commands.

Storage The program instructions for a computer are stored in electronic memory. Some programs may require that certain input data be stored for later reference or future processing. In others, output commands may be delayed or stored before they are transmitted to devices elsewhere in the system.

Computers have two types of memory: permanent and temporary. Permanent memory is called **read-only memory (ROM)** because the computer can only read the contents; it cannot change the data stored in it. This data is retained even when power to the computer is shut off. Part of the ROM is built into the computer, and the rest is located in an IC chip called a **programmable read-only memory (PROM)** or calibration assembly. See Figure 53–3. Many chips are erasable, meaning that the program can be changed. These chips are called erasable programmable read-only memory or EPROM. Since the early 1990s most programmable memory has been electronically erasable, meaning that the program in the chip can be reprogrammed by using a scan tool and the proper software. This computer reprogramming is usually called *reflashing*. These chips are electrically erasable programmable read-only memory, abbreviated **EEPROM** or **E²PROM.**



Figure 53–3 A replaceable PROM used in an older General Motors computer. Notice that the sealed access panel has been removed to gain access.

All vehicles equipped with onboard diagnosis second generation, called OBD II, are equipped with EEPROMs.

Temporary memory is called **random-access memory (RAM)** because the microprocessor can write or store new data into it as directed by the computer program, as well as read the data already in it. Automotive computers use two types of RAM memory: **volatile** and **nonvolatile.** Volatile RAM memory is lost whenever the ignition is turned off. However, a type of volatile RAM called **keep-alive memory (KAM)** can be wired directly to battery power. This prevents its data from being erased when the ignition is turned off. Both RAM and KAM have the disadvantage of losing their memory when disconnected from their power source. One example of RAM and KAM is the loss of station settings in a programmable radio when the battery is disconnected. Since all the settings are stored in RAM, they have to be reset when the battery is reconnected. System trouble codes are commonly stored in RAM and can be erased by disconnecting the battery.

Nonvolatile RAM memory can retain its information even when the battery is disconnected. One use for this type of RAM is the storage of odometer information in an electronic speedometer. The memory chip retains the mileage accumulated by the vehicle. When speedometer replacement is necessary, the odometer chip is removed and installed in the new speedometer unit. KAM is used primarily in conjunction with adaptive strategies.

Output After the computer has processed the input signals, it sends voltage signals or commands to other devices in the system, such as system actuators. An **actuator** is an electrical or mechanical device that converts electrical energy into heat, light, or motion, such as adjusting engine idle speed, altering suspension height, or regulating fuel metering.

Computers also can communicate with, and control, each other through their output and input functions. This means that the output signal from one computer system can be the input signal for another computer system through a network.

Most outputs work electrically in one of three ways:

- Switched
- Pulse width modulated
- Digital

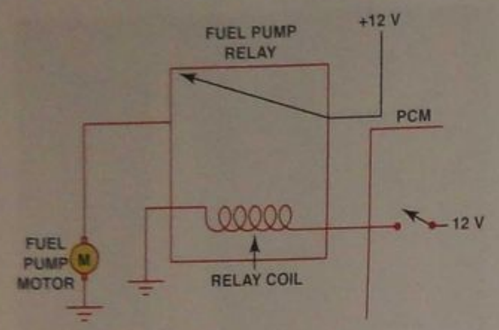


Figure 53–4 A typical output driver. In this case, the PCM applies voltage to the fuel pump relay coil to energize the fuel pump.

A switched output is an output that is either on or off. In many circuits, the PCM uses a relay to switch a device on or off. This is because the relay is a low-current device that can switch a higher-current device. Most computer circuits cannot handle a lot of current. By using a relay circuit as shown in Figure 53–4, the PCM provides the output control to the relay, which in turn provides the output control to the device. The relay coil, which the PCM controls, typically draws less than 0.5 amps. The device that the relay controls may draw 30 amps or more. These switches are actually transistors, often called **output drivers.**

Low-Side Drivers **Low-side drivers,** often abbreviated **LSD,** are transistors that complete the ground path in the circuit. Ignition voltage is supplied to the relay as well as battery voltage. The computer output is connected to the ground side of the relay coil. The computer energizes the fuel pump relay by turning the transistor on and completing the ground path for the relay coil. A relatively low current flows through the relay coil and transistor that is inside the computer. This causes the relay to switch and provides the fuel pump with battery voltage. The majority of switched outputs have typically been low-side drivers. See Figure 53–5. Low-side drivers can often perform a diagnostic circuit check by monitoring the voltage from the relay to check that the control circuit for the relay is complete. A low-side driver, however, cannot detect a short-to-ground.

High-Side Drivers **High-side drivers,** often abbreviated **HSD,** control the power side of the circuit. In these applications when the transistor is switched on, voltage is applied to the device. A ground has been provided to the device so when the high-side driver switches the device will be energized. In some applications, high-side drivers are used instead of low-side drivers to provide better circuit protection. General Motors vehicles have used a high-side driver to control the fuel pump relay instead of a low-side driver. In the event of an accident, should the circuit to the fuel pump relay become grounded, a high-side driver would cause a short circuit, which would cause the fuel pump relay to de-energize. High-side drivers inside modules can detect electrical faults such as a lack of continuity when the circuit is not energized. See Figure 53–6.

Pulse Width Modulation Pulse width modulation (PWM) is a method of controlling an output using a digital signal. Instead of just turning devices on or off, the computer can control output devices more precisely by using pulse width modulation. For example, a vacuum solenoid could be a pulse width modulated device. If the vacuum solenoid is controlled by a switched driver, switching either on or off would mean that either full vacuum would flow through the solenoid or no vacuum would flow through the solenoid. However, to

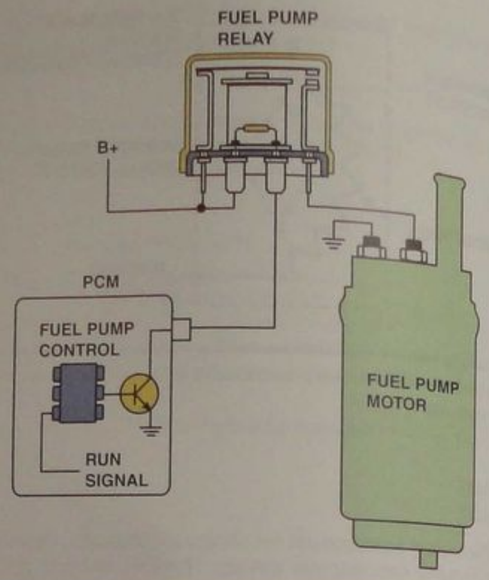


Figure 53–5 A typical low-side driver (LSD) which uses a control module to control the ground side of the relay coil.

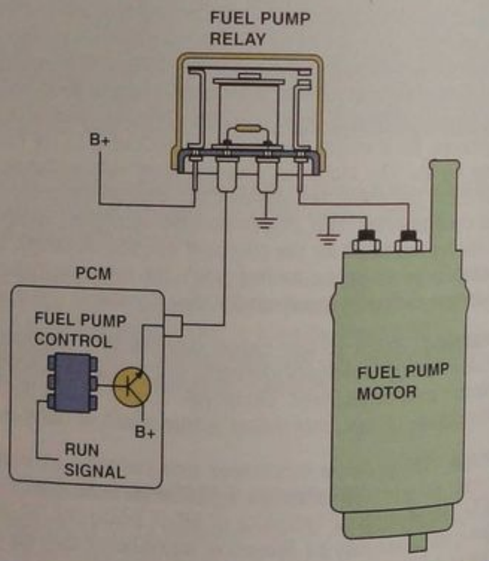


Figure 53–6 A typical module-controlled high-side driver (HSD) where the module itself supplies the electrical power to the device. The logic circuit inside the module can detect circuit faults including continuity of the circuit and if there is a short-to-ground in the circuit being controlled.

control the amount of vacuum that flows through the solenoid, pulse width modulation could be used. A PWM signal is a digital signal, usually 0 volts and 12 volts, that is cycling at a fixed frequency. Varying the length of time that the signal is on, provides a signal that can vary the on and off time of an output. The ratio of on-time relative to the period of the cycle is referred to as **duty cycle.** See Figure 53–7. Depending on the frequency of the signal, which is usually fixed, this signal would turn the device on and off a fixed number of times per second. When, for example, the voltage is high (12 volts) 90% of the time and low (0 volts) the other 10% of the time, the signal has a

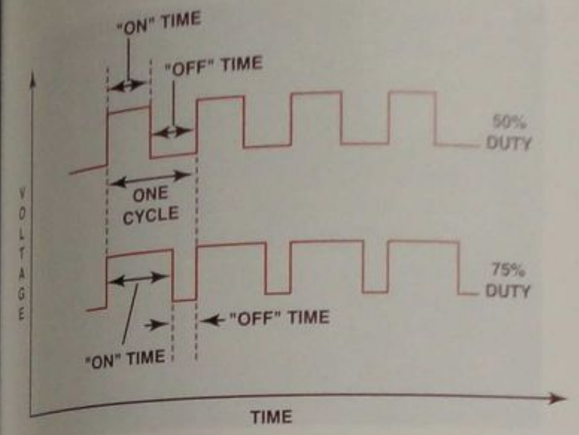


Figure 53–7 Both the top and bottom pattern have the same frequency. However, the amount of on-time varies. Duty cycle is the percentage of the time during a cycle that the signal is turned on.

90% duty cycle. In other words, if this signal were applied to the vacuum solenoid, the solenoid would be on 90% of the time. This would allow more vacuum to flow through the solenoid. The computer has the ability to vary this on and off time or pulse width modulation at any rate between 0 and 100%.

A good example of pulse width modulation is the cooling fan speed control. The speed of the cooling fan is controlled by varying the amount of on-time that the battery voltage is applied to the cooling fan motor.

100% duty cycle—the fan runs at full speed
75% duty cycle—the fan runs at 3/4 speed
50% duty cycle—the fan runs at 1/2 speed
25% duty cycle—the fan runs at 1/4 speed

The use of PWM, therefore, results in very precise control of an output device to achieve the amount of cooling needed and conserve electrical energy compared to simply timing the cooling fan on high when needed. PWM may be used to control vacuum through a solenoid, the amount of purge of the evaporative purge solenoid, the speed of a fuel pump motor, control of a linear motor, or even the intensity of a light bulb.

DIGITAL COMPUTERS

In a **digital** computer, the voltage signal or processing function is a simple high/low, yes/no, on/off signal. The digital signal voltage is limited to two voltage levels: high voltage and low voltage. Since there is no stepped range of voltage or current in between, a digital binary signal is a "square wave."

The signal is called "digital" because the on and off signals are processed by the computer as the digits or numbers 0 and 1. The number system containing only these two digits is called the **binary** system. Any number or letter from any number system or language alphabet can be translated into a combination of binary 0s and 1s for the digital computer.

A digital computer changes the analog input signals (voltage) to digital bits (*b*inary digi*ts*) of information through an **analog-to-digital (AD) converter** circuit. The binary digital number is used by the computer in its calculations or logic networks. Output signals usually are digital signals that turn system actuators on and off.



Figure 53–8 Many electronic components are used to construct a typical vehicle computer. Notice the quantity of chips, resistors, and capacitors used in this General Motors computer.

The digital computer can process thousands of digital signals per second because its circuits are able to switch voltage signals on and off in billionths of a second. See Figure 53–8.

Parts of a Computer The software consists of the programs and logic functions stored in the computer's circuitry. The hardware is the mechanical and electronic parts of a computer.

Central Processing Unit (CPU) The microprocessor is the **central processing unit (CPU)** of a computer. Since it performs the essential mathematical operations and logic decisions that make up its processing function, the CPU can be considered the heart of a computer. Some computers use more than one microprocessor, called a coprocessor.

Computer Memory Other IC devices store the computer operating program, system sensor input data, and system actuator output data, information that is necessary for CPU operation.

Computer Programs By operating a vehicle on a dynamometer and manually adjusting the variable factors such as speed, load, and spark timing, it is possible to determine the optimum output settings for the best driveability, economy, and emission control. This is called **engine mapping.** See Figure 53–9.

Engine mapping creates a three-dimensional performance graph that applies to a given vehicle and power train combination. Each combination is mapped in this manner to produce a PROM. This allows an automaker to use one basic computer for all models; a unique PROM individualizes the computer for a particular model. Also, if a driveability problem can be resolved by a change in the program, the manufacturers can release a revised PROM to supersede the earlier part.

Many older vehicle computers used a single PROM that plugged into the computer. See Figure 53–10. Some Ford computers used a larger "calibration module" that contained the system PROM.

NOTE: If the onboard computer needs to be replaced, the PROM or calibration module must be removed from the defective unit and installed in the replacement computer. Since the mid-1990s, computers must be programmed or *flashed* before being put into service.

Clock Rates and Timing The microprocessor receives sensor input voltage signals, processes them by using information from

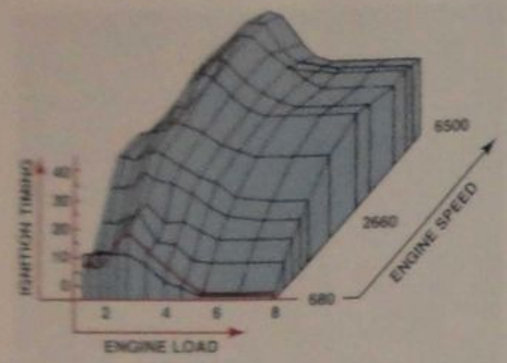


Figure 53–9 Typical ignition timing map developed from testing and used by the vehicle computer to provide the optimum ignition timing for all engine speeds and load combinations.

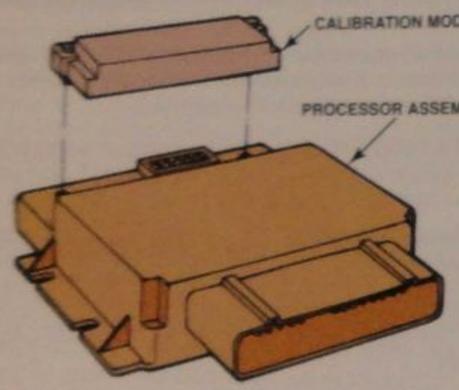


Figure 53–10 The calibration module on many Ford computers contains a system PROM.

other memory units, and then sends voltage signals to the appropriate actuators. The microprocessor communicates by transmitting long strings of 0s and 1s in a language called binary code. But the microprocessor must have some way of knowing when one signal ends and another begins. That is the job of a crystal oscillator called a **clock generator.** See Figure 53–11. The computer's crystal oscillator generates a steady stream of one-bit-long voltage pulses. Both the microprocessor and the memories monitor the clock pulses while they are communicating. Because they know how long each voltage pulse should be, they can distinguish between a 0 and a 1. To complete the process, the input and output circuits also watch the clock pulses.

Computer Speeds Not all computers operate at the same speed; some are faster than others. The speed at which a computer operates is specified by the cycle time, or clock speed, required to perform certain measurements. Cycle time or clock speed is measured in megahertz (4.7 MHz, 8.0 MHz, 15 MHz, 18 MHz, etc.).

Baud Rate The computer transmits bits of a serial data stream at precise intervals. The computer's processing speed is called the baud rate, or bits per second. Just as mph helps in estimating the length of time required to travel a certain distance, the baud rate is useful in estimating how long a given computer will need to transmit a specified amount of data to another computer. Storage of a single character requires eight bits per byte, plus an additional two

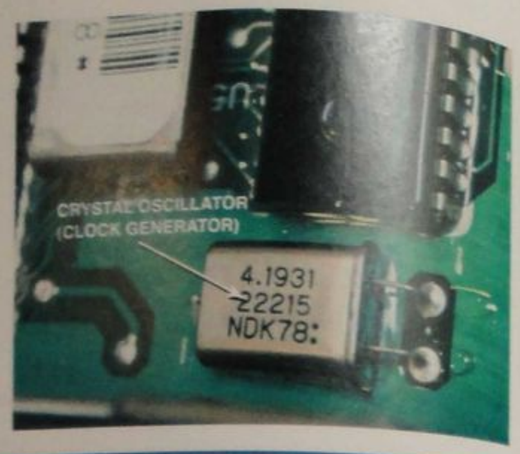


Figure 53–11 The clock generator produces a series of pulses that are used by the microprocessor and other components to stay in step with each other at a steady rate.

bits to indicate stop and start. This means that transmission of one character requires 10 bits. Dividing the baud rate by 10 tells us the maximum number of words per second that can be transmitted. For example, if the computer has a baud rate of 600, approximately 60 words can be received or sent per minute.

Automotive computers have evolved from a baud rate of 160 used in the early 1980s to a baud rate as high as 500,000 for some networks. The speed of data transmission is an important factor both in system operation and in system troubleshooting.

Control Module Locations The onboard automotive computer has many names. It may be called an **electronic control unit (ECU), electronic control module (ECM), electronic control assembly (ECA),** or a **controller,** depending on the manufacturer and the computer application. The Society of Automotive Engineers (SAE) bulletin, J-1930, standardizes the name as a power train control module (PCM). The computer hardware is all mounted on one or more circuit boards and installed in a metal case to help shield it from electromagnetic interference (EMI). The wiring harnesses that link the computer to sensors and actuators connect to multipin connectors or edge connectors on the circuit boards.

Onboard computers range from single-function units that control a single operation to multifunction units that manage all of the separate (but linked) electronic systems in the vehicle. They vary in size from a small module to a notebook-sized box. Most other engine computers are installed in the passenger compartment either under the instrument panel or in a side kick panel where they can be shielded from physical damage caused by temperature extremes, dirt, and vibration, or interference by the high currents and voltages of various underhood systems. See Figures 53–12 and 53–13.

COMPUTER INPUT SENSORS

The vehicle computer uses the signals (voltage levels) from the following engine sensors:

- **Engine speed (RPM or revolutions per minute) sensor.** This signal comes from the primary signal in the ignition module.
- **MAP (manifold absolute pressure) sensor.** This sensor detects engine load. The computer uses this information for fuel delivery and for onboard diagnosis of other sensors and systems such as the exhaust gas recirculation (EGR) system.



Figure 53–12 This power train control module (PCM) is located under the hood on this Chevrolet pickup truck.



Figure 53–13 This PCM on a Chrysler vehicle can only be seen by hoisting the vehicle because it is located next to the radiator, and in the airflow to help keep it cool.

- **MAF (mass airflow) sensor.** This sensor measures the mass (weight and density) of the air entering the engine. The computer uses this information to determine the amount of fuel needed by the engine.
- **ECT (engine coolant temperature) sensor.** This sensor measures the temperature of the engine coolant needed by the computer to determine the amount of fuel and spark advance. This is a major sensor, especially when the engine is cold and when the engine is first started.
- **O2S (oxygen sensor).** This sensor measures the oxygen in the exhaust stream. These sensors are used for fuel control and to check other sensors and systems.
- **TP (throttle position) sensor.** This sensor measures the throttle opening and is used by the computer to control fuel delivery as well as spark advance and the shift points of the automotive transmission/transaxle.
- **VS (vehicle speed) sensor.** This sensor measures the vehicle speed using a sensor located at the output of the transmission/transaxle or by monitoring sensors at the wheel speed sensors.
- **Knock sensor.** The voltage signal from the knock sensor (KS) is sent to the PCM. The PCM retards the ignition timing until the knocking stops.

COMPUTER OUTPUTS

A vehicle computer can do just two things.

- Turn a device on.
- Turn a device off.

The computer can turn devices such as fuel injectors on and off very rapidly or keep them on for a certain amount of time. Typical output devices include the following.

- **Fuel injectors.** The computer can vary the amount of time the injectors are held open, thereby controlling the amount of fuel supplied to the engine.
- **Ignition timing.** The computer can trigger the signal to the ignition module to fire the spark plugs based on information from the sensors. The spark is advanced when the engine is cold and/or when the engine is operating under light load conditions.
- **Transmission shifting.** The computer provides a ground to the shift solenoids and torque converter clutch solenoid. The operation of the automatic transmission/transaxle is optimized based on vehicle sensor information.
- **Idle speed control.** The computer can pulse the idle speed control (ISC) or idle air control (IAC) device to maintain engine idle speed and to provide an increased idle speed when needed, such as when the air-conditioning system is operating.
- **Evaporative emission control solenoids.** The computer can control the flow of gasoline fumes from the charcoal canister to the engine and seal off the system to perform a fuel system leak detection test as part of the OBD II onboard diagnosis.

MODULE COMMUNICATION AND NETWORKS

Since the 1990s, vehicles use modules to control most of the electrical component operation. A typical vehicle will have 10 or more modules and they communicate with each other over data lines or hard wiring, depending on the application.

Serial Data **Serial data** is data that is transmitted by a series of rapidly changing voltage signals pulsed from low to high or from high to low. Most modules are connected together in a network because of the following advantages:

- A decreased number of wires is needed, thereby saving weight, cost, as well as helping with installation at the factory, and decreased complexity, making servicing easier.
- Common sensor data can be shared with those modules that may need the information, such as vehicle speed, outside air temperature, and engine coolant temperature.

Multiplexing **Multiplexing** is the process of sending multiple signals of information at the same time over a signal wire and then separating the signals at the receiving end. This system of intercommunication of computers or processors is referred to as a **network.** See Figure 53–14. By connecting the computers together on a communications network, they can easily share

information back and forth. This multiplexing has a number of advantages, including:

- The elimination of redundant sensors and dedicated wiring for these multiple sensors.
- The reduction of the number of wires, connectors, and circuits.
- Addition of more features and option content to new vehicles.
- Weight reduction, increasing fuel economy.
- Allows features to be changed with software upgrades instead of component replacement.

The three most common types of networks used on General Motors vehicles include:

1. **Ring link networks.** In a ring-type network, all modules are connected to each other by a serial data line in a line until all are connected in a ring. See Figure 53–15.

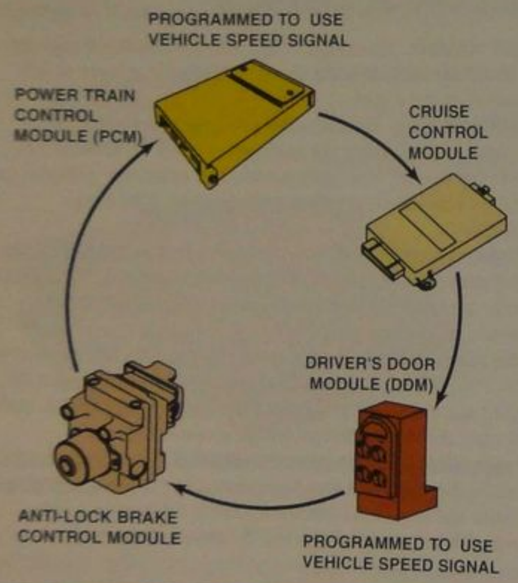


Figure 53–14 A network allows all modules to communicate with other modules.

2. **Star link.** In a star link network, a serial data line attaches to each module and then each is connected to a central point. This central point is called a **splice pack**, abbreviated SP such as in "SP 306." The splice pack uses a bar to splice all of the serial lines together. Some GM vehicles use two or more splice packs to tie the modules together. When more than one splice pack is used, a serial data line connects one splice pack to the others. In most applications the bus bar used in each splice pack can be removed. When the bus bar is removed a special tool (J 42236) can be installed in place of the removed bus bar. Using this tool, the serial data line for each module can be isolated and tested for a possible problem. Using the special tool at the splice pack makes diagnosing this type of network easier than many others. See Figure 53–16 for an example of a star link network system.
3. **Ring/Star hybrid.** In a ring/star network, the modules are connected using both types of network configuration. Check service information (SI) for details on how this network is connected on the vehicle being diagnosed and always follow the recommended diagnostic steps.

SAE COMMUNICATION CLASSIFICATIONS

The Society of Automotive Engineers (SAE) standards include three categories of in-vehicle network communications, including the following.

Class A Low-speed networks (less than 10,000 bits per second [10 kbs]) are generally used for trip computers, entertainment, and other convenience features. Most low-speed Class A communication functions are performed using the following:

- UART standard (Universal Asynchronous Receive/Transmit) used by General Motors (8192 bps).
- CCD (Chrysler Collision Detection) used by Chrysler (7812.5 bps).

NOTE: The "collision" in CCD-type bus communication refers to the program that avoids conflicts of information exchange within the bus, and does not refer to airbags or other accident-related circuits of the vehicle.

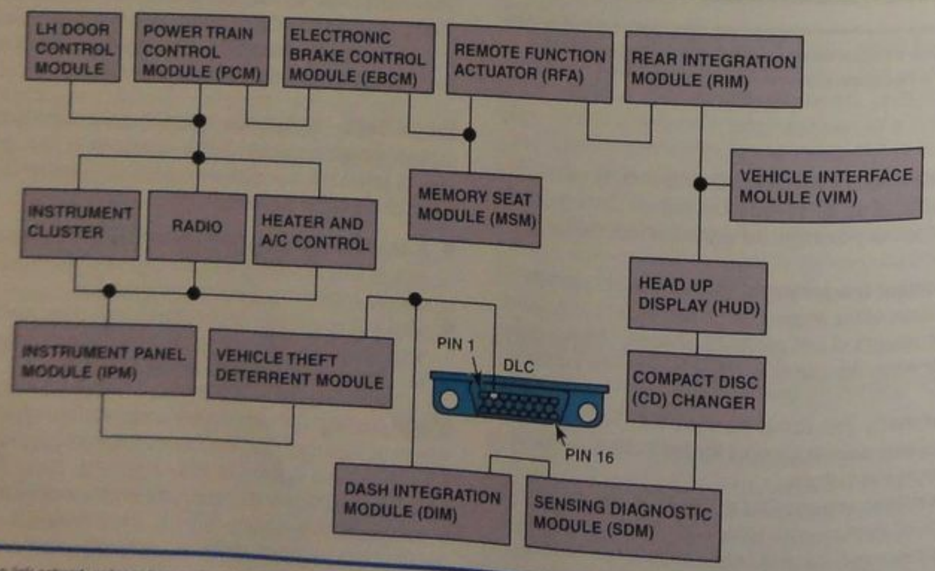


Figure 53–15 A ring link network reduces the number of wires it takes to interconnect all of the modules.

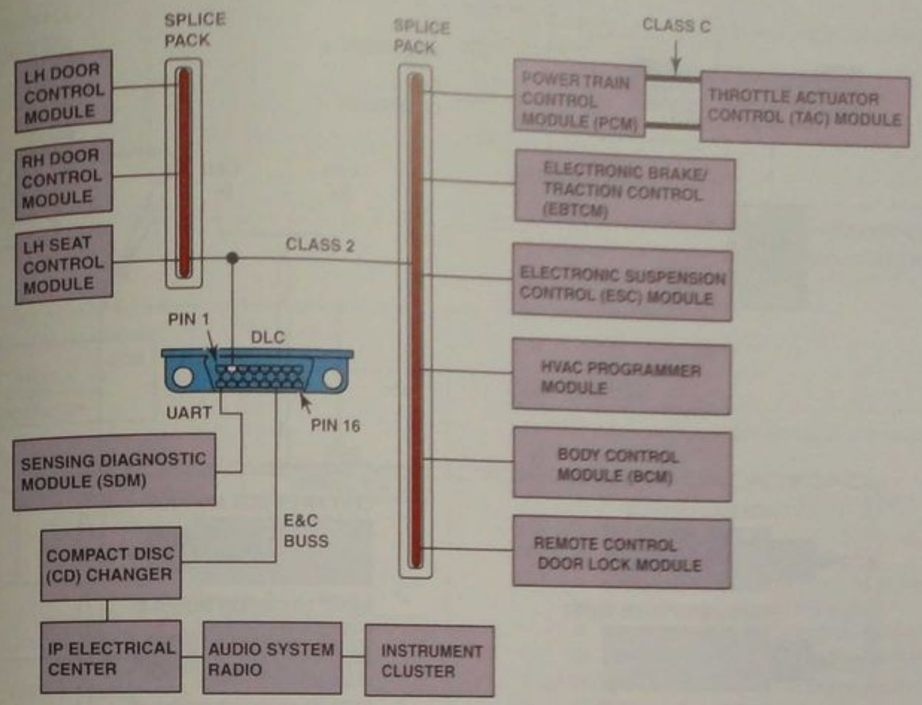


Figure 53–16 A star-link-type network where all of the modules are connected together using splice packs.

- Chrysler SCI (Serial Communications Interface) is used to communicate between the engine controller and a scan tool (62.5 kbps).
- ACP (Audio Control Protocol) is used for remote control of entertainment equipment (twisted pairs) on Ford vehicles.

Class B Medium-speed networks (10,000 to 125,000 bits per second [10 to 125 kbs]) are generally used for information transfer among modules, such as instrument clusters, temperature sensor data, and other general uses.

- General Motors GMLAN; both low- and medium-speed and Class 2, which uses 0-to 7-volt pulses with an available pulse width. Meets SAE 1850 variable pulse width (VPW).
- Chrysler Programmable Communication Interface (PCI). Meets SAE standard J-1850 pulse width modulated (PWM).
- Ford Standard Corporate Protocol (SCP). Meets SAE standard J-1850 pulse width modulated (PWM).

Class C High-speed networks (125,000 to 1,000,000 bits per second [125,000 to 1,000,000 kbs]) are generally used for real-time power train and vehicle dynamic control. Most high-speed bus communication is **controller area network** or **CAN.** See Figure 53–17.

FREQUENTLY ASKED QUESTION ???

What Is a Bus?

A bus is a term used to describe a communication network. Therefore, there are connections to the bus and *bus communications*, both of which refer to digital messages being transmitted among electronic modules or computers.

MODULE COMMUNICATION DIAGNOSIS

Most vehicle manufacturers specify that a scan tool be used to diagnose modules and module communications. Always follow the recommended testing procedures, which usually require the use of a factory scan tool.

Some tests of the communication bus (network) and some of the service procedures require the service technician to attach a DMM, set to DC volts, to monitor communications. A variable voltage usually indicates that messages are being sent and received.

Most high-speed bus systems use resistors at each end called **terminating resistors.** These resistors are used to help reduce interference into other systems in the vehicle.

Usually two 120-ohm resistors are installed at each end and are therefore connected electrically in parallel. Two 120-ohm resistors connected in parallel would measure 60 ohms if being tested using an ohmmeter. See Figure 53–18.

OBD II DATA LINK CONNECTOR

All OBD II vehicles use a 16-pin connector that includes: See Figure 53–19 on page 615.

Pin 4 = chassis ground

Pin 5 = signal ground

Pin 16 = battery power (4A max)

Vehicles may use one of two major standards including:

- ISO 9141-2 Standard (ISO = International Standards Organization)

Pins 7 and 15 (or wire at pin 7 and no pin at 2 or a wire at 7 and at 2 and/or 10)

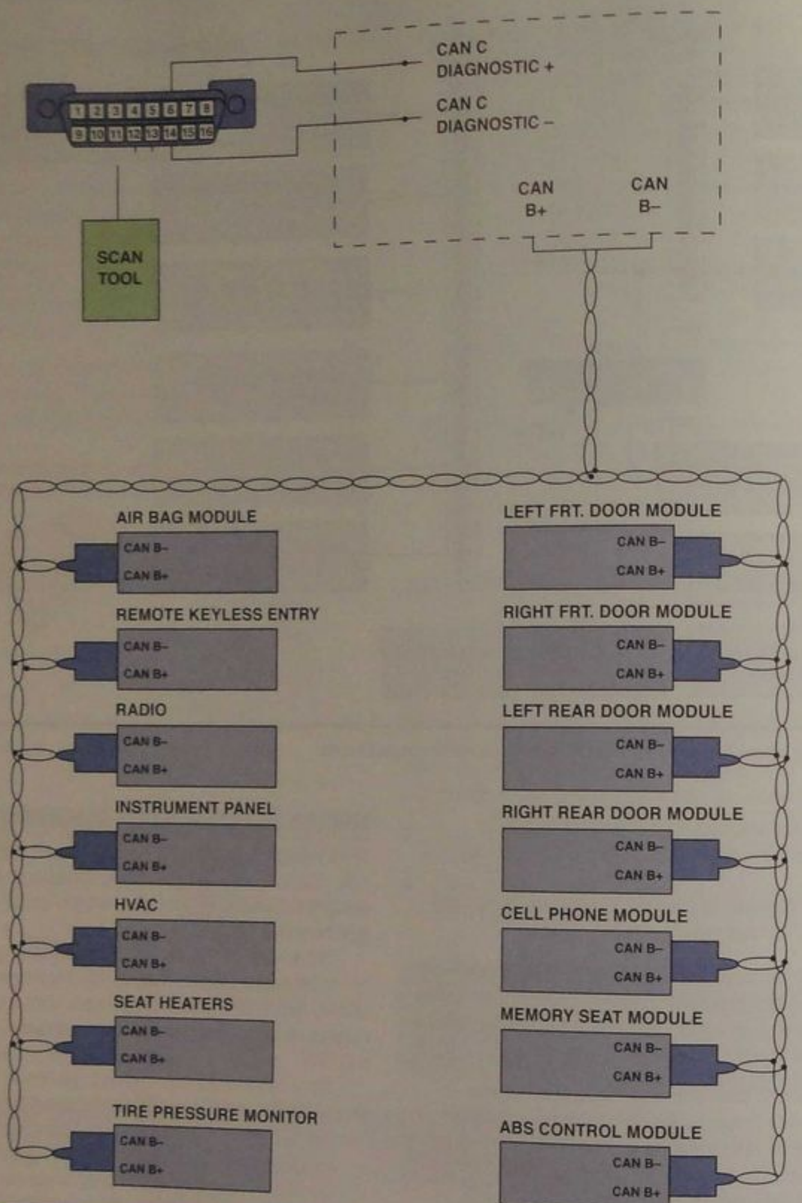


Figure 53–17 A typical bus system showing module CAN communications and twisted pairs of wire.

- **SAE J-1850 Standard** (SAE = Society of Automotive Engineers)

Two types: **VPW** (variable pulse width) or **PWM** (pulse width modulated)

Pins 2 and 10 (no wire at pin 7)

General Motors vehicles use:

- SAE J-1850 (VPW—Class 2—10.4 kb) standard, which uses pins 2, 4, 5, and 16 and not 10
- **GM Domestic OBD II**

Pin 1 and 9—CCM (Comprehensive Component Monitor) slow baud rate—8192 UART

Pins 2 and 10—OEM Enhanced—Fast Rate—40,500 baud rate

Pins 7 and 15—Generic OBD II—ISO 9141—10,400 baud rate

Chrysler, European, and Asian vehicles use:

- ISO 9141-2 standard, which uses pins 4, 5, 7, 15, and 16
- **Chrysler OBD II**

Pins 2 and 10—CCM

Pins 3 and 14—OEM Enhanced—60,500 baud rate

Pins 7 and 15—Generic OBD II - ISO 9141—10,400 baud rate

Ford vehicles use:

- SAE J-1850(PWM) (PWM—41.6 kb) standard, which uses pins 2, 4, 5, 10, and 16
- **Ford Domestic OBD II**

Pins 2 and 10—CCM

Pins 6 and 14—OEM Enhanced—Class C—40,500 baud rate

Pins 7 and 15—Generic OBD II—ISO 9141—10,400 baud rate

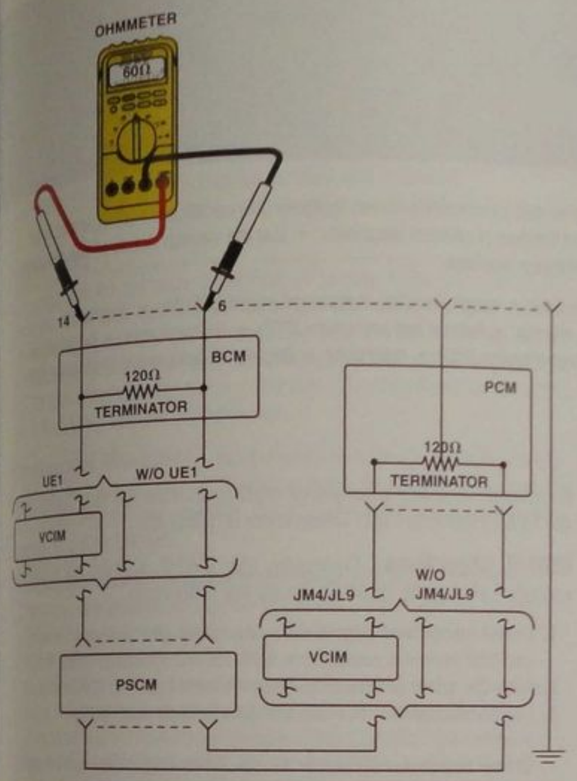


Figure 53–18 Checking the terminating resistors using an ohmmeter at the DLC.



OBD-II DLC

PIN NO.	ASSIGNMENTS
1.	MANUFACTURER'S DISCRETION
2.	BUS + LINE, SAE J1850
3.	MANUFACTURER'S DISCRETION
4.	CHASSIS GROUND
5.	SIGNAL GROUND
6.	MANUFACTURER'S DISCRETION
7.	K LINE, ISO 9141
8.	MANUFACTURER'S DISCRETION
9.	MANUFACTURER'S DISCRETION
10.	BUS – LINE, SAE J1850
11.	MANUFACTURER'S DISCRETION
12.	MANUFACTURER'S DISCRETION
13.	MANUFACTURER'S DISCRETION
14.	MANUFACTURER'S DISCRETION
15.	L LINE, ISO 9141
16.	VEHICLE BATTERY POSITIVE (4A MAX)

Figure 53–19 Sixteen-pin OBD II DLC with terminals identified. Scan tools use the power pin (16) ground pin (4) for power so that a separate cigarette lighter plug is not necessary on OBD II vehicles.

SUMMARY

1. The Society of Automotive Engineers (SAE) standard J-1930 specifies that the term power train control module (PCM) be used for the computer that controls the engine and transmission in a vehicle.
2. The four basic computer functions include input, processing, storage, and output.
3. Read-only memory (ROM) can be programmable (PROM), erasable (EPROM), or electrically erasable (EEPROM).
4. Computer input sensors include engine speed (RPM), MAP, MAF, ECT, O2S, TP, and VS.
5. A computer can only turn a device on or turn a device off, but it can do the operation very rapidly.

REVIEW QUESTIONS

1. What part of the vehicle computer is considered to be the brain?
2. What is the difference between volatile and nonvolatile RAM?
3. List four input sensors.
4. List four output devices.

CHAPTER QUIZ

1. What unit of electricity is used as a signal for a computer?
   a. Volt
   b. Ohm
   c. Ampere
   d. Watt
2. The four basic computer functions include _____.
   a. Writing, processing, printing, and remembering
   b. Input, processing, storage, and output
   c. Data gathering, processing, output, and evaluation
   d. Sensing, calculating, actuating, and processing
3. All OBD II vehicles use what type of read-only memory?
   a. ROM
   b. PROM
   c. EPROM
   d. EEPROM
4. The "brain" of the computer is the _____.
   a. PROM
   b. RAM
   c. CPU
   d. AD converter
5. Computer processing speed is measured in _____.
   a. Baud rate
   b. Clock speed (Hz)
   c. Voltage
   d. Bytes
6. Which item is a computer input sensor?
   a. RPM
   b. Throttle position angle
   c. Engine coolant temperature
   d. All of the above
7. Which item is a computer output device?
   a. Fuel injector
   b. Transmission shift solenoid
   c. Evaporative emission control solenoid
   d. All of the above
8. The SAE term for the vehicle computer is _____.
   a. PCM
   b. ECM
   c. ECA
   d. Controller
9. What two things can a vehicle computer actually perform (output)?
   a. Store and process information
   b. Turn something on or turn something off
   c. Calculate and vary temperature
   d. Control fuel and timing only
10. Analog signals from sensors are changed to digital signals for processing by the computer through which type of circuit?
    a. Digital
    b. Analog
    c. AD converter
    d. PROM

CHAPTER

54 Onboard Diagnosis

OBJECTIVES: After studying Chapter 54, the reader will be able to: Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain the purpose and function of onboard diagnosis. • List the various duties of the diagnostic executive (task master). • List five continuous monitors. • List five noncontinuous monitors.

KEY TERMS: California air resources board (CARB) • component identification (CID) • comprehensive component monitor (CCM) • diagnostic executive • enable criteria • exponentially weighted moving average (EWMA) monitor • federal test procedure (FTP) • freeze-frame • functionality • malfunction indicator lamp (MIL) • on-board diagnosis (OBD) • parameter identification (PID) • rationality • Society of Automotive Engineers (SAE) • task identification (TID) • task manager

ON-BOARD DIAGNOSTICS GENERATION-II (OBD-II) SYSTEMS

During the 1980s, most manufacturers began equipping their vehicles with full-function control systems capable of alerting the driver of a malfunction and of allowing the technician to retrieve codes that identify circuit faults. These early diagnostic systems were meant to reduce emissions and speed up vehicle repair.

The automotive industry calls these systems **On-Board Diagnostics (OBDs).** The **California Air Resources Board (CARB)** developed the first regulation requiring manufacturers selling vehicles in that state to install OBD. OBD Generation I (OBD I) applies to all vehicles sold in California beginning with the 1988 model year. It carries the following requirements:

1. An instrument panel warning lamp able to alert the driver of certain control system failures, now called a **malfunction indicator lamp (MIL).** See Figure 54–1.
2. The system's ability to record and transmit DTCs for emission-related failures.
3. Electronic system monitoring of the HO2S, EGR valve, and evaporative purge solenoid. Although not U.S. EPA-required, during this time most manufacturers also equipped vehicles sold outside of California with OBD I.

By failing to monitor the catalytic converter, the evaporative system for leaks, and the presence of engine misfire, OBD I did not do enough to lower automotive emissions. This led the CARB and the EPA to develop OBD Generation II (OBD II).



Figure 54–1 A typical malfunction indicator lamp (MIL) often labeled "check engine."

OBD-II Objectives Generally, the CARB defines an OBD-II equipped vehicle by its ability to do the following:

1. Detect component degradation or a faulty emission-related system that prevents compliance with federal emission standards.
2. Alert the driver of needed emission-related repair or maintenance.
3. Use standardized DTCs and accept a generic scan tool.

These requirements apply to all 1996 and later model light-duty vehicles. The Clean Air Act of 1990 directed the EPA to develop new regulations for OBD. The primary purpose of OBD II is emission-related, whereas the primary purpose of OBD I (1988) was to detect faults in sensors or sensor circuits. OBD-II regulations require that not only sensors be tested but also all exhaust emission control devices, and that they be verified for proper operation.

All new vehicles must pass the **Federal Test Procedure (FTP)** for exhaust emissions while being tested for 505 seconds on rollers that simulate the urban drive cycle around downtown Los Angeles.

NOTE: IM 240 is simply a shorter 240-second version of the 505-second federal test procedure.

The regulations for OBD-II vehicles state that the vehicle computer must be capable of testing for, and determining, if the exhaust emissions are within 1.5 times the FTP limits. To achieve this goal, the computer must do the following:

1. Test all exhaust emission system components for correct operation.
2. Actively operate the system and measure the results.
3. Continuously monitor all aspects of the engine operation to be certain that the exhaust emissions do not exceed 1.5 times the FTP.
4. Check engine operation for misfire.
5. Turn on the MIL (check engine) if the computer senses a fault in a circuit or system.
6. Record a **freeze-frame,** which is a snapshot of all of the engine data at the time the DTC was set.
7. Flash the MIL if an engine misfire occurs that could damage the catalytic converter.

DIAGNOSTIC EXECUTIVE AND TASK MANAGER

On OBD-II systems, the PCM incorporates a special segment of software. On Ford and GM systems, this software is called the **diagnostic executive.** On Chrysler systems, it is called the **task manager.** This software program is designed to manage the operation of all OBD-II monitors by controlling the sequence of steps necessary to execute the diagnostic tests and monitors.

MONITORS

A monitor is an organized method of testing a specific part of the system. Monitors are simply tests that the computer performs to evaluate components and systems. If a component or system failure is detected while a monitor is running, a DTC will be stored and the MIL illuminated by the second trip. The two types of monitors are continuous and noncontinuous.

Continuous Monitors As required conditions are met, continuous monitors begin to run. These continuous monitors will run for the remainder of the vehicle drive cycle. The three continuous monitors are as follows:

- **Comprehensive component monitor (CCM).** This monitor watches the sensors and actuators in the OBD-II system. Sensor values are constantly compared with known-good values stored in the PCM's memory.

  The CCM is an internal program in the PCM designed to monitor a failure in any electronic component or circuit (including emission-related and non-emission-related circuits) that provide input or output signals to the PCM. The PCM considers that an input or output signal is inoperative when a failure exists due to an open circuit, out-of-range value, or if an onboard rationality check fails. If an emission-related fault is detected, the PCM will set a code and activate the MIL (requires two consecutive trips).

  Many PCM sensors and output devices are tested at key-on or immediately after engine start-up. However, some devices, such as the IAC, are only tested by the CCM after the engine meets certain engine conditions. The number of times the CCM must detect a fault before it will activate the MIL depends upon the manufacturer, but most require two consecutive trips to activate the MIL. The components tested by the CCM include:

  Four-wheel-drive low switch
  Brake switch
  Camshaft (CMP) and crankshaft (CKP) sensors
  Clutch switch (manual transmissions/transaxles only)
  Cruise servo switch
  Engine coolant temperature (ECT) sensor
  EVAP purge sensor or switch
  Fuel composition sensor
  Intake air temperature (IAT) sensor
  Knock sensor (KS)
  Manifold absolute pressure (MAP) sensor
  Mass air-flow (MAF) sensor
  Throttle-position (TP) sensor
  Transmission temperature sensor
  Transmission turbine speed sensor
  Vacuum sensor
  Vehicle speed (VS) sensor
  EVAP canister purge and EVAP purge vent solenoid
  Idle air control (IAC) solenoid
  Ignition control system
  Transmission torque converter clutch solenoid
  Transmission shift solenoids

- **Misfire monitor.** This monitor looks at engine misfire. The PCM uses the information received from the crankshaft position sensor (CKP) to calculate the time between the edges of the reluctor, as well as the rotational speed and acceleration. By comparing the acceleration of each firing event, the PCM can determine if a cylinder is not firing correctly.

  Misfire type A. Upon detection of a misfire type A (200 revolutions), which would cause catalyst damage, the MIL will blink once per second during the actual misfire, and a DTC will be stored.

  Misfire type B. Upon detection of a misfire type B (1000 revolutions), which will exceed 1.5 times the EPA federal test procedure (FTP) standard or cause a vehicle to fail an inspection and maintenance tailpipe emissions test, the MIL will illuminate and a DTC will be stored.

  The DTC associated with multiple cylinder misfire for a type A or type B misfire is DTC P0300. The DTCs associated with an individual cylinder misfire for a type A or type B misfire are DTCs P0301, P0302, P0303, P0304, P0305, P0306, P0307, P0308, P0309, and P0310.

- **Fuel trim monitor.** The PCM continuously monitors short- and long-term fuel trim. Constantly updated adaptive fuel tables are stored in long-term memory (KAM), and used by the PCM for compensation due to wear and aging of the fuel system components. The MIL will illuminate when the PCM determines the fuel trim values have reached and stayed at their limits for too long a period of time.

Noncontinuous Monitors Noncontinuous monitors run (at most) once per vehicle drive cycle. The noncontinuous monitors are as follows:

O2S monitor
O2S heater monitor
Catalyst monitor
EGR monitor
EVAP monitor
Secondary AIR monitor
Transmission monitor
PCV system monitor
Thermostat monitor

Once a noncontinuous monitor has run to completion, it will not be run again until the conditions are met during the next vehicle drive cycle. Also after a noncontinuous monitor has run to completion, the readiness status on your scan tool will show "complete" or "done" for that monitor. Monitors that have not run to completion will show up on your scanner as "incomplete."

OBD-II MONITOR INFORMATION

Comprehensive Component Monitor The circuits and components covered by the comprehensive component monitor (CCM) do not include those directly monitored by another monitor.

However, OBD II also requires that inputs from power train components to the PCM be tested for **rationality,** and that outputs to power train components from the PCM be tested for **functionality.**

Both inputs and outputs are to be checked *electrically*. Rationality checks refer to a PCM comparison of input value to values.

Example:

TPS	3 V
MAP	18 in./Hg
RPM	700 RPM
PRNDL	Park

NOTE: Comprehensive component monitors are continuous. Therefore enabling conditions do not apply.

- Monitor runs continuously
- Monitor includes sensors, switches, relays, solenoids, and PCM hardware
- All are checked for opens, shorts-to-ground, and shorts-to-voltage
- Inputs are checked for rationality
- Outputs are checked for functionality
- Most are one-trip DTCs
- Freeze-frame is priority 3
- Three consecutive good trips are used to extinguish the MIL
- Forty warm-up cycles are used to erase DTC and freeze-frame
- Two minutes run time without reoccurrence of the fault constitutes a "good trip"

Continuous Running Monitors

- Monitors run continuously, only stop if they fail
- Fuel system: rich/lean
- Misfire: catalyst damaging/FTP (emissions)
- Two-trip faults (except early generation catalyst damaging misfire)
- MIL, DTC, freeze-frame after two consecutive faults
- Freeze-frame is priority 2 on first trip
- Freeze frame is priority 4 on maturing trip
- Three consecutive good trips in a similar condition window are used to extinguish the MIL
- Forty warm-up cycles are used to erase DTC and freeze-frame (80 to erase one-trip failure if similar conditions cannot be met)

Once Per Trip Monitors

- Monitor runs once per trip, pass or fail
- O_2 response, O_2 heaters, EGR, purge flow EVAP leak, secondary air, catalyst
- Two-trip DTCs
- MIL, DTC, freeze-frame after two consecutive faults
- Freeze-frame is priority 1 on first trip
- Freeze-frame is priority 3 on maturing trip
- Three consecutive good trips are used to extinguish the MIL
- Forty warm-up cycles are used to erase DTC and freeze-frame

Exponentially Weighted Moving Average (EWMA) Monitors The **exponentially weighted moving average (EWMA) monitor** is a mathematical method used to determine performance.

- Catalyst monitor
- EGR monitor
- PCM runs six consecutive failed tests; fails in one trip
- Three consecutive failed tests on next trip, then fails
- Freeze-frame is priority 3
- Three consecutive good trips are used to extinguish the MIL
- Forty warm-up cycles are used to erase DTC and freeze-frame

Noncontinuous Monitors Noncontinuous monitors run (at most) once per vehicle drive cycle. The noncontinuous monitors are as follows:

O2S monitor
O2S heater monitor
Catalyst monitor
EGR monitor
EVAP monitor
Secondary AIR monitor
Transmission monitor
PCV system monitor
Thermostat monitor

Once a noncontinuous monitor has run to completion, it will not be run again until the conditions are met during the next vehicle drive cycle. Also after a noncontinuous monitor has run to completion, the readiness status on your scan tool will show "complete" or "done" for that monitor. Monitors that have not run to completion will show up on your scanner as "incomplete."

ENABLING CRITERIA

With so many different tests (monitors) to run, the PCM needs an internal director to keep track of when each monitor should run. As mentioned, different manufacturers have different names for this director, such as the diagnostic executive or the task manager. Each monitor has enabling criteria. These criteria are a set of conditions that must be met before the task manager will give the go-ahead for each monitor to run. Most enabling criteria follow simple logic, for example:

- The task manager will not authorize the start of the O2S monitor until the engine has reached operating temperature and the system has entered closed loop.
- The task manager will not authorize the start of the EGR monitor when the engine is at idle, because the EGR is always closed at this time.

Because each monitor is responsible for testing a different part of the system, the enabling criteria can differ greatly from one monitor to the next. The task manager must decide when each monitor should run, and in what order, to avoid confusion.

There may be a conflict if two monitors were to run at the same time. The results of one monitor might also be tainted if a second monitor were to run simultaneously. In such cases, the task manager decides which monitor has a higher priority. Some monitors also depend on the results of other monitors before they can run.

A monitor may be classified as pending if a failed sensor or other system fault is keeping it from running on schedule.

The task manager may suspend a monitor if the conditions are not correct to continue. For example, if the catalyst monitor is running during a road test and the PCM detects a misfire, the catalyst monitor will be suspended for the duration of the misfire.

Trip A trip is defined as a key-on condition that contains the necessary conditions for a particular test to be performed followed by a key-off. These conditions are called the **enable criteria.** For example, for the EGR test to be performed, the engine must be at normal operating temperature and decelerating for a minimum amount of time. Some tests are performed when the engine is cold, whereas others require that the vehicle be cruising at a steady highway speed.

Warm-Up Cycle Once a MIL is deactivated, the original code will remain in memory until 40 warm-up cycles are completed without the fault reappearing. A warm-up cycle is defined as a trip with an engine temperature increase of at least 40°F and where engine temperature reaches at least 160°F (71°C).

MIL Condition: Off This condition indicates that the PCM has not detected any faults in an emissions-related component or system, or that the MIL circuit is not working.

MIL Condition: On Steady This condition indicates a fault in an emissions-related component or system that could affect the vehicle emission levels.

MIL Condition: Flashing This condition indicates a misfire or fuel control system fault that could damage the catalytic converter.

NOTE: In a misfire condition with the MIL on steady, if the driver reaches a vehicle speed and load condition with the engine misfiring at a level that could cause catalyst damage, the MIL would start flashing. It would continue to flash until engine speed and load conditions caused the level of misfire to subside. Then the MIL would go back to the on-steady condition. This situation might result in a customer complaint of a MIL with an intermittent flashing condition.

MIL: Off The PCM will turn off the MIL if any of the following actions or conditions occur:

- The codes are cleared with a scan tool.
- Power to the PCM is removed at the battery or with the PCM power fuse for an extended period of time (may be up to several hours or longer).
- A vehicle is driven on three consecutive trips with a warm-up cycle and meets all code set conditions without the PCM detecting any faults.

The PCM will set a code if a fault is detected that could cause tailpipe emissions to exceed 1.5 times the FTP standard; however, the PCM will not deactivate the MIL until the vehicle has been driven on three consecutive trips with vehicle conditions similar to actual conditions present when the fault was detected. This is not merely three vehicle start-ups and trips. It means three trips during which certain engine operating conditions are met so that the OBD-II monitor that found the fault can run again and pass the diagnostic test.

OBD-II DTC NUMBERING DESIGNATION

A scan tool is required to retrieve DTCs from an OBD-II vehicle. Every OBD-II scan tool will be able to read all generic **Society of Automotive Engineers (SAE)** DTCs from any vehicle. See Figure 54–2 for definitions and explanations of OBD alphanumeric DTCs. The diagnostic trouble codes (DTCs) are grouped into major categories, depending on the location of the fault on the system involved.

Pxxx codes—power train DTCs (engine, transmission-related faults)
Bxxx codes—body DTCs (accessories, interior-related faults)
Cxxx codes—chassis DTCs (suspension and steering-related faults)
Uxxx codes—network DTCs (module communication-related faults)

DTC Numbering Explanation The number in the hundredth position indicates the specific vehicle system or subgroup that failed.

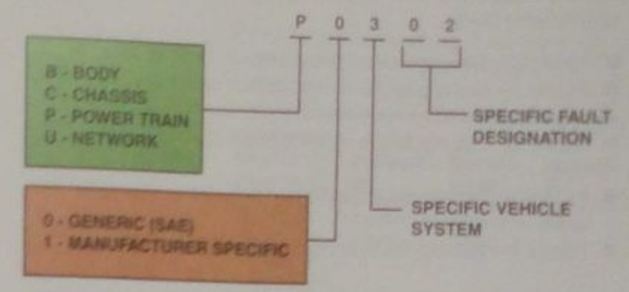


Figure 54–2 OBD-II DTC identification format.

This position should be consistent for P0xxx and P1xxx type codes. The following numbers and systems were established by SAE:

- P0100—Air metering and fuel system fault
- P0200—Fuel system (fuel injector only) fault
- P0300—Ignition system or misfire fault
- P0400—Emission control system fault
- P0500—Idle speed control, vehicle speed (VS) sensor fault
- P0600—Computer output circuit (relay, solenoid, etc.) fault
- P0700—Transaxle, transmission faults

NOTE: The tens and ones numbers indicate the part of the system at fault.

Types of DTCs Not all OBD-II DTCs are of the same importance for exhaust emissions. Each type of DTC has different requirements for it to set, and the computer will only turn on the MIL for emissions-related DTCs.

Type A Codes A type A DTC is emission-related and will cause the MIL to be turned on the *first trip* if the computer has detected a problem. Engine misfire or a very rich or lean air–fuel ratio, for example, would cause a type A DTC. These codes alert the driver to an emission problem that may cause damage to the catalytic converter.

Type B Codes A type B code will be stored and the MIL will be turned on during the *second consecutive trip*, alerting the driver to the fact that a diagnostic test was performed and failed.

NOTE: Type A and B codes are emission-related codes that will cause the lighting of the malfunction indicator lamp (MIL), usually labeled "check engine" or "service engine soon."

Type C and D Codes Type C and D codes are for use with non-emission-related diagnostic tests; they will cause the lighting of a "service" lamp (if the vehicle is so equipped). Type C codes are also called type C1 codes and D codes are also called type C0 codes.

DIAGNOSTIC TROUBLE CODE PRIORITY

CARB has also mandated that all diagnostic trouble codes (DTCs) be stored according to individual priority. DTCs with a higher priority

overwrite those with a lower priority. The OBD-II System DTC Priority is listed below.

- Priority 0—Non-emission-related codes
- Priority 1—One-trip failure of two-trip fault for non-fuel, non-misfire codes
- Priority 2—One-trip failure of two-trip fault for fuel or misfire codes
- Priority 3—Two-trip failure or matured fault of non-fuel, non-misfire codes
- Priority 4—Two-trip failure or matured fault for fuel or misfire codes

OBD-II Freeze-Frame To assist the service technician, OBD II requires the computer to take a "snapshot" or freeze-frame of all data at the instant an emission-related DTC is set. A scan tool is required to retrieve this data.

NOTE: Although OBD II requires that just one freeze-frame of data be stored, the instant an emission-related DTC is set, vehicle manufacturers usually provide expanded data about the DTC beyond that required. However, retrieving this enhanced data usually requires the use of the vehicle-specific scan tool.

Freeze-frame items include:

- Calculated load value
- Engine speed (RPM)
- Short-term and long-term fuel trim percent
- Fuel system pressure (on some vehicles)
- Vehicle speed (mph)
- Engine coolant temperature
- Intake manifold pressure
- Closed/open-loop status
- Fault code that triggered the freeze-frame
- If a misfire code is set, identify which cylinder is misfiring

A DTC should not be cleared from the vehicle computer memory unless the fault has been corrected and the technician is so directed by the diagnostic procedure. If the problem that caused the DTC to be set has been corrected, the computer will automatically clear the DTC after 40 consecutive warm-up cycles with no further faults detected (misfire and excessively rich or lean condition codes require 80 warm-up cycles). The codes can also be erased by using a scan tool.

NOTE: Disconnecting the battery may not erase OBD-II DTCs or freeze-frame data. Most vehicle manufacturers recommend using a scan tool to erase DTCs rather than disconnecting the battery, because the memory for the radio, seats, and learned engine operating parameters is lost if the battery is disconnected.

FREQUENTLY ASKED QUESTION ???

What Are Pending Codes?

Pending codes are set when operating conditions are met and the component or circuit is not within the normal range, yet the conditions have not yet been met to set a DTC. For example, a sensor may require two consecutive faults before a DTC is set. If a scan tool displays a pending code or a failure, a driveability concern could also be present. The pending code can help the technician to determine the root cause before the customer complains of a check engine light indication.

ENABLING CONDITIONS OR CRITERIA

These are the exact engine operating conditions required for a diagnostic monitor to run.

Example:

Specific RPM
Specific ECT, MAP, run time, VSS, etc.

Pending Under some situations the PCM will not run a monitor if the MIL is illuminated and a fault is stored from another monitor. In these situations, the PCM postpones monitors pending a resolution of the original fault. The PCM does not run the test until the problem is remedied.

For example, when the MIL is illuminated for an oxygen sensor fault, the PCM does not run the catalyst monitor until the oxygen sensor fault is remedied. Since the catalyst monitor is based on signals from the oxygen sensor, running the test would produce inaccurate results.

Conflict There are also situations when the PCM does not run a monitor if another monitor is in progress. In these situations, the effects of another monitor running could result in an erroneous failure. If this conflict is present, the monitor is not run until the conflicting condition passes. Most likely, the monitor will run later after the conflicting monitor has passed.

For example, if the fuel system monitor is in progress, the PCM does not run the EGR monitor. Since both tests monitor changes in air-fuel ratio and adaptive fuel compensation, the monitors conflict with each other.

Suspend Occasionally, the PCM may not allow a two-trip fault to mature. The PCM will suspend the maturing fault if a condition exists that may induce erroneous failure. This prevents illuminating the MIL for the wrong fault and allows more precise diagnosis.

For example, if the PCM is storing a one-trip fault for the oxygen sensor and the EGR monitor, the PCM may still run the EGR monitor but will suspend the results until the oxygen sensor monitor either passes or fails. At that point, the PCM can determine if the EGR system is actually failing or if an oxygen sensor is failing.

Rationality Test While input signals to the PCM are constantly being monitored for electrical opens and shorts, they are also tested for rationality. This means that the input signal is compared against other inputs and information to see if it makes sense under the current conditions.

PCM sensor inputs that are checked for rationality include:

- MAP sensor
- O_2 sensor
- ECT
- Camshaft position sensor (CMP)
- VS sensor
- Crankshaft position sensor (CKP)
- IAT sensor
- TP sensor
- Ambient air temperature sensor
- Power steering switch
- O_2 sensor heater
- Engine controller
- Brake switch
- P/N switch
- Transmission controls

Functionality Test A functionality test refers to PCM inputs checking the operation of the outputs.

Example:

PCM commands the IAC open; expected change in engine RPM is not seen
IAC 60 counts
RPM 700 RPM

PCM outputs that are checked for functionality include:

- EVAP canister purge solenoid
- EVAP purge vent solenoid
- Cooling fan
- Idle air control solenoid
- Ignition control system
- Transmission torque converter clutch solenoid
- Transmission shift solenoids (A,B,1–2, etc.)

Electrical Test Refers to the PCM check of both input and outputs for the following:

- Open
- Shorts
- Ground

PCM Determination of Faults Chart

Monitor Name	Monitor Type (How Often It Completes)	Number of Faults on Separate Trips to Set a Pending DTC	Number of Separate Consecutive Trips to Light MIL, Store a DTC	Number of Trips with No Faults to Erase a Maturing DTC	Number of Trips with No Fault to Turn the MIL Off	Number of Warm-Up Cycles to Erase DTC after MIL Is Turned Off
CCM	Continuous (when trip conditions allow it)	1	2	1–Trip	3–Trips	40
Catalyst	Once per drive cycle	1	3	1	3–OBD-II drive cycle	40
Misfire Type A	Continuous		1		3–Similar conditions	80
Misfire Type B	Continuous	1	2	1	3–Similar conditions	80
Fuel System	Continuous	1	2	1	3–Similar conditions	80
Oxygen Sensor	Once per trip	1	2	1–Trip	3–Trips	40
EGR	Once per trip	1	2	1–Trip	3–Trips	40
EVAP	Once per trip	1	1	1–Trip	3–Trips	40
AIR	Once per trip	1	2	1–Trip	3–Trips	40

Example:
ECT
Shorted high (input to PCM) above capable voltage, i.e., 5-volt sensor with 12-volt input to PCM would indicate a short to voltage or a short high.

	Monitor Type	Conditions to Set DTC and Illuminate MIL	Extinguish MIL	Clear DTC Criteria	Applicable DTC
Comprehensive Monitor	Continuous 1-trip monitor	(See note below) Input and output failure—rationally, functionally, electrically	3 consecutive pass trips	40 warm-up cycles	P0123

NOTE: The number of times the comprehensive component monitor must detect a fault depends on the vehicle manufacturer. On some vehicles, the comprehensive component monitor will activate the MIL as soon as it detects a fault. On other vehicles, the comprehensive component monitor must fail two times in a row.

- Freeze-frame captured on first-trip failure.
- Enabling conditions: Many PCM sensors and output devices are tested at key-on or immediately after engine start-up. However, some devices (ECT, idle speed control) are only tested by the comprehensive component monitor after the engine meets particular engine conditions.
- Pending: No pending condition
- Conflict: No conflict conditions
- Suspend: No suspend conditions

GENERIC OBD-II

All OBD-II vehicles must be able to display data on a generic (also called *global*) scan tool under nine different modes of operation. These modes include:

Mode One	Current power train data (**parameter identification** display or **PID**)
Mode Two	Freeze-frame data
Mode Three	Diagnostic trouble codes
Mode Four	Clear and reset diagnostic trouble codes (DTCs), freeze-frame data, and readiness status monitors for noncontinuous monitors only
Mode Five	Oxygen sensor monitor test results
Mode Six	Onboard monitoring of test results for noncontinuously monitored systems
Mode Seven	Onboard monitoring of test results for continuously monitored systems
Mode Eight	Bidirectional control of onboard systems
Mode Nine	Module identification

The generic (global) data is used by most state emission programs. Generic OBD-II displays often use hexadecimal numbers, which use 16 numbers instead of 10. The numbers 0 to 9 (zero counts as a number) make up the first 10 and then capital letters A to F complete the 16 numbers. To help identify the number as being

in a hexadecimal format, a dollar sign ($) is used in front of the number or letter. See the conversion chart below:

Decimal Number	Hexadecimal Code
0	$0
1	$1
2	$2
3	$3
4	$4
5	$5
6	$6
7	$7
8	$8
9	$9
10	$A
11	$B
12	$C
13	$D
14	$E
15	$F

Hexadecimal coding is also used to identify tests (**test identification [TID]** and **component identification [CID]**).

FREQUENTLY ASKED QUESTION ???

How Can You Tell Generic from Factory?

When using a scan tool on an OBD-II-equipped vehicle, if the display asks for make, model, and year, then the factory or enhanced part of the PCM is being accessed. If the generic or global part of the PCM is being scanned, then there is no need to know the vehicle details.

DIAGNOSING PROBLEMS USING MODE SIX

Mode six information can be used to diagnose faults by following three steps:

1. Check the monitor status before starting repairs. This step will show how the system failed.
2. Look at the component or parameter that triggered the fault. This step will help pin down the root cause of the failure.
3. Look to the monitor enable criteria, which will show what it takes to fail or pass the monitor.

SUMMARY

1. If the MIL is on, retrieve the DTC and follow the manufacturer's recommended procedure to find the root cause of the problem.
2. All monitors must have the enable criteria achieved before a test is performed.
3. OBD-II vehicles use a 16-pin DLC and common DTCs.
4. OBD II includes generic (SAE), as well as vehicle manufacturer-specific DTCs, and data display.

REVIEW QUESTIONS

1. What does the PCM do during a drive cycle to test emission-related components?
2. What is the difference between a type A and type B OBD-II DTC?
3. What is the difference between a trip and a warm-up cycle?
4. What could cause the MIL to flash?

CHAPTER QUIZ

1. A freeze-frame is generated on an OBD-II vehicle _____.
   a. When a type C or D diagnostic trouble code is set
   b. When a type A or B diagnostic trouble code is set
   c. Every other trip
   d. When the PCM detects a problem with the O2S
2. An ignition misfire or fuel mixture problem is an example of what type of DTC?
   a. Type A
   b. Type B
   c. Type C
   d. Type D
3. How many terminals are in an OBD-II DLC?
   a. 5
   b. 9
   c. 12
   d. 16
4. OBD II has been on all passenger vehicles in the United States since _____.
   a. 1986
   b. 1991
   c. 1996
   d. 2000
5. A generic scan tool can access the same information at the same rate as an enhanced original equipment manufacturer's scan tool.
   a. True
   b. False
6. DTC P0302 is a _____.
   a. Generic DTC
   b. Vehicle manufacturer-specific DTC
   c. Idle speed-related DTC
   d. Transmission/transaxle-related DTC
7. The MIL is turned off if _____.
   a. The codes are cleared with a scan tool
   b. Power to the PCM is disconnected
   c. The vehicle is driven on three consecutive trips with a warm-up cycle and meets all code set conditions without the PCM detecting any faults
   d. Any of the above occur
8. Which DTC could indicate that the gas cap is loose or defective?
   a. P0221
   b. P1301
   c. P0442
   d. P1603
9. The computer will automatically clear a DTC if there are no additional detected faults after _____.
   a. Forty consecutive warm-up cycles
   b. Eighty warm-up cycles
   c. Two consecutive trips
   d. Four key-on/key-off cycles
10. A pending code is set when a fault is detected on _____.
    a. A one-trip fault item
    b. The first fault of a two-trip failure
    c. The catalytic converter efficiency
    d. Thermostat problem (too long to closed-loop status)

CHAPTER 55 Computer Sensors

OBJECTIVES: After studying Chapter 55, the reader will be able to: Prepare for ASE Engine Performance (A8) certification test content area "E" (Computerized Engine Controls Diagnosis and Repair). • Explain the purpose and function of the ECT and IAT temperature sensors. • Describe how to test temperature sensors. • Discuss how MAP sensors work. • List the methods that can be used to test MAP sensors. • List how the operation of the MAP sensor affects vehicle operation. • Discuss MAP sensor rationality tests. • Discuss how MAF sensors work. • List the methods that can be used to test MAF sensors. • List how the operation of the MAF sensor affects vehicle operation. • Discuss MAF sensor rationality tests. • Discuss how oxygen sensors (O_2S) work. • Describe the symptoms of a failed oxygen sensor.

KEY TERMS: barometric manifold absolute pressure (BMAP) • barometric pressure (BARO) sensor • bias voltage • cylinder head temperature (CHT) • closed-loop operation • cross counts • engine coolant temperature (ECT) • false air • false lean indication • false rich indication • fuel trim • hot film sensor • hot wire sensor • intake air temperature (IAT) • Karman vortex sensor • lean air–fuel ratio sensor (LAF) • linear air–fuel ratio sensor • manifold absolute pressure (MAP) • mass airflow sensor (MAF) • negative temperature coefficient (NTC) • open-loop operation • oxygen sensor (O_2S) • piezoresistivity • pressure differential • skewed • speed density • tap test • throttle-body temperature (TBT) • throttle position (TP) • transmission fluid temperature (TFT) • transmission oil temperature (TOT) • vacuum • vane airflow sensor (VAF) • wide-band O_2S

ENGINE COOLANT TEMPERATURE SENSORS

Computer-equipped vehicles use an **engine coolant temperature (ECT)** sensor. When the engine is cold, the fuel mixture must be richer to prevent stalling and engine stumble. When the engine is warm, the fuel mixture can be leaner to provide maximum fuel economy with the lowest possible exhaust emissions. Because the computer controls spark timing and fuel mixture, it will need to know the engine temperature. An engine coolant temperature sensor (ECT) screwed into the engine coolant passage will provide the computer with this information. See Figure 55–1.

This will be the most important (high authority) sensor while the engine is cold. The ignition timing can also be tailored to engine (coolant) temperature. A hot engine cannot have the spark timing as far advanced as can a cold engine. The ECT sensor is also used as an important input for the following:

- Idle air control (IAC) position
- Oxygen sensor closed-loop status
- Canister purge on/off times
- Idle speed

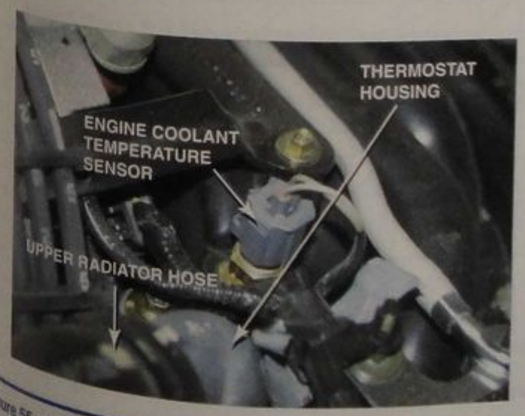


Figure 55–1 A typical engine coolant temperature (ECT) sensor. ECT sensors are located near the thermostat housing on most engines.

Engine coolant temperature sensors are constructed of a semiconductor material that decreases in resistance as the temperature of the sensor increases. Coolant sensors have very high resistance when the coolant is cold and low resistance when the coolant is hot. This is referred to as having a **negative temperature coefficient (NTC),** which is opposite to the situation with most other electrical components. See Figure 55–2.

Therefore, if the coolant sensor has a poor connection (high resistance) at the wiring connector, the computer will supply a richer-than-normal fuel mixture based on the resistance of the coolant sensor. Poor fuel economy and a possible-rich code can be caused by a defective sensor or high resistance in the sensor wiring. If the sensor was shorted or defective and had too low a resistance, a leaner-than-normal fuel mixture would be supplied to the engine. A too-lean fuel mixture can cause driveability problems and a possible lean computer code.

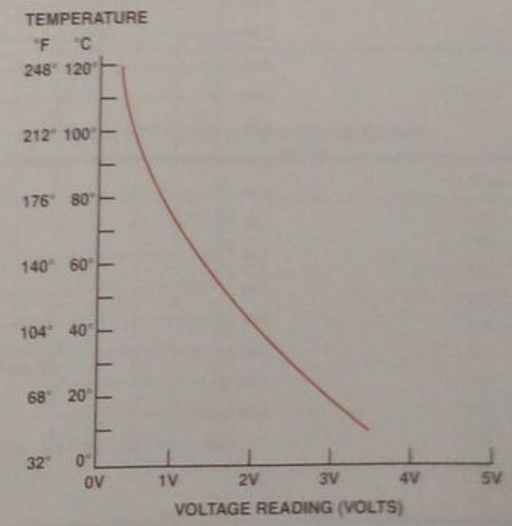


Figure 55–2 A typical ECT sensor temperature versus voltage curve.

STEPPED ECT CIRCUITS

Some vehicle manufacturers use a step-up resistor to effectively broaden the range of the ECT sensor. Chrysler and General Motors vehicles use the same sensor as a non-stepped ECT circuit, but instead apply the sensor voltage through two different resistors.

- When the temperature is cold, usually below 120°F (50°C), the ECT sensor voltage is applied through a high-value resistor inside the PCM.
- When the temperature is warm, usually above 120°F (50°C), the ECT sensor voltage is applied through a much lower resistance value inside the PCM. See Figure 55–3.

The purpose of this extra circuit is to give the PCM a more accurate reading of the engine coolant temperature compared to the same sensor with only one circuit. See Figure 55–4.

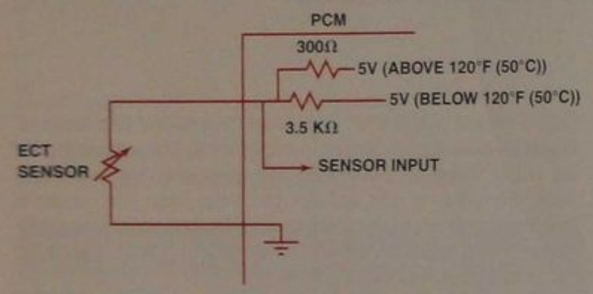


Figure 55–3 A typical two-step ECT circuit showing that when the coolant temperature is low, the PCM applies a 5-volt reference voltage to the ECT sensor through a higher resistance compared to when the temperature is higher.

TESTING THE ENGINE COOLANT TEMPERATURE SENSOR

Testing the Engine Coolant Temperature by Visual Inspection The correct functioning of the engine coolant temperature (ECT) sensor depends on the following items that should be checked or inspected:

- **Properly filled cooling system.** Check that the radiator reservoir bottle is full and that the radiator itself is filled to the top.

WARNING: Be sure that the radiator is cool before removing the radiator cap to avoid being scalded by hot coolant.

The ECT sensor must be submerged in coolant to be able to indicate the proper coolant temperature.

- **Proper pressure maintained by the radiator cap.** If the radiator cap is defective and cannot allow the cooling system to become pressurized, air pockets could develop. These air pockets could cause the engine to operate at a hotter-than-normal temperature and prevent proper temperature measurement, especially if the air pockets occur around the sensor.
- **Proper antifreeze–water mixture.** Most vehicle manufacturers recommend a 50/50 mixture of antifreeze and water as the best compromise between freezing protection and heat transfer ability.
- **Proper operation of the cooling fan.** If the cooling fan does not operate correctly, the engine may overheat.

Testing the ECT Using a Multimeter Both the resistance (in ohms) and the voltage drop across the sensor can be measured and compared with specifications. See Figure 55–5. See the following charts showing examples of typical engine coolant temperature sensor specifications. Some vehicles use a PCM to attach another resistor in the ECT circuit to provide a more accurate measure of the engine temperature. See Figure 55–6.

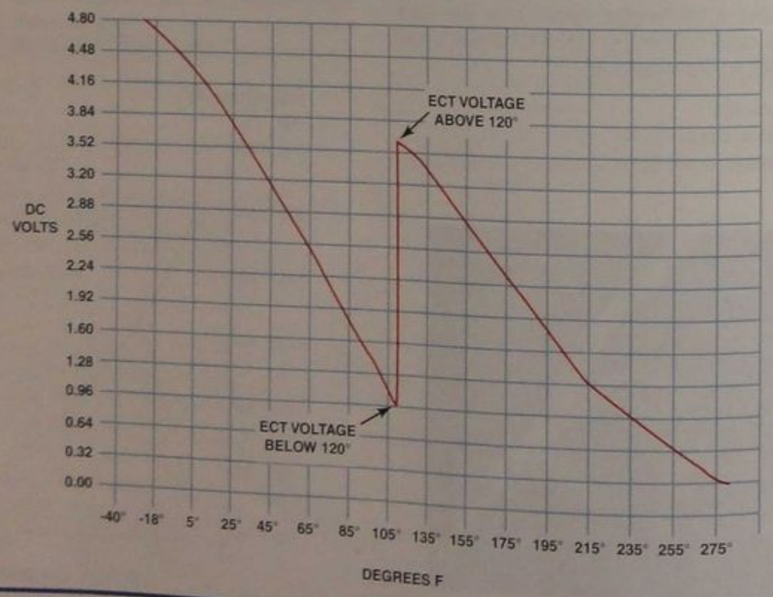


Figure 55–4 The transistors between steps usually occur at a temperature that would not interfere with cold engine starts or the cooling fan operation. In this example, the transition occurs when the sensor voltage is about 1 volt and rises to about 3.6 volts.

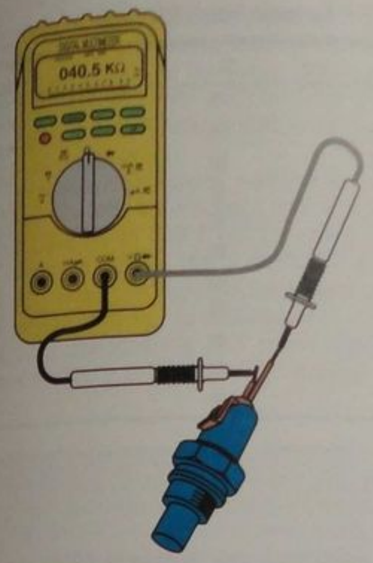


Figure 55–5 Measuring the resistance of the ECT sensor. The resistance measurement can then be compared with specifications.

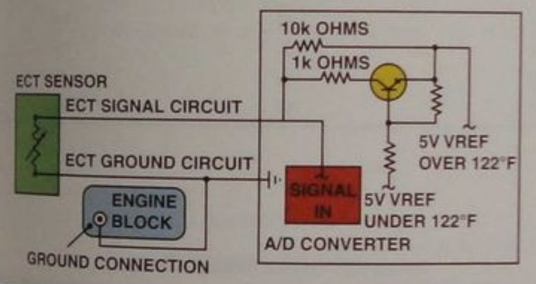


Figure 55–6 When the voltage drop reaches approximately 1.20 volts, the PCM turns on a transistor. The transistor connects a 1-kΩ resistor in parallel with the 10-kΩ resistor. Total circuit resistance now drops to around 909 ohms. This function allows the PCM to have full binary control at cold temperatures up to approximately 122°F, and a second full binary control at temperatures greater than 122°F.

General Motors ECT Sensor with Pull-up Resistor

°F	°C	Ohms	Voltage Drop Across Sensor
−40	−40	100,000	5
−22	−30	53,000	4.78
−4	−20	29,000	4.34
14	−10	16,000	3.89
32	0	9,400	3.45
50	10	5,700	3.01
68	20	3,500	2.56
86	30	2,200	1.80
104	40	1,500	1.10
			Pull-up resistor switched by PCM
122	50	970	3.25
140	60	679	2.88
158	70	470	2.56
176	80	330	2.24
194	90	240	1.70
212	100	177	1.42
230	110	132	1.15
248	120	100	.87

Ford ECT Sensor

°F	°C	Resistance (Ω)	Voltage (V)
50	10	58,750	3.52
68	20	37,300	3.06
86	30	24,270	2.26
104	40	16,150	2.16
122	50	10,970	1.72
140	60	7,600	1.35
158	70	5,370	1.04
176	80	3,840	0.80
194	90	2,800	0.61
212	100	2,070	0.47
230	110	1,550	0.36
248	120	1,180	0.28

General Motors ECT Sensor without Pull-up Resistor

°F	°C	Ohms	Voltage Drop Across Sensor
−40	−40	100,000+	4.95
18	−8	14,628	4.68
32	0	9,420	4.52
50	10	5,670	4.25
68	20	3,520	3.89
86	30	2,238	3.46
104	40	1,459	2.97
122	50	973	2.47
140	60	667	2.00
158	70	467	1.59
176	80	332	1.25
194	90	241	0.97
212	100	177	0.75

Chrysler ECT Sensor without Pull-up Resistor

°F	°C	Voltage (V)
130	54	3.77
140	60	3.60
150	66	3.40
160	71	3.20
170	77	3.02
180	82	2.80
190	88	2.60
200	93	2.40
210	99	2.20
220	104	2.00
230	110	1.80
240	116	1.62
250	121	1.45

Chrysler ECT Sensor with Pull-up Resistor

°F	°CM	Volts
−20	−29	4.70
−10	−23	4.57
0	−18	4.45
10	−12	4.30
20	−7	4.10
30	−1	3.90
40	4	3.60
50	10	3.30
60	16	3.00
70	21	2.75
80	27	2.44
90	32	2.15
100	38	1.83
		Pull-up resistor switched by PCM
110	43	4.20
120	49	4.10
130	54	4.00
140	60	3.60
150	66	3.40
160	71	3.20
170	77	3.02
180	82	2.80
190	88	2.60
200	93	2.40
210	99	2.20
220	104	2.00
230	110	1.80
240	116	1.62
250	121	1.45

Nissan ECT Sensor

°F	°C	Resistance (Ω)
14	−10	7,000–11,400
68	20	2,100–2,900
122	50	680–1,000
176	80	260–390
212	100	180–200

Mercedes ECT

°F	°C	Voltage (DCV)
60	20	3.5
86	30	3.1
104	40	2.7
122	50	2.3
140	60	1.9
158	70	1.5
176	80	1.2
194	90	1.0
212	100	0.8

European Bosch ECT Sensor

°F	°C	Resistance (Ω)
32	0	6,500
50	10	4,000
68	20	3,000
86	30	2,000
104	40	1,500
122	50	900
140	60	650
158	70	500
176	80	375
194	90	295
212	100	230

Honda ECT Sensor (Resistance Chart)

°F	°C	Resistance (Ω)
0	−18	15,000
32	0	5,000
68	20	3,000
104	40	1,000
140	60	500
176	80	400
212	100	250

Honda ECT Sensor (Voltage Chart)

°F	°C	Voltage (V)
0	−18	4.70
10	−12	4.50
20	−7	4.29
30	−1	4.10
40	4	3.86
50	10	3.61
60	16	3.35
70	21	3.08
80	27	2.81
90	32	2.50
100	38	2.26
110	43	2.00
120	49	1.74
130	54	1.52
140	60	1.33
150	66	1.15
160	71	1.00
170	77	0.88
180	82	0.74
190	88	0.64
200	93	0.55
210	99	0.47

If resistance values match the approximate coolant temperature and there is still a coolant sensor trouble code, the problem is generally in the wiring between the sensor and the computer. Always consult the manufacturers' recommended procedures for checking this wiring. If the resistance values do not match, the sensor may need to be replaced.

Normal operating temperature varies with vehicle make and model. Some vehicles are equipped with a thermostat with an opening temperature of 180°F (82°C), whereas other vehicles use a thermostat that is 195°F (90°C) or higher. Before replacing the ECT sensor, be sure that the engine is operating at the temperature specified by the manufacturer. Most manufacturers recommend checking the ECT sensor after the cooling fan has cycled twice, indicating a fully warmed engine. See Figure 55–7.

NOTE: Many manufacturers install another resistor in parallel inside the computer to change the voltage drop across the ECT sensor. This is done to expand the scale of the ECT sensor and to make the sensor more sensitive. Therefore, if measuring *voltage* at the ECT sensor, check with the service manual for the proper voltage at each temperature.

Testing the ECT Sensor Using a Scan Tool Follow the scan tool manufacturer's instructions and connect a scan tool to the data link connector (DLC) of the vehicle. Comparing the temperature of the engine coolant as displayed on a scan tool with the actual temperature of the engine is an excellent method to test an engine coolant temperature sensor.

1. Record the scan tool temperature of the coolant (ECT).
2. Measure the actual temperature of the coolant using an infrared pyrometer or contact-type temperature probe.

HINT: Often the coolant temperature gauge in the dash of the vehicle can be used to compare with the scan tool temperature. Although not necessarily accurate, it may help to diagnose a faulty sensor, especially if the temperature shown on the scan tool varies greatly from the temperature indicated on the dash gauge.

The maximum difference between the two readings should be 10°F (5°C). If the actual temperature varies by more than 10°F from the temperature indicated on the scan tool, check the ECT sensor wiring and connector for damage or corrosion. If the connector and wiring are okay, check the sensor with a DVOM for resistance and compare to the actual engine temperature chart. If that checks out okay, check the computer.

NOTE: Some manufacturers use two coolant sensors, one for the dash gauge and another one for the computer.

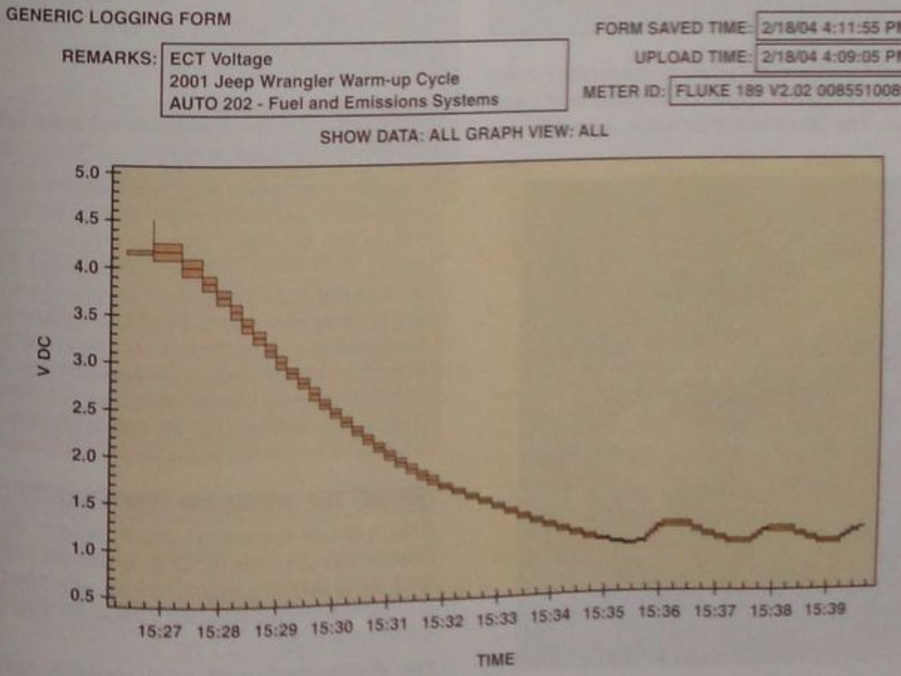


Figure 55–7 A chart showing the voltage decrease of the ECT sensor as the temperature increases from a cold start. The bumps at the bottom of the waveform represent temperature decreases when the thermostat opens and is controlling coolant temperature.

TECH TIP ✔ **Quick and Easy ECT Test**

To check that the wiring and the computer are functioning regarding the ECT sensor, connect a scan tool and look at the ECT temperature display.

Step #1 Unplug the connector from the ECT sensor. The temperature displayed on the scan tool should read about −40.

NOTE: −40° Celsius is also −40° Fahrenheit. This is the point where both temperature scales meet.

Step #2 With the connector still removed from the ECT sensor, use a fused jumper lead and connect the two terminals of the connector together. The scan tool should display about 285°F (140°C).

This same test procedure will work for the IAT and most other temperature sensors.

INTAKE AIR TEMPERATURE SENSOR

The **intake air temperature (IAT)** sensor is a negative temperature coefficient (NTC) thermistor that decreases in resistance as the temperature of the sensor increases. The IAT sensor can be located in one of the following locations:

- In the air cleaner housing
- In the air duct between the air filter and the throttle body, as shown in Figure 55–8
- Built into the mass airflow (MAF) or airflow sensor
- Screwed into the intake manifold where it senses the temperature of the air entering the cylinders

NOTE: An IAT installed in the intake manifold is the most likely to suffer damage due to an engine backfire, which can often destroy the sensor.

The purpose and function of the intake air temperature sensor is to provide the engine computer (PCM) the temperature of the air entering the engine. The IAT sensor information is used for fuel control (adding or subtracting fuel) and spark timing, depending on the temperature of incoming air.

- If the air temperature is cold, the PCM will modify the amount of fuel delivery and add fuel.
- If the air temperature is hot, the PCM will subtract the calculated amount of fuel.
- Spark timing is also changed, depending on the temperature of the air entering the engine. The timing is advanced if the temperature is cold and retarded from the base programmed timing if the temperature is hot.
- Cold air is more dense, contains more oxygen, and therefore requires a richer mixture to achieve the proper air–fuel mixture. Air at 32°F (0°C) is 14% denser than air at 100°F (38°C).
- Hot air is less dense, contains less oxygen, and therefore requires less fuel to achieve the proper air–fuel mixture.

The IAT sensor is a low-authority sensor and is used by the computer to modify the amount of fuel and ignition timing as determined by the engine coolant temperature sensor.

The IAT sensor is used by the PCM as a backup in the event that the ECT sensor is determined to be inoperative.

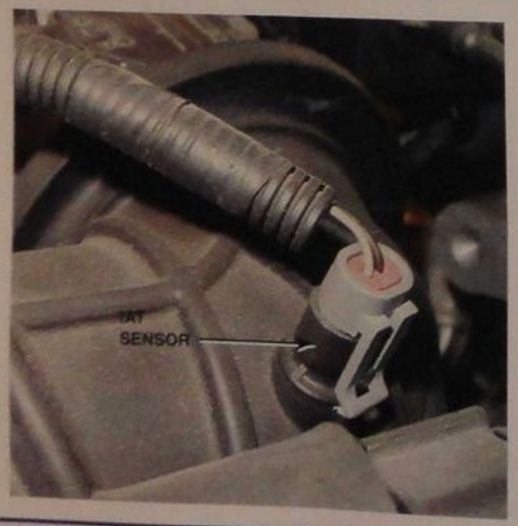


Figure 55–8 The IAT sensor on this General Motors 3800 V-6 engine is in the air passage duct between the air cleaner housing and the throttle plate.

NOTE: Some engines use a **throttle-body temperature (TBT)** sensor to sense the temperature of the air entering the engine, instead of an intake air temperature sensor.

Engine temperature is most accurately determined by looking at the engine coolant temperature (ECT) sensor. In certain conditions, the IAT has an effect on performance and driveability. One such condition is a warm engine being stopped in very cold weather. In this case, when the engine is restarted, the ECT may be near normal operating temperature such as 200(F (93°C) yet the air temperature could be −20°F (−30°C). In this case, the engine requires a richer mixture due to the cold air than the ECT would seem to indicate.

TECH TIP ✔ **Poor Fuel Economy? Black Exhaust Smoke? Look at the IAT**

If the intake air temperature sensor is defective, it may be signaling the computer that the intake air temperature is extremely cold when in fact it is warm. In such a case the computer will supply a mixture that is much richer than normal.

If a sensor is physically damaged or electrically open, the computer will often set a diagnostic trouble code (DTC). This DTC is based on the fact that the sensor temperature did not change for a certain amount of time, usually about 8 minutes. If, however, the wiring or the sensor itself has excessive resistance, a DTC will not be set and the result will be lower-than-normal fuel economy, and in serious cases, black exhaust smoke from the tailpipe during acceleration.

TESTING THE INTAKE AIR TEMPERATURE SENSOR

If the intake air temperature sensor circuit is damaged or faulty, a diagnostic trouble code (DTC) is set and the malfunction indicator lamp (MIL) may or may not turn on depending on the condition and the type and model of the vehicle. To diagnose the IAT sensor follow these steps:

Step #1 After the vehicle has been allowed to cool for several hours, use a scan tool, observe the IAT, and compare it to the engine coolant temperature (ECT). The two temperatures should be within 5°F of each other.

Step #2 Perform a thorough visual inspection of the sensor and the wiring. If the IAT is screwed into the intake manifold, remove the sensor and check for damage.

Step #3 Check the voltage and compare to the following chart.

Intake Air Temperature Sensor Temperature vs. Resistance and Voltage Drop (Approximate)

°C	°F	Ohms	Voltage Drop Across the Sensor
−40	−40	100,000	4.95
−30	−18	15,000	4.68
−8	32	9,400	4.52
0	50	5,700	4.25
10	68	3,500	3.89
20	86	2,200	3.46
30	104	1,500	2.97
40	122	1,000	2.47
50	140	700	2.00
60	158	500	1.59
70	176	300	1.25
80	194	250	0.97
90	212	200	0.75

FREQUENTLY ASKED QUESTION ???

What Exactly Is an NTC Sensor?

A negative temperature coefficient (NTC) thermistor is a semiconductor whose resistance decreases as the temperature increases. In other words, the sensor becomes more electrically conductive as the temperature increases. Therefore, when a voltage is applied, typically 5 volts, the signal voltage is high when the sensor is cold because the sensor has a high resistance and little current flows through to ground. See Figure 55–9.

However, when the temperature increases, the sensor becomes more electrically conductive and takes more of the 5 volts to ground, resulting in a lower signal voltage as the sensor warms.

TRANSMISSION FLUID TEMPERATURE SENSOR

The **transmission fluid temperature (TFT),** also called **transmission oil temperature (TOT),** sensor is an important sensor for the proper operation of the automatic transmission. A TFT sensor is a negative temperature coefficient (NTC) thermistor that decreases in resistance as the temperature of the sensor increases. See the following charts.

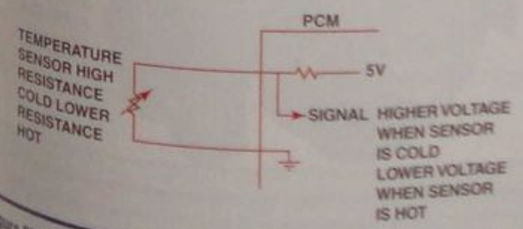


Figure 55–9 A typical temperature sensor circuit.

General Motors

Transaxle Sensor—Temperature to Resistance to Voltage (Approximate)

°C	°F	Resistance Ohms
0	32	7,987–10,859
10	50	4,934–6,407
20	68	3,106–3,923
30	86	1,991–2,483
40	104	1,307–1,611
50	122	878–1,067
60	140	605–728
70	158	425–507
80	176	304–359
90	194	221–259
100	212	163–190

Chrysler

Sensor Resistance (Ohms)—Transmission Temperature Sensor

°C	°F	Resistance Ohms
−40	−40	291,490–381,710
−20	−4	85,850–108,390
−10	14	49,250–61,430
0	32	29,330–35,990
10	50	17,990–21,810
20	68	11,370–13,610
25	77	9,120–10,880
30	86	7,370–8,750
40	104	4,900–5,750
50	122	3,330–3,880
60	140	2,310–2,670
70	158	1,630–1,870
80	176	1,170–1,340
90	194	860–970
100	212	640–720
110	230	480–540
120	248	370–410

Ford

Transmission Fluid Temperature

°C	°F	Resistance Ohms
−40 to −20	−40 to −4	967 K–284 K
−19 to −1	−3 to 31	284 K–100 K
0 to 20	32 to 68	100 K–37 K
21 to 40	69 to 104	37 K–16 K
41 to 70	105 to 158	16 K–5 K
71 to 90	159 to 194	5 K–2.7 K
91 to 110	195 to 230	2.7 K–1.5 K
111 to 130	231 to 266	1.5 K–0.8 K
131 to 150	267 to 302	0.8 K–0.54 K

The transmission fluid temperature signal is used by the power train control module (PCM) to perform certain strategies based on the temperature of the automatic transmission fluid. For example:

- If the temperature of the automatic transmission fluid is low (typically below 32°F (0°C)), the shift points may be delayed and overdrive disabled. The torque converter clutch also may not be applied to assist in the heating of the fluid.
- If the temperature of the automatic transmission fluid is high (typically above 260°F (130°C)), the overdrive is disabled and the torque converter clutch is applied to help reduce the temperature of the fluid.

NOTE: Check service information for the exact shift strategy based on high and low transmission fluid temperatures for the vehicle being serviced.

Cylinder Head Temperature Sensor Some vehicles are equipped with **cylinder head temperature (CHT)** sensors.

VW Golf 14°F (10°C) = 11,600 Ω
68°F (20°C) = 2,900 Ω
176°F (80°C) = 390 Ω

Engine Fuel Temperature (EFT) Sensor Some vehicles, such as many Ford vehicles that are equipped with an electronic returnless type of fuel injection, use an engine fuel temperature (EFT) sensor to give the PCM information regarding the temperature and, therefore, the density of the fuel.

Exhaust Gas Recirculation (EGR) Temperature Sensor Some engines, such as Toyota, are equipped with exhaust gas recirculation (EGR) temperature sensors. EGR is a well-established method for reduction of NO_x emissions in internal combustion engines. The exhaust gas contains unburned hydrocarbons, which are recirculated in the combustion process. Recirculation is controlled by valves, which operate as a function of exhaust gas speed, load, and temperature. The gas reaches a temperature of about 850°F (450°C) for which a special heavy-duty glass-encapsulated NTC sensor is available.

The PCM monitors the temperature in the exhaust passage between the EGR valve and the intake manifold. If the temperature increases when the EGR is commanded on, the PCM can determine that the valve or related components are functioning.

Engine Oil Temperature Sensor Engine oil temperature sensors are used on many General Motors' vehicles and are used as an input to the oil life monitoring system. The computer program inside the PCM calculates engine oil life based on run time, engine RPM, and oil temperature.

TEMPERATURE SENSOR DIAGNOSTIC TROUBLE CODES

The OBD-II diagnostic trouble codes that relate to temperature sensors include both high- and low-voltage codes, as well as intermittent codes.

Diagnostic Trouble Code	Description	Possible Causes
P0112	IAT sensor low voltage	• IAT sensor internally shorted-to-ground • IAT sensor wiring shorted-to-ground • IAT sensor damaged by backfire (usually associated with IAT sensors that are mounted in the intake manifold) • Possible defective PCM
P0113	IAT sensor high voltage	• IAT sensor internally (electrically) open • IAT sensor signal, circuit, or ground circuit open • Possible defective PCM
P0117	ECT sensor low voltage	• ECT sensor internally shorted to ground • The ECT sensor circuit wiring shorted-to-ground • Possible defective PCM
P0118	ECT sensor high voltage	• ECT sensor internally (electrically) open • ECT sensor signal, circuit, or ground circuit open • Engine operating in an overheated condition • Possible defective PCM

THROTTLE POSITION SENSORS

Most computer-equipped engines use a **throttle position (TP)** sensor to signal to the computer the position of the throttle. See Figure 55–10. The TP sensor consists of a potentiometer, a type of variable resistor.

Potentiometers A potentiometer is a variable-resistance sensor with three terminals. One end of the resistor receives reference voltage, while the other end is grounded. The third terminal is attached to a movable contact that slides across the resistor to vary its resistance. Depending on whether the contact is near the supply end or the ground end of the resistor, return voltage is high or low. See Figure 55–11.

Throttle position (TP) sensors are among the most common potentiometer-type sensors. The computer uses their input to determine the amount of throttle opening and the rate of change.

A typical sensor has three wires:

- A 5-volt reference feed wire from the computer
- A signal return (ground wire back to the computer)
- A voltage signal wire back to the computer; as the throttle is opened, the voltage to the computer changes



Figure 55–10 A typical TP sensor mounted on the throttle plate of this port-injected engine.

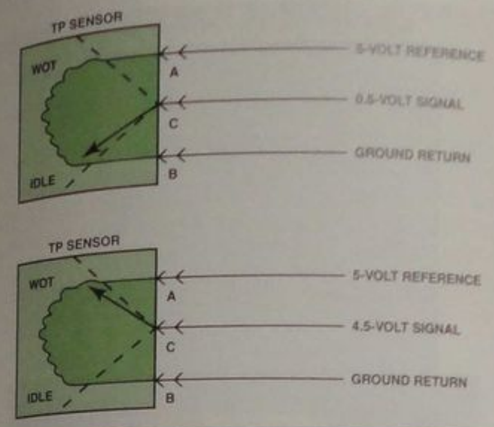


Figure 55–11 The signal voltage from a throttle position increases as the throttle is opened because the wiper arm is closer to the 5-volt reference. At idle, the resistance of the sensor winding effectively reduces the signal voltage output to the computer.

Normal throttle position voltage on most vehicles is about 0.5 volt at idle (closed throttle) and 4.5 volts at wide-open throttle (WOT).

HINT: The TP sensor voltage at idle is usually about 10% of the TP sensor voltage when the throttle is wide open, but can vary from as low as 0.3 volt to 1.2 volts, depending on the make and model of vehicle.

TP SENSOR COMPUTER INPUT FUNCTIONS

- The computer senses any change in throttle position and changes the fuel mixture and ignition timing. The actual change in fuel mixture and ignition timing is also partly determined by the other sensors, such as the manifold pressure (engine vacuum), engine RPM, the coolant temperature, and oxygen sensor(s). Some throttle position sensors are adjustable and should be set according to the exact engine manufacturer's specifications.
- The throttle position (TP) sensor used on fuel-injected vehicles acts as an "electronic accelerator pump." This means that the computer will pulse additional fuel from the injectors when the throttle is depressed. Because the air can quickly flow into the engine when the throttle is opened, additional fuel must be supplied to prevent the air–fuel mixture from going lean, causing the engine to hesitate when the throttle is depressed. If the TP sensor is unplugged or defective, the engine may still operate satisfactorily, but hesitate upon acceleration.
- The PCM supplies the TP sensor with a regulated voltage that ranges from 4.8 to 5.1 volts. This reference voltage is usually referred to as a 5-volt reference or "Vref." The TP output signal is an input to the PCM, and the TP sensor ground also flows through the PCM.

See the Ford throttle position (TP) sensor chart for an example of how sensor voltage changes with throttle angle.

NOTE: Generally, any reading higher than 80% represents wide-open throttle to the computer.

Ford Throttle Position (TP) Sensor Chart

Throttle Angle (Degrees)	Voltage (V)
0	0.50
10	0.97
20	1.44
30	1.90
40	2.37
50	2.84
60	3.31
70	3.78
80	4.24

PCM USES FOR THE TP SENSOR

The TP sensor is used by the power train control module (PCM) for the following reasons:

Clear Flood Mode If the throttle is depressed to the floor during engine cranking, the PCM will either greatly reduce or entirely eliminate any fuel-injector pulses to aid in cleaning a flooded engine. If the throttle is depressed to the floor and the engine is not flooded with excessive fuel, the engine may not start.

Torque Converter Clutch Engagement and Release The torque converter clutch will be released if the PCM detects rapid acceleration to help the transmission deliver maximum torque to the drive wheels. The torque converter clutch is also disengaged when the accelerator pedal is released with the vehicle moving to help engine braking.

Rationality Testing for MAP and MAF Sensors As part of the rationality tests for the MAP and/or MAF sensor, the TP sensor signal is compared to the reading from other sensors to determine if they match. For example, if the throttle position sensor is showing wide-open throttle (WOT), the MAP and/or MAF reading should also indicate that this engine is under a heavy load. If not, a diagnostic trouble code could be set for the TP, as well as the MAP and/or MAF sensors.

Automatic Transmission Shift Points The shift points are delayed if the throttle is opened wide to allow the engine speed to increase, thereby producing more power and aiding in the acceleration of the vehicle. If the throttle is barely open, the shift point occurs at the minimum speed designed for the vehicle.

Target Idle Speed (Idle Control Strategy) When the TP sensor voltage is at the idle, the PCM then controls idle speed using the idle air control (IAC) and/or spark timing variation to maintain the commanded idle speed. If the TP sensor indicates that the throttle has moved off idle, fuel delivery and spark timing are programmed for acceleration. Therefore, if the throttle linkage is stuck or binding, the idle speed may not be correct.

Air-Conditioning Compressor Operation The TP sensor is also used as an input sensor for traction control and air-conditioning compressor operation. If the PCM detects that the throttle is at or close to wide open, the air-conditioning compressor is disengaged.

Backs Up Other Sensors The TP sensor is used as a backup to the MAP sensor and/or MAF in the event the PCM detects that one or both are not functioning correctly. The PCM then calculates fuel needs and spark timing based on the engine speed (RPM) and throttle position.

TESTING THE THROTTLE POSITION SENSOR

A TP sensor can be tested using one or more of the following tools:

- A digital voltmeter with three test leads connected in series between the sensor and the wiring harness connector or back probing using T-pins.
- A scan tool or a specific tool recommended by the vehicle manufacturer.
- A breakout box that is connected in series between the computer and the wiring harness connector(s). A typical breakout box includes test points at which TP voltages can be measured with a digital voltmeter.
- An oscilloscope.

Use jumper wires, T-pins to back probe the wires, or a breakout box to gain electrical access to the wiring to the TP sensor. See Figure 55–12.

NOTE: The procedure that follows is the usual method used by many manufacturers. Always refer to service literature for the exact recommended procedure and specifications for the vehicle being tested.

The procedure for testing the sensor using a digital multimeter is as follows:

1. Turn the ignition switch on (engine off).
2. Measure the voltage between the signal wire and ground (reference low) wire. The voltage should be about 0.5 volt.

NOTE: Consult the service information for exact wire colors or locations.

3. With the engine still not running (but with the ignition still on), slowly increase the throttle opening. The voltage signal from the TP sensor should also increase. Look for any "dead spots" or open circuit readings as the throttle is increased to the wide-open position.



Figure 55–12 A meter lead connected to a T-pin that was gently pushed along the signal wire of the TP sensor until the point of the pin touched the metal terminal inside the plastic connector.

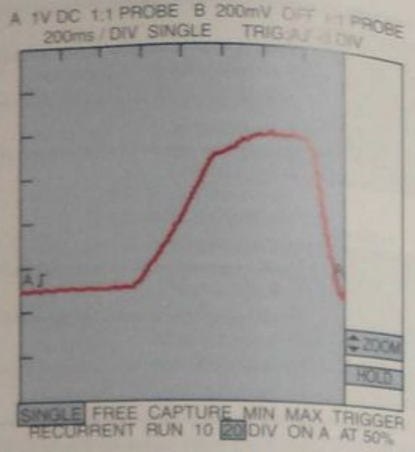


Figure 55–13 A typical waveform of a TP sensor signal as recorded on a DSO when the accelerator pedal was depressed with the ignition switch on (engine off). Clean transitions and the lack of any glitches in this waveform indicate a good sensor.

See Figure 55–13 for an example of how a good TP sensor would look when tested with a digital storage oscilloscope (DSO).

HINT: Use the accelerator pedal to depress the throttle because this applies the same forces on the TP sensor as the driver does during normal driving. Moving the throttle by hand under the hood may not accurately test the TP sensor.

4. With the voltmeter still connected, slowly return the throttle down to the idle position. The voltage from the TP sensor should also decrease evenly on the return to idle.

The TP sensor voltage at idle should be within the acceptable range as specified by the manufacturer. Some TP sensors can be adjusted by loosening their retaining screws and moving the sensor in relation to the throttle opening. This movement changes the output voltage of the sensor.

All TP sensors should also provide a smooth transition voltage reading from idle to WOT and back to idle. Replace the TP sensor if erratic voltage readings are obtained or if the correct setting at idle cannot be obtained.

TESTING A TP SENSOR USING THE MIN/MAX FUNCTION

Many digital multimeters are capable of recording voltage readings over time and then displaying the minimum, maximum, and average readings. To perform a min/max test of the TP sensor, manually set the meter to read higher than 4 volts.

Step #1 Connect the red meter lead to the signal wire and the black meter lead to a good ground on the ground return wire at the TP sensor.

Step #2 With the ignition on, engine off, slowly depress and release the accelerator pedal from inside the vehicle.

Step #3 Check the minimum and maximum voltage reading on the meter display. Any 0- or 5-volt reading would indicate a fault or short in the TP sensor.

TECH TIP **Check Power and Ground Before Condemning a Bad Sensor**

Most engine sensors use a 5-volt reference and a ground. If the 5 volts to the sensor is too high (shorted to voltage) or too low (high resistance), then the sensor output will be **skewed** or out of range. Before replacing the sensor that did not read correctly, measure both the 5-volt reference and ground. To measure the ground, simply turn the ignition on (engine off) and touch one test lead of a DMM set to read DC volts to the sensor ground and the other to the negative terminal of the battery. Any reading higher than 0.2 volt (200 mV) represents a poor ground. See Figures 55–14 and 55–15.

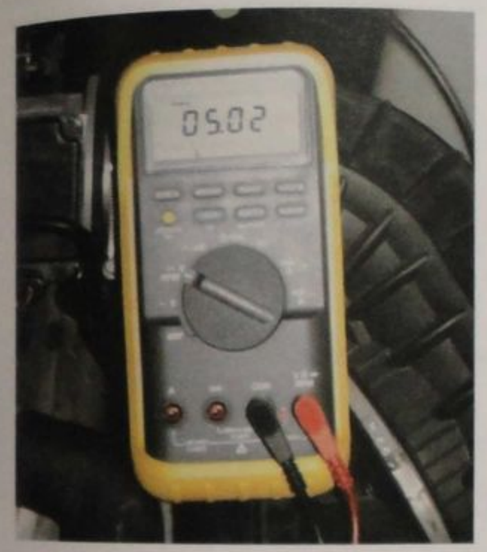


Figure 55–14 Checking the 5-volt reference from the computer being applied to the TP sensor with the ignition switch on (engine off).



Figure 55–15 Checking the voltage drop between the TP sensor ground and a good engine ground with the ignition on (engine off). A reading of greater than 0.6 volt (600 mV) represents a bad computer ground.

TESTING THE TP SENSOR USING A SCAN TOOL

A scan tool can be used to check for proper operation of the throttle position sensor using the following steps:

Step #1 With the key on, engine off, the TP sensor voltage display should be about 0.5 volt, but can vary from as low as 0.3 volt to as high as 1.2 volts.

Step #2 Check the scan tool display for the percentage of throttle opening. The reading should be zero and gradually increase in percentage as the throttle is depressed.

Step #3 The idle air control (IAC) counts should increase as the throttle is opened and decrease as the throttle is closed. Start the engine and observe the IAC counts as the throttle is depressed.

Step #4 Start the engine and observe the TP sensor reading. Use a wedge or thin object to increase the throttle opening slightly. The throttle percentage reading should increase. Shut off and restart the engine. If the percentage of throttle opening returns to 0%, the PCM determines that the increased throttle opening is now the new minimum and resets the idle position of the TP sensor. Remove the wedge and cycle the ignition key. The throttle position sensor should again read zero percentage.

NOTE: Some engine computers are not capable of resetting the throttle position sensor.

TP SENSOR DIAGNOSTIC TROUBLE CODES

The diagnostic trouble codes (DTCs) associated with the throttle position sensor include the following:

Diagnostic Trouble Code	Description	Possible Causes
P0122	TP sensor low voltage	• TP sensor internally shorted-to-ground • TP sensor wiring shorted-to-ground • TP sensor or wiring open
P0123	TP sensor high voltage	• TP sensor internally shorted to 5-volt reference • TP sensor ground open • TP sensor wiring shorted-to-voltage
P0121	TP sensor signal does not agree with MAP	• Defective TP sensor • Incorrect vehicle-speed (VS) sensor signal • MAP sensor out-of-calibration or defective

MAP/BARO SENSORS

Air Pressure—High and Low You can think of an internal combustion engine as a big air pump. As the pistons move up and down in the cylinders, they pump in air and fuel for combustion and pump out exhaust gases. They do this by creating a difference in air pressure. The air outside an engine has weight and exerts pressure, as does the air inside an engine.

As a piston moves down on an intake stroke with the intake valve open, it creates a larger area inside the cylinder for the air to fill. This lowers the air pressure within the engine. Because the pressure inside the engine is lower than the pressure outside, air flows into the engine to fill the low-pressure area and equalizes the pressure.

The low pressure within the engine is called **vacuum.** Vacuum causes the higher-pressure air on the outside to flow into the low-pressure area inside the cylinder. The difference in pressure between the two areas is called a **pressure differential.** See Figure 55–16.

PRINCIPLES OF PRESSURE SENSORS

Intake manifold pressure changes with changing throttle positions. At wide-open throttle, manifold pressure is almost the same as atmospheric pressure. On deceleration or at idle, manifold pressure

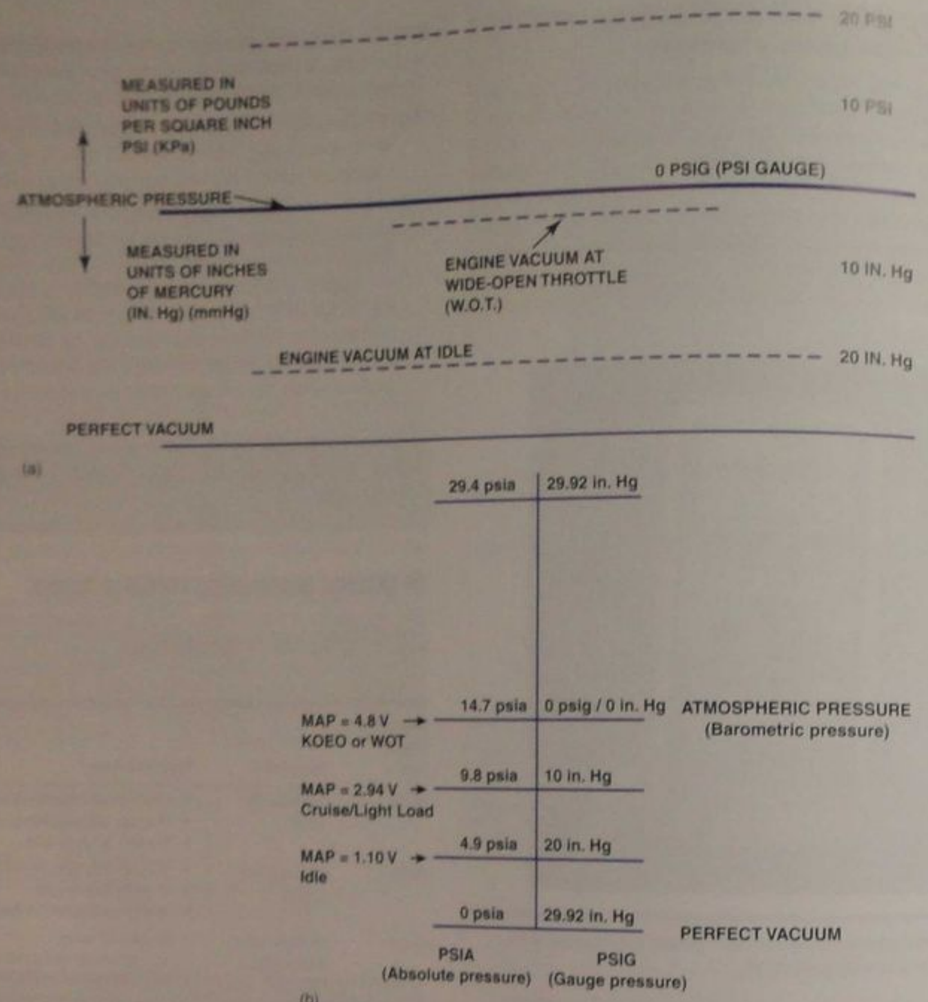


Figure 55–16 (a) As an engine is accelerated under a load, the engine vacuum drops. This drop in vacuum is actually an increase in absolute pressure in the intake manifold. A MAP sensor senses all pressures greater than that of a perfect vacuum. (b) The relationship between absolute pressure, vacuum, and gauge pressure.

is below atmospheric pressure, thus creating a vacuum. In cases where turbo charging or supercharging is used, under part- or full-load condition, intake manifold pressure rises above atmospheric. Also, oxygen content and barometric pressure change with differences in altitude and the computer must be able to compensate by making changes in the flow of fuel entering the engine. The engine type that uses the MAP sensor to determine the amount of fuel needed is called a **speed density** system. To provide the computer with changing airflow information, a fuel-injection system may use:

- Manifold absolute pressure (MAP) sensor
- Manifold absolute pressure (MAP) sensor plus barometric absolute pressure (BARO) sensor
- Barometric and manifold absolute pressure sensors combined (BMAP)

The **manifold absolute pressure (MAP)** sensor may be a ceramic capacitor diaphragm, an aneroid bellows, or a piezoresistive crystal. It has a sealed vacuum reference input on one side; the other side is connected (vented) to the intake manifold. This sensor housing also contains signal conditioning circuitry. See Figure 55–17.

Pressure changes in the manifold cause the sensor to deflect, varying its analog or digital return signal to the computer. As the air

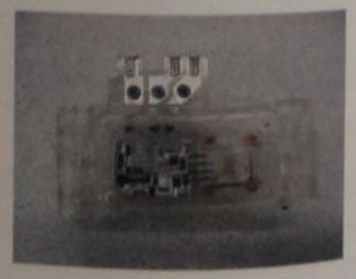


Figure 55–17 A plastic MAP sensor used for training purposes showing the electronic circuit board and electrical connections.

pressure increases, the MAP sensor generates a higher voltage or higher frequency return signal to the computer.

CONSTRUCTION OF MANIFOLD ABSOLUTE PRESSURE (MAP) SENSORS

The manifold absolute pressure (MAP) sensor is used by the engine computer to sense engine load. The typical MAP sensor consists of a ceramic or silicon wafer sealed on one side with a perfect vacuum and exposed to intake manifold vacuum on the other side. As the engine vacuum changes, the pressure difference on the wafer changes the output voltage or frequency of the MAP sensor.

A manifold absolute pressure (MAP) sensor is used on many engines for the PCM to determine the load on the engine. The relationship among barometer pressure, engine vacuum, and MAP sensor voltage includes:

- Absolute pressure is equal to barometric pressure minus intake manifold vacuum.
- A decrease in manifold vacuum means an increase in manifold pressure.
- The MAP sensor compares manifold vacuum to a perfect vacuum.
- Barometric pressure minus MAP sensor reading equals intake manifold vacuum.
  Normal engine vacuum is 17 to 21 in. Hg.
- Supercharged and turbocharged engines require a MAP sensor that is calibrated for pressures above atmospheric, as well as for vacuum.

Silicon-Diaphragm Strain Gauge MAP Sensor This is the most commonly used design for a MAP sensor and the output is a DC analog (variable) voltage. One side of a silicon wafer is exposed to engine vacuum and the other side is exposed to a perfect vacuum.

There are four resistors attached to the silicon wafer, which changes in resistance when strain is applied to the wafer. This change in resistance due to strain is called **piezoresistivity.** The resistors are electrically connected to a Wheatstone bridge circuit and then to a differential amplifier, which creates a voltage in proportion to the vacuum applied.

A typical General Motors MAP sensor voltage varies from 0.88 to 1.62 at engine idle at or near sea level.

- 17 in. Hg is equal to about 1.62 volts
- 21 in. Hg is equal to about 0.88 volt

Therefore, a good reading should be about 1.0 volt from the MAP sensor on a sound engine at idle speed.

Engine Load	Manifold Vacuum	Manifold Absolute Pressure	MAP Sensor Volt Signal
Heavy (WOT)	Low (almost 0 in. Hg)	High (almost atmospheric)	High (4.6–4.8 V)
Light (idle)	High (17–21 in. Hg)	Low (lower than atmospheric)	Low (0.8–1.6 V)

Capacitor—Capsule MAP Sensor A capacitor-capsule is a type of MAP sensor used by Ford which uses two ceramic (alumina) plates with an insulating washer spacer in the center to create a capacitor. Changes in engine vacuum cause the plates to deflect, which changes the capacitance. The electronics in the sensor then generate a varying digital frequency output signal, which is proportional to the engine vacuum. See Figure 55–18. See Figure 55–19 for a scope waveform of a digital MAP sensor.

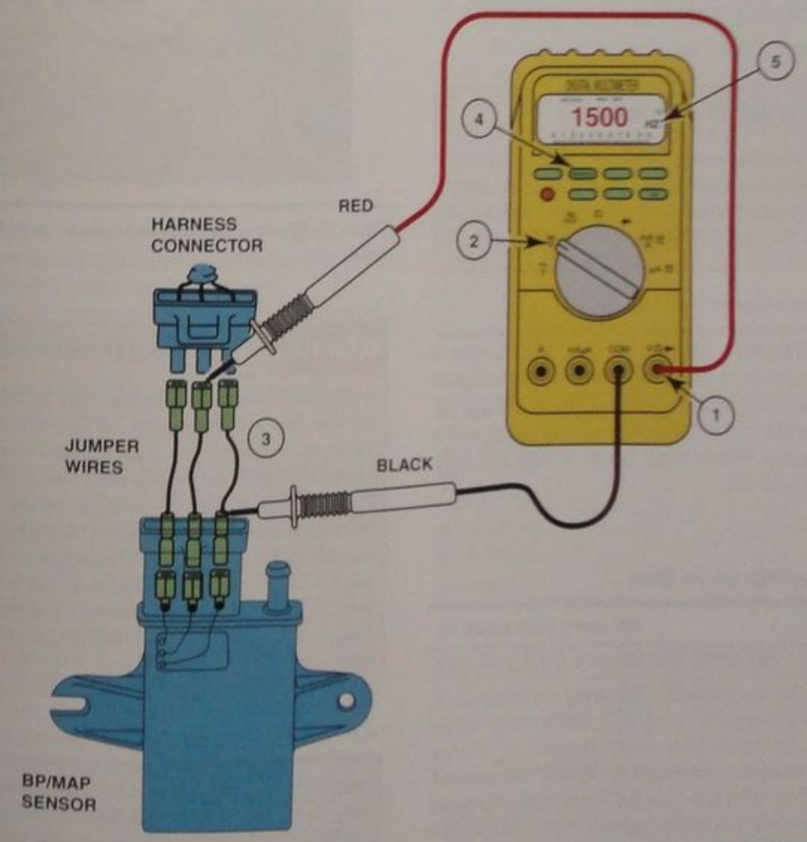


Figure 55–18 A DMM set to test a MAP sensor. (1) Connect the red meter lead to the V meter terminal and the black meter lead to the COM meter terminal. (2) Select DC volts. (3) Connect the test leads to the sensor signal wire and the ground wire. (4) Select hertz (Hz) if testing a MAP sensor whose output is a varying frequency; otherwise keep it on DC volts. (5) Read the change of frequency as the vacuum is applied to the sensor. Compare the vacuum reading and the frequency (or voltage) reading to the specifications. *(Courtesy of Fluke Corporation)*

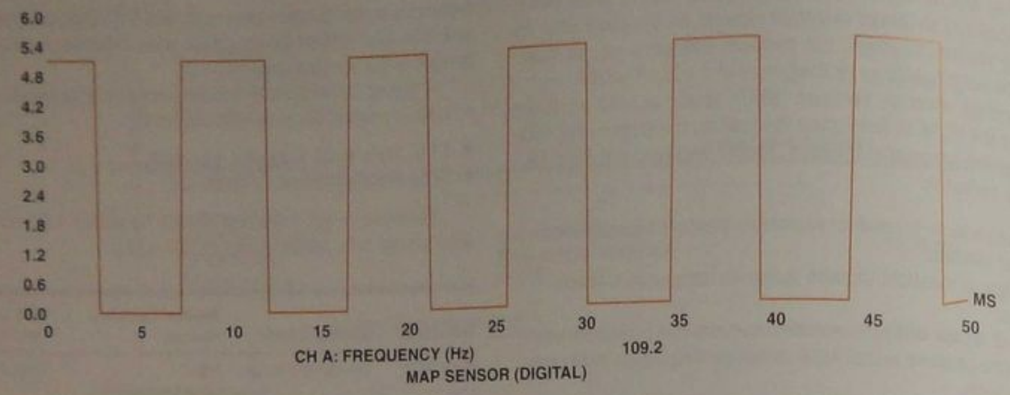


Figure 55–19 A waveform of a typical digital MAP sensor.

Ford MAP Sensor Chart

MAP Sensor Output (Hz)	Engine Operating Conditions	Intake Manifold Vacuum (in. Hg)
156–159 Hz	Key on, engine off	0 in. Hg
102–109 Hz	Engine at idle (sea level)	17–21 in. Hg
156–159 Hz	Engine at wide-open throttle (WOT)	About 0 in. Hg

TECH TIP ✔ **If It's Green, It's a Signal Wire**

Ford-built vehicles usually use a green wire as the signal wire back to the computer from the sensors. It may not be a solid green, but if there is green somewhere on the wire, then it is the signal wire. The other wires are the power and ground wires to the sensor.

Ceramic Disc MAP Sensor The ceramic disc MAP sensor is used by Chrysler and it converts manifold pressure into a capacitance discharge. The discharge controls the amount of voltage delivered by the sensor to the PCM. The output is the same as the previously used strain gauge/Wheatstone bridge design and is interchangeable. See Figure 55–20.

Chrysler MAP Sensor Chart

Vacuum (in. Hg)	MAP Sensor Signal Voltage (V)
0.5	4.8
1.0	4.6
3.0	4.1
5.0	3.8
7.0	3.5
10.0	2.9
15.0	2.1
20.0	1.2
25.0	0.5



Figure 55–20 A ceramic-disc-type MAP sensor showing the substrate and the circuit.

TECH TIP ✔ **Use the MAP Sensor as a Vacuum Gauge**

A MAP sensor measures the pressure inside the intake manifold compared with absolute zero (perfect vacuum). For example, an idling engine that has 20 inches of mercury (in. Hg) of vacuum has a lower pressure inside the intake manifold than when the engine is under a load and the vacuum is at 10 in. Hg. A decrease in engine vacuum results in an increase in manifold pressure. A normal engine should produce between 17 and 21 in. Hg at idle. Comparing the vacuum reading with the voltage reading output of the MAP sensor indicates that the reading should be between 1.62 and 0.88 volt or 109 to 102 Hz or lower on Ford MAP sensors. Therefore, a digital multimeter (DMM), scan tool, or scope can be used to measure the MAP sensor voltage and be used instead of a vacuum gauge.

NOTE: This chart was developed by testing a MAP sensor at a location about 600 feet above sea level. For best results, a chart based on your altitude should be made by applying a known vacuum, and reading the voltage of a known-good MAP sensor. Vacuum usually drops about 1 inch per 1,000 feet of altitude.

Vacuum (in. Hg)	GM (volts)	Ford (Hz)
	4.80	156–159
0	4.52	
1	4.46	
2	4.26	
3	4.06	
4	3.88	141–143
5	3.66	
6	3.50	
7	3.30	
8	3.10	
9	2.94	127–130
10	2.76	
11	2.54	
12	2.36	
13	2.20	
14	2.00	114–117
15	1.80	
16	1.62	
17	1.42	108–109
18	1.20	
19	1.10	102–104
20	0.88	
21	0.66	
22		

PCM USES OF THE MAP SENSOR

The PCM uses the MAP sensor to determine the following:

- **The load on the engine.** The MAP sensor is used on a speed-density-type fuel-injector system to determine the load on the engine, and therefore the amount of fuel needed. On engines equipped with a mass air flow (MAF) sensor, the MAP is used as a backup to the MAF, for diagnosis of other sensors, and systems such as the EGR system.
- **Altitude, fuel, and spark control calculations.** At key on, the MAP sensor determines the altitude (acts as a BARO sensor) and adjusts the fuel delivery and spark timing accordingly.
  - If the altitude is high, generally over 5,000 feet (1,500 meters), the PCM will reduce fuel delivery and advance the ignition timing.
  - The altitude is also reset when the engine is accelerated to wide-open throttle and the MAP sensor is used to reset the altitude reading. See Figure 55–21.
- **EGR system operation.** As part of the OBD-II standards, the exhaust gas recirculation (EGR) system must be checked for proper operation. One method used by many vehicle manufacturers is to command the EGR valve on and then watch the MAP sensor signal. The opening of the EGR pintle should decrease engine vacuum. If the MAP sensor does not react with the specified drop in manifold vacuum (increase in manifold pressure), an EGR flow rate problem diagnostic trouble code is set.
- **Detect deceleration (vacuum increases).** The engine vacuum rises when the accelerator is released, which changes the MAP sensor voltage. When deceleration is detected by the PCM, fuel is either stopped or greatly reduced to improve exhaust emissions.
- **Monitor engine condition.** As an engine wears, the intake manifold vacuum usually decreases. The PCM is programmed to detect the gradual change in vacuum and is able to keep the air–fuel mixture in the correct range. If the PCM were not capable of making adjustments for engine wear, the lower vacuum could be interpreted as increased load on the engine, resulting in too much fuel being injected, thereby reducing fuel economy and increasing exhaust emissions.
- **Load detection for returnless-type fuel injection.** On fuel delivery systems that do not use a return line back to the fuel tank, the engine load calculation for the fuel needed is determined by the signals from the MAP sensor.
- **Altitude and map sensor values.** On an engine equipped with a speed-density-type fuel injection, the MAP sensor is the most important sensor needed to determine injection pulse width. Changes in altitude change the air density as well as weather conditions. Barometric pressure and altitude are inversely related:
  - As altitude increases—barometric pressure decreases
  - As altitude decreases—barometric pressure increases

As the ignition switch is rolled from off to the start position, the PCM reads the MAP sensor value to determine atmospheric and air pressure conditions. This barometric pressure reading is updated every time the engine is started and whenever wide-open throttle is detected. The barometric pressure reading at that time is updated. See the chart that compares altitude to MAP sensor voltage.

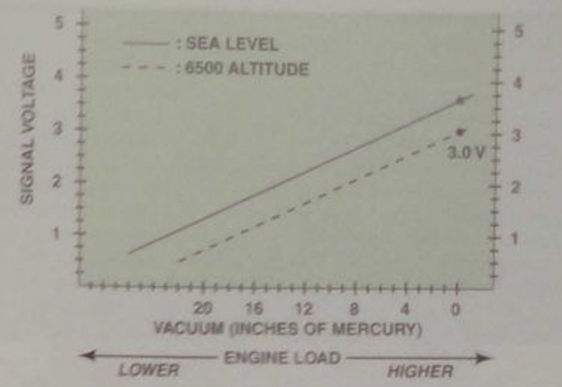


Figure 55–21 Altitude affects the MAP sensor voltage.

Altitude and MAP Sensor Voltage

Altitude	MAP Sensor Voltage (Can Vary Due to Atmospheric Conditions)
Sea level	4.6 to 4.8 volts
2,500 (760 m)	4.0 volts
5,000 (1520 m)	3.7 volts
7,500 (2300 m)	3.35 volts
10,000 (3050 m)	3.05 volts
12,500 (3800 m)	2.80 volts
15,000 (4600 m)	2.45 volts

BAROMETRIC PRESSURE SENSOR

A **barometric pressure (BARO)** sensor is similar in design, but senses more subtle changes in barometric absolute pressure (atmospheric air pressure). It is vented directly to the atmosphere. The **barometric manifold absolute pressure (BMAP)** sensor is actually a combination of a BARO and MAP sensor in the same housing. The BMAP sensor has individual circuits to measure barometric and manifold pressure. This input not only allows the computer to adjust for changes in atmospheric pressure due to weather, but also is the primary sensor used to determine altitude.

NOTE: A MAP sensor and a BARO sensor are usually the same sensor, but the MAP sensor is connected to the manifold and a BARO sensor is open to the atmosphere. The MAP sensor is capable of reading barometric pressure due to the ignition switch is turned to the on position before the engine starts. Therefore, altitude and weather changes are available to the computer. During intermittent driving, it may be an advantage to stop and then restart the engine so that the engine computer can take another barometric pressure reading and recalibrate that sensor based on the new altitude. See the Ford MAP/BARO altitude chart for an example of how altitude affects intake manifold pressure. The computer on some vehicles will monitor the throttle position sensor and use the MAP sensor reading at wide-open throttle (WOT) to update the BARO sensor if it has changed during driving.

Ford MAP/BARO Altitude Chart

Altitude (feet)	Volts (V)
0	1.59
1,000	1.56
2,000	1.53
3,000	1.50
4,000	1.47
5,000	1.44
6,000	1.41
7,000	1.38

NOTE: Some older Chrysler-based vehicles were equipped with a combination BARO and IAT sensor. The sensor was mounted on the bulkhead (firewall), and sensed the under-hood air temperature.

REAL WORLD FIX **The Cavalier Convertible Story**

The owner of a Cavalier convertible stalled to a service technician that the "check engine" (MIL) was on. The technician found a diagnostic trouble code (DTC) for a MAP sensor. The technician removed the hose at the MAP sensor and discovered that gasoline had accumulated in the sensor and dripped out of the hose as it was being removed. The technician replaced the MAP sensor and test drove the vehicle to confirm the repair. Almost at once the check engine light came on with the same MAP sensor code. After several hours of troubleshooting without success in determining the cause, the technician decided to start over again. Almost at once, the technician discovered that no vacuum was getting to the MAP sensor where a vacuum gauge was connected with a T-fitting in the vacuum line to the MAP sensor. The vacuum port in the base of the throttle body was clogged with carbon. After a thorough cleaning and clearing the DTC, the Cavalier again performed properly and the check engine light did not come on again. The technician had assumed that if gasoline was able to reach the sensor through the vacuum hose, surely vacuum could reach the sensor. The technician learned to stop assuming when diagnosing a vehicle and concentrate more on testing the simple things first.

TESTING THE MAP SENSOR

Most pressure sensors operate on 5 volts from the computer and return a signal (voltage or frequency) based on the pressure (vacuum) applied to the sensor. If a MAP sensor is being tested, make certain that the vacuum hose and hose fittings are sound and making a good, tight connection to a manifold vacuum source on the engine.

Four different types of test instruments can be used to test a pressure sensor:

1. A digital voltmeter with three test leads connected in series between the sensor and the wiring harness connector or back probe the terminals.
2. A scope connected to the sensor output, power, and ground.
3. A scan tool or a specific tool recommended by the vehicle manufacturer.
4. A breakout box connected in series between the computer and the wiring harness connection(s). A typical breakout box includes test points at which pressure sensor values can be measured with a digital voltmeter (or frequency counter, if a frequency-type MAP sensor is being tested).

NOTE: Always check service information for the exact testing procedure and specifications for the vehicle being tested.

Testing the MAP Sensor Using a DMM or Scope Use jumper wires or T-pins to back probe the connector, or a breakout box to gain electrical access to the wiring to the pressure sensor. Most pressure sensors use three wires:

1. A 5-volt wire from the computer
2. A variable-signal wire back to the computer
3. A ground or reference low wire

The procedure for testing the sensor is as follows:

1. Turn the ignition on (engine off).
2. Measure the voltage (or frequency) of the sensor output.
3. Using a hand-operated vacuum pump (or other variable vacuum source), apply vacuum to the sensor.

A good pressure sensor should change voltage (or frequency) in relation to the applied vacuum. If the signal does not change or the values are out of range according to the manufacturers' specifications, the sensor must be replaced.

TECH TIP **Visual Check of the MAP Sensor**

A defective vacuum hose to a MAP sensor can cause a variety of driveability problems including poor fuel economy, hesitation, stalling, and rough idle. A small air leak (vacuum leak) around the hose can cause these symptoms and often set a trouble code in the vehicle computer. When working on a vehicle that uses a MAP sensor, make certain that the vacuum hose travels consistently downward on its route from the sensor to the source of manifold vacuum. Inspect the hose, especially if another technician has previously replaced the factory-original hose. It should not be so long that it sags down at any point. Condensed fuel and/or moisture can become trapped in this low spot in the hose and cause all types of driveability problems and MAP sensor codes.

When checking the MAP sensor, if anything comes out of the sensor itself, it should be replaced. This includes water, gasoline, or any other substance.

Testing the Map Sensor Using a Scan Tool A scan tool can be used to test a MAP sensor by monitoring the injector pulse width (in milliseconds) when vacuum is being applied to the MAP sensor using a hand-operated vacuum pump. See Figure 55–22.

Step #1 Apply about 20 in. Hg of vacuum to the MAP sensor and start the engine.



Figure 55–22 A typical hand-operated vacuum pump.

Step #2 Observe the injector pulse width. On a warm engine, the injector pulse width will normally be 1.5 to 3.5 ms.

Step #3 Slowly reduce the vacuum to the MAP sensor and observe the pulse width. A lower vacuum to the MAP sensor indicates a heavier load on the engine and the injector pulse width should increase.

NOTE: If 23 in. Hg or more vacuum is applied to the MAP sensor with the engine running, this high vacuum will often stall the engine. The engine will become the high vacuum is interpreted by the PCM to indicate that the engine is being decelerated, which shuts off the fuel. During engine deceleration, the PCM shuts off the fuel injectors to reduce exhaust emissions and increase fuel economy.

FUEL-RAIL PRESSURE SENSOR

A fuel-rail pressure (FRP) sensor is used on some vehicles such as Ford that are equipped with electronic returnless fuel injection. This sensor provides fuel pressure information to the PCM for fuel injection pulse width calculations.

MAP/BARO DIAGNOSTIC TROUBLE CODES

The diagnostic trouble codes (DTCs) associated with the MAP and BARO sensors include:

Diagnostic Trouble Code	Description	Possible Causes
P0106	BARO sensor out-of-range at key on	• MAP sensor fault • MAP sensor O-ring damaged or missing
P0107	MAP sensor low voltage	• MAP sensor fault • MAP sensor signal circuit shorted-to-ground • MAP sensor 5-volt supply circuit open
P0108	Map sensor high voltage	• MAP sensor fault • MAP sensor O-ring damaged or missing • MAP sensor signal circuit shorted-to-voltage

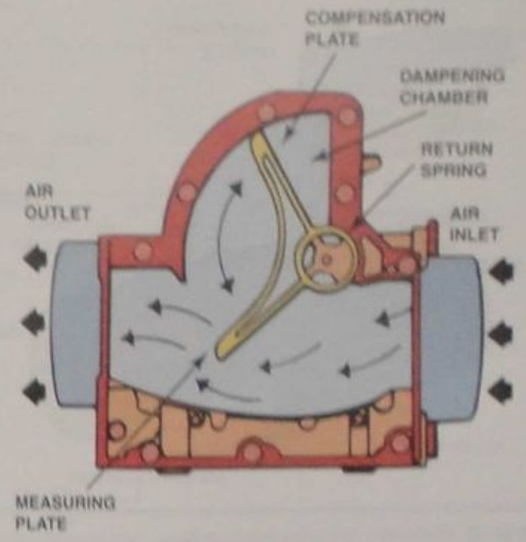


Figure 55–23 A vane airflow (VAF) sensor.

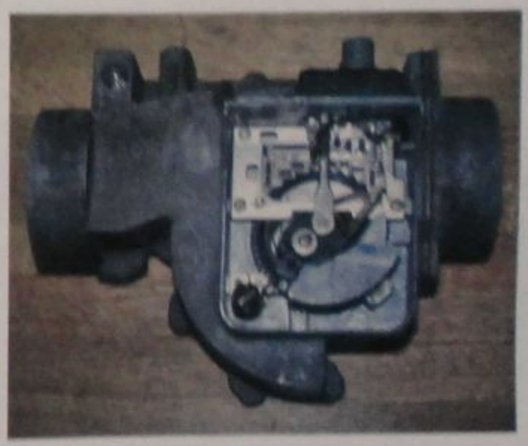


Figure 55–24 A typical air vane sensor with the cover removed. The movable arm contacts a carbon resistance path as the vane opens. Many air vane sensors also have contacts that close to supply voltage to the electric fuel pump as the air vane starts to open when the engine is being cranked and air is being drawn into the engine.

AIRFLOW SENSORS

Older port fuel-injection systems that use airflow volume for fuel calculation usually have a movable vane in the intake stream. The vane is part of the **vane airflow (VAF)** sensor. The vane is deflected by intake air flow. See Figure 55–23.

The vane airflow sensor used in Bosch L-Jetronic, Ford, and most Japanese electronic port fuel-injection systems is a movable vane connected to a laser-calibrated potentiometer. The vane is mounted on a pivot pin and is deflected by intake airflow proportionate to air velocity. As the vane moves, it also moves the potentiometer. This causes a change in the signal voltage supplied to the computer. See Figure 55–24.

For example, if the reference voltage is 5 volts, the potentiometer's signal to the computer will vary from a 0 voltage signal (no airflow) to almost a 5-volt signal (maximum airflow). In this way, the potentiometer provides the information the computer needs to vary the injector pulse width proportionate to airflow. There is a special "dampening chamber" built into the VAF to

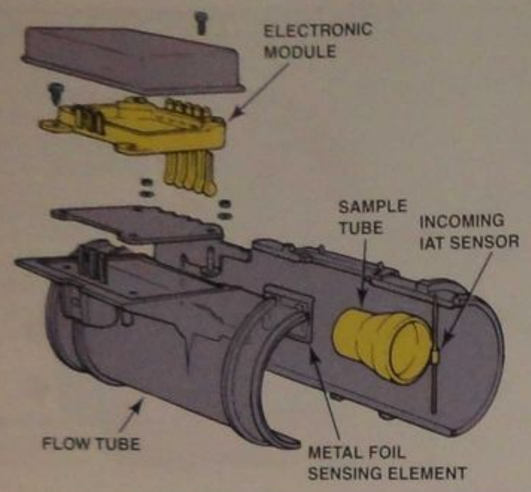


Figure 55–25 This five-wire mass airflow sensor consists of a metal foil sensing unit, an intake air temperature (IAT) sensor, and the electronic module.

smooth out vane pulsations which would be created by intake manifold air-pressure fluctuations caused by the valve opening and closing. Many vane airflow sensors include a switch to energize the electric fuel pump. This is a safety feature that prevents the operation of the fuel pump if the engine stalls.

ANALOG AND DIGITAL MAF SENSORS

Some MAF sensors produce a digital DC voltage signal whose frequency changes with the amount of airflow through the sensor. The frequency range also varies with the make of sensor and can range from 0- to 300-Hz for older General Motors MAF sensors to 1,000- to 9,000-Hz for most newer designs.

Some MAF sensors, such as those used by Ford and others, produce a changing DC voltage, rather than frequency, and range from 0- to 5-volts DC.

MASS AIRFLOW SENSOR TYPES

There are several types of mass airflow sensors.

Hot Film Sensor The **hot film sensor** uses a temperature-sensing resistor (thermistor) to measure the temperature of the incoming air. Through the electronics within the sensor, a conductive film is kept at a temperature 70°C above the temperature of the incoming air. See Figure 55–25.

Because the amount and density of the air both tend to contribute to the cooling effect as the air passes through the sensor, this type of sensor can actually produce an output based on the *mass* of the airflow. *Mass equals volume times density.* For example, cold air is denser than warm air so a small amount of cold air may have the same mass as a larger amount of warm air. Therefore, a mass airflow sensor is designed to measure the mass, not the volume, of the air entering the engine.

The output of this type of sensor is usually a frequency based on the amount of air entering the sensor. The more air that enters the sensor, the more the hot film is cooled. The electronics inside the sensor, therefore, increase the current flow through the hot film to maintain the 70°C temperature differential between the air temperature and the temperature of the hot film. This change in current flow is converted to a frequency output that the computer can use as a measurement of air flow. Most of these types of sensors are referred to as **mass airflow (MAF) sensors** because, unlike the air vane sensor, the MAF sensor takes into account relative humidity, altitude, and temperature of the air. The denser the air, the greater the cooling effect on the hot film sensor and the greater the amount of fuel required for proper combustion.

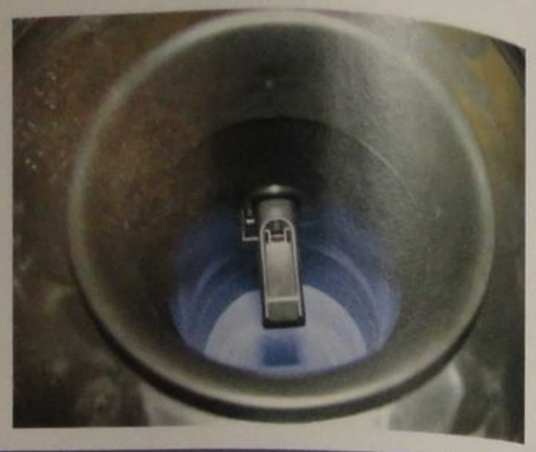


Figure 55–26 The sensing wire in a typical hot wire mass airflow sensor.

Hot Wire Sensor The **hot wire sensor** is similar to the hot film type, but uses a hot wire to sense the mass airflow instead of the hot film. Like the hot film sensor, the hot wire sensor uses a temperature-sensing resistor (thermistor) to measure the temperature of the air entering the sensor. See Figure 55–26. The electronic circuitry within the sensor keeps the temperature of the wire at 70°C above the temperature of the incoming air.

Both designs operate in essentially the same way. A resistor wire or screen installed in the path of intake airflow is heated to a constant temperature by electric current provided by the computer. Air flowing past the screen or wire cools it. The degree of cooling varies with air velocity, temperature, density, and humidity. These factors combine to indicate the mass of air entering the engine. As the screen or wire cools, more current is required to maintain the specified temperature. As the screen or wire heats up, less current is required. The operating principle can be summarized as follows:

- More intake air volume = cooler sensor, more current.
- Less intake air volume = warmer sensor, less current.

The computer constantly monitors the change in current and translates it into a voltage signal that is used to determine injector pulse width.

Burn-Off Circuit Some MAF sensors use a burn-off circuit to keep the sensing wire clean of dust and dirt. A high current is passed through the sensing wire for a short time, but long enough to cause the wire to glow due to the heat. The burn-off circuit is turned on when the ignition switch is switched off after the engine has been operating long enough to achieve normal operating temperature.

KARMAN VORTEX SENSORS

In 1912, a Hungarian scientist named Theodore Van Karman observed that vortexes were created when air passed over a pointed surface. This type of sensor sends a sound wave through the turbulence created by incoming air passing through the sensor. Air mass is calculated based on the time required for the sound waves to cross the turbulent air passage.

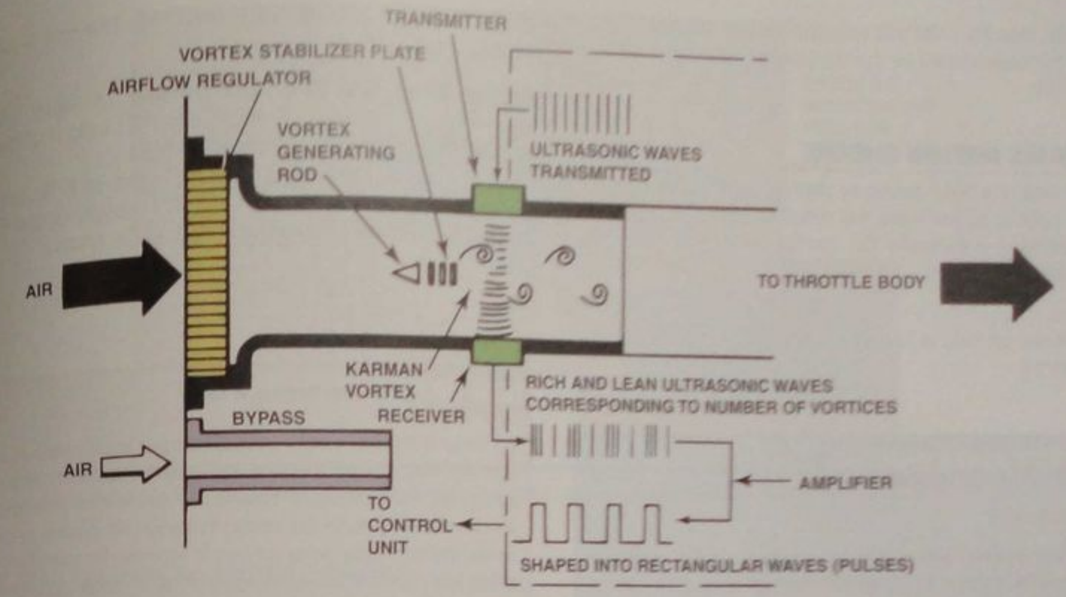


Figure 55–27 A Karman Vortex airflow sensor uses a triangle-shaped rod to create vortexes as the air flows through the sensor. The electronics in the sensor itself converts these vortexes to a digital square wave signal.

There are two basic designs of **Karman Vortex** airflow sensors. The two types include:

- **Ultrasonic.** This type of sensor uses ultrasonic waves to detect the vortexes that are produced, and produce a digital (on and off) signal where frequency is proportional to the amount of air passing through the sensor. See Figure 55–27.
- **Pressure-type.** Chrysler uses a pressure-type Karman Vortex sensor that uses a pressure sensor to detect the vortexes. As the airflow through the sensor increases, so do the number of pressure variations. The electronics in the sensor convert these pressure variations to a square wave (digital DC voltage) signal, whose frequency is in proportion to the airflow through the sensor.

REAL WORLD FIX

The Dirty MAF Sensor Story

The owner of a Buick Park Avenue equipped with a 3800 V-6 engine complained that the engine would hesitate during acceleration, showed lack of power, and seemed to surge or miss at times. A visual inspection found everything to be like new, including a new air filter. There were no stored diagnostic trouble codes (DTCs). A look at the scan data showed airflow to be within the recommended 3 to 7 grams per second. A check of the frequency output showed the problem.

Idle frequency = 2.177 kHz (2,177 Hz)

Normal frequency at idle speed should be 2.37 to 2.52 kHz. Cleaning the hot wire of the MAF sensor restored proper operation. The sensor wire was covered with what looked like fine fibers, possibly from the replacement air filter.

NOTE: Older GM MAF sensors operated at a lower frequency of 32 to 150 Hz, with 32 Hz being the average reading at idle and 150 Hz for wide-open throttle.

FREQUENTLY ASKED QUESTION ???

What Is Meant by a "High-Authority Sensor?"

A high-authority sensor is a sensor that has a major influence over the amount of fuel being delivered to the engine. For example, at engine start-up, the engine coolant temperature (ECT) sensor is a high-authority sensor and the oxygen sensor (O2S) is a low-authority sensor. However, as the engine reaches operating temperature, the oxygen sensor becomes a high-authority sensor and can greatly affect the amount of fuel being supplied to the engine. See the chart.

High-Authority Sensors	Low-Authority Sensors
ECT (especially when the engine starts and is warming up)	IAT (intake air temperature) sensors modify and back up the ECT
O2S (after the engine reaches closed-loop operation)	TFT (transmission fluid temperature)
MAP	PRNDL (shift position sensor)
MAF	KS (knock sensor)
TP (high authority during acceleration and deceleration)	EFT (engine fuel temperature)

PCM USES FOR AIRFLOW SENSORS

The PCM uses the information from the airflow sensor for the following purposes:

- Airflow sensors are used mostly to determine the amount of fuel needed and base pulse-width numbers. The greater the mass of the incoming air, the longer the injectors are pulsed on.
- Airflow sensors back up the TP sensor in the event of a loss of signal or an inaccurate throttle position sensor signal. If the MAF

sensor fails, then the PCM will calculate the fuel delivery needs of the engine based on throttle position and engine speed (RPM).

TESTING MASS AIRFLOW SENSORS

Start the testing of a MAF sensor by performing a thorough visual inspection. Look at all the hoses that direct and send air, especially between the MAF sensor and the throttle body. Also check the electrical connector for:

- Corrosion
- Terminals that are bent or pushed out of the plastic connector
- Frayed wiring

FREQUENTLY ASKED QUESTION ???

What Is False Air?

Airflow sensors and mass airflow (MAF) sensors are designed to measure *all* the air entering the engine. If an air inlet hose was loose or had a hole, extra air could enter the engine without being measured. This extra air is often called **false air.** See Figure 55–28.

Because this extra air is unmeasured, the computer does not provide enough fuel delivery and the engine operates too lean, especially at idle. A small hole in the air inlet hose would represent a fairly large percentage of false air at idle, but would represent a very small percentage of extra air at highway speeds.

To diagnose for false air, look at long-term fuel trim numbers at idle and at 3000 RPM.

HINT: If the engine runs well in reverse, yet runs terrible in any forward gear, carefully look at the inlet hose for air leaks that would open when the engine torque moves the engine slightly on its mounts.

MAF Sensor Output Test A digital multimeter can also be used to check the MAF sensor. See the chart that shows the voltage output compared with the grams per second of airflow through the sensor. Normal airflow is 3 to 7 grams per second.

Analog MAF Sensor Grams per Second/Voltage Chart

Grams per Second	Sensor Voltage
0	0.2
2	0.7
4	1.0 (typical idle value)
8	1.5
15	2.0
30	2.5
50	3.0
80	3.5
110	4.0
150	4.5
175	4.8

Tap Test With the engine running at idle speed, *gently* tap the MAF sensor with the fingers of an open hand. If the engine stumbles or stalls, the MAF sensor is defective. This test is commonly called the **tap test.**

Digital Meter Test of a MAF Sensor A digital multimeter can be used to measure the frequency (Hz) output of the sensor and compare the reading with specifications.

The frequency output and engine speed in RPM can also be plotted on a graph to check to see if the frequency and RPM are proportional, resulting in a straight line on the graph.

TECH TIP ✓ The Unplug It Test

If a sensor is defective yet still produces a signal to the computer, the computer will often accept the reading and make the required changes in fuel delivery and spark advance. If, however, the sensor is not reading correctly, the computer will process this wrong information and perform an action assuming that information being supplied is accurate. For example, if a mass airflow (MAF) sensor is telling the computer that 12 grams of air per second is going into the engine, the computer will then pulse the injector for 6.4 ms or whatever figure it is programmed to provide. However, if the air going into the engine is actually 14 grams per second, the amount of fuel supplied by the injectors will not be enough to provide proper engine operation. If the MAF sensor is unplugged, the computer knows that the sensor is not capable of supplying airflow information, so it defaults to a fixed amount of fuel based on the values of other sensors such as the TP and MAP sensors. "If in doubt, take it out."

If the engine operates better with a sensor unplugged, then suspect that the sensor is defective. A sensor that is not supplying the correct information is said to be *skewed.* The computer will not see a diagnostic trouble code for this condition because the computer can often not detect that the sensor is supplying wrong information.

Contaminated Sensor Dirt, oil, silicon, or even spider webs can coat the sensing wire. Because it tends to insulate the sensing wire at low airflow rates, a contaminated sensor often overestimates the amount of air entering the engine at idle, and therefore causes the fuel system to go rich. At higher engine speeds near wide-open throttle (WOT), the contamination can cause the sensor to underestimate the amount of air entering the engine. As a result, the fuel system will go lean, causing spark knock and lack of power concerns. To check for contamination, check the fuel trim numbers.

If the fuel trim is negative (removing fuel) at idle, yet is positive (adding fuel) at higher engine speeds, a contaminated MAF sensor is a likely cause. Other tests for a contaminated MAF sensor include:

- At WOT, the grams per second, as read on a scan tool, should exceed 100.
- At WOT, the voltage, as read on a digital voltmeter, should exceed 4 volts for an analog sensor.
- At WOT, the frequency, as read on a meter or scan tool, should exceed 7 kHz for a digital sensor.

If the readings do not exceed these values, then the MAF sensor is contaminated.

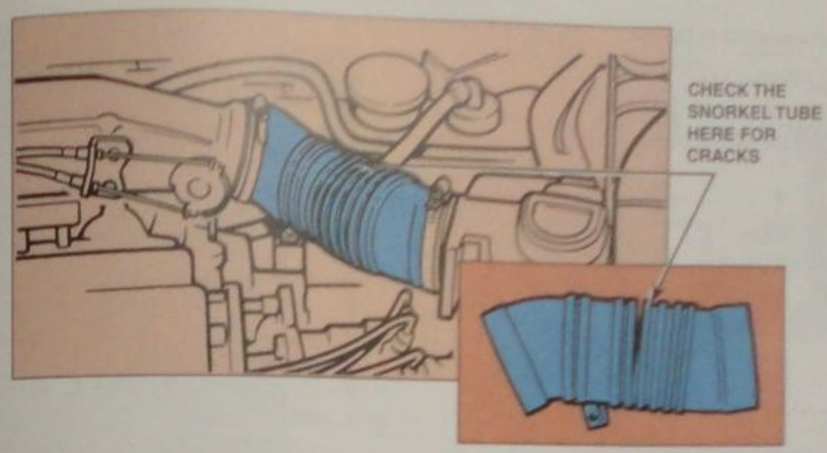


Figure 55–28 Carefully check the hose between the MAF sensor and the throttle plate for cracks or splits that could create extra (false) air into the engine that is not measured by the MAF sensor.

MAF-RELATED DIAGNOSTIC TROUBLE CODES

The diagnostic trouble codes (DTCs) associated with the mass airflow and air vane sensors include:

Diagnostic Trouble Code	Description	Possible Causes
P0100	Mass or volume airflow circuit problems	• Open or short in mass airflow circuit • Defective MAF sensor
P0101	Mass airflow circuit range problems	• Defective MAF sensor (check for false air)
P0102	Mass airflow circuit low output	• Defective MAF sensor • MAF sensor circuit open or shorted-to-ground • Open 12-volt supply voltage circuit
P0103	Mass airflow circuit high output	• Defective MAF sensor • MAF sensor circuit shorted-to-voltage

OXYGEN SENSORS

Automotive computer systems use a sensor in the exhaust system to measure the oxygen content of the exhaust. These sensors are called **oxygen sensors (O2S).** The oxygen sensor is installed in the exhaust manifold or located downstream from the manifold in the exhaust pipe. See Figure 55–29.

The oxygen sensor is directly in the path of the exhaust gas stream where it monitors oxygen level in both the exhaust stream and the ambient air. In a zirconia oxygen sensor, the tip contains a thimble made of zirconium dioxide (ZrO_2), an electrically conductive material capable of generating a small voltage in the presence of oxygen.

Exhaust from the engine passes through the end of the sensor where the gases contact the outer side of the thimble. Atmospheric air enters through the other end of the sensor or through the wire of the sensor and contacts the inner side of the thimble. The inner and outer surfaces of the thimble are plated with platinum. The inner surface becomes a negative electrode; the outer surface is a positive electrode. The atmosphere contains a relatively constant 21% of oxygen. Rich exhaust gases contain little oxygen. Exhaust from a lean mixture contains more oxygen.

Negatively charged oxygen ions are drawn to the thimble where they collect on both the inner and outer surfaces. See Figure 55–30.

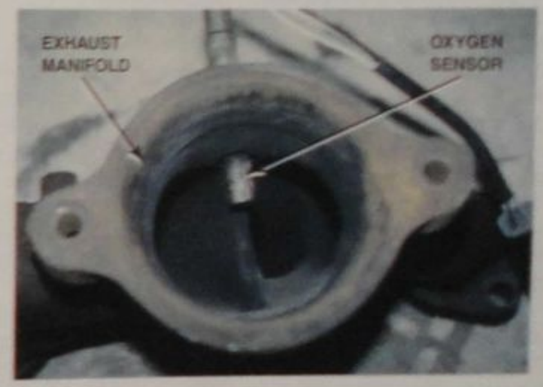


Figure 55–29 Many fuel-control oxygen sensors are located in the exhaust manifold near its outlet so that the sensor can detect the presence or absence of oxygen in the exhaust stream for all cylinders that feed into the manifold.

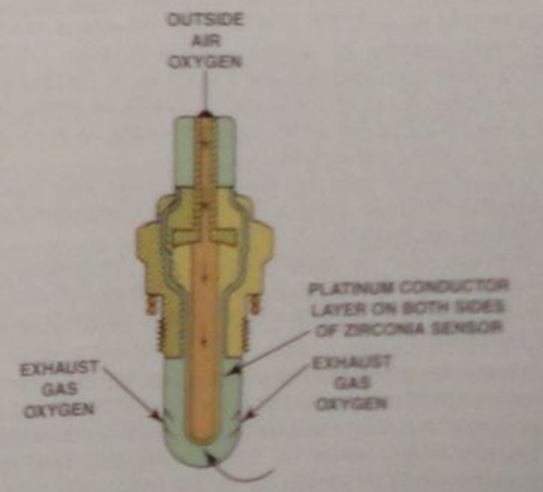


Figure 55–30 A cross-sectional view of a typical zirconia oxygen sensor.

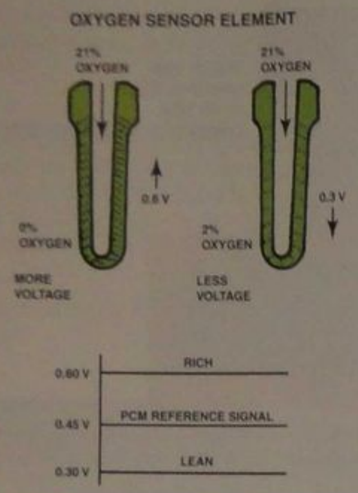


Figure 55–31 A difference in oxygen content between the atmosphere and the exhaust gases enables an O2S sensor to generate voltage.

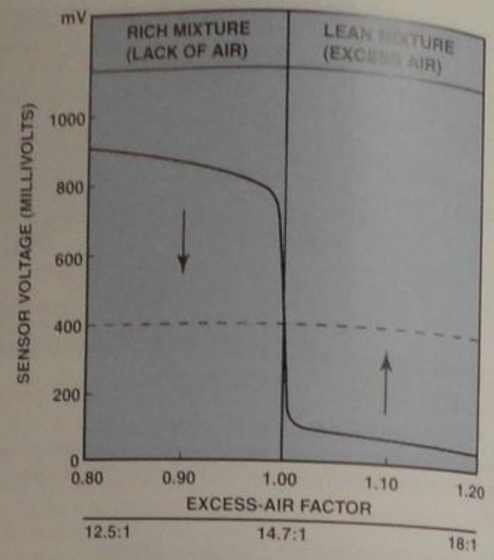


Figure 55–32 The oxygen sensor provides a quick response at the stoichiometric air–fuel ratio of 14.7:1.

Because the percentage of oxygen present in the atmosphere exceeds that in the exhaust gases, the atmosphere side of the thimble draws more negative oxygen ions than the exhaust side. The difference between the two sides creates an electrical potential, or voltage. When the concentration of oxygen on the exhaust side of the thimble is low (rich exhaust), a high voltage (0.60 to 1.0 volts) is generated between the electrodes. As the oxygen concentration on the exhaust side increases (lean exhaust), the voltage generated drops low (0.00 to 0.3 volt). See Figure 55–31.

This voltage signal is sent to the computer where it passes through the input conditioner for amplification. The computer interprets a high-voltage signal (low-oxygen content) as a rich air–fuel ratio, and a low-voltage signal (high-oxygen content) as a lean air–fuel ratio. Based on the O2S signal (above or below 0.45 volt), the computer compensates by making the mixture either leaner or richer as required to continually vary close to a 14.7:1 air–fuel ratio to satisfy the needs of the three-way catalytic converter. The O2S is the key sensor of an electronically controlled fuel metering system for emission control.

An O2S does not send a voltage signal until its tip reaches a temperature of about 572°F (300°C). Also, O2 sensors provide their fastest response to mixture changes at about 1,472°F (800°C). When the engine starts and the O2S is cold, the computer runs the engine in the open-loop mode, drawing on prerecorded data in the PROM for fuel control on a cold engine, or when O2S output is not within certain limits.

If the exhaust contains very little oxygen (O2S), the computer assumes that the intake charge is rich (too much fuel) and reduces fuel delivery. See Figure 55–32.

However, when the oxygen level is high, the computer assumes that the intake charge is lean (not enough fuel) and increases fuel delivery. There are several different designs of oxygen sensors, including:

- **One-wire oxygen sensor.** The one wire of the one-wire oxygen sensor is the O2S signal wire. The ground for the O2S is through the shell and threads of the sensor and through the exhaust manifold.
- **Two-wire oxygen sensor.** The two-wire sensor has a signal wire and a ground wire for the O2S.
- **Three-wire oxygen sensor.** The three-wire sensor design uses an electric resistance heater to help get the O2S up to temperature more quickly and to help keep the sensor at operating temperature even at idle speeds. The three wires include the O2S signal, the power, and ground for the heater.
- **Four-wire oxygen sensor.** The four-wire sensor is a heated O2S (HO2S) that uses an O2S signal wire and signal ground. The other two wires are the power and ground for the heater.

REAL WORLD FIX — **The Chevrolet Pickup Truck Story**

The owner of a 1996 Chevrolet pickup truck complained that the engine ran terribly. It would hesitate and surge, yet there were no diagnostic trouble codes (DTCs). After hours of troubleshooting, the technician discovered while talking to the owner that the problem started after the transmission had been repaired, yet the transmission shop said that the problem was an engine problem and not related to the transmission.

A thorough visual inspection revealed that the front and rear oxygen sensor connectors had been switched. The computer was trying to compensate for an air–fuel mixture condition that did not exist. Reversing the O2S connectors restored proper operation of the truck.

Zirconia Oxygen Sensors The most common type of oxygen sensor is made from zirconia (zirconium dioxide). It is usually constructed using powder that is pressed into a thimble shape and coated with porous platinum material that acts as electrodes. All zirconia sensors use 18-mm-diameter threads with a washer. See Figure 55–33.

Zirconia oxygen sensors (O2S) are constructed so that oxygen ions flow through the sensor when there is a difference between the oxygen content inside and outside of the sensor. An ion is an electrically charged particle. The greater the differences in the oxygen content between the inside and outside of the sensor, the higher the voltage created.

- **Rich mixture.** A rich mixture results in little oxygen in the exhaust stream. Compared to the outside air, this represents a large difference and the sensors create a relatively high voltage of about 1.0 volt (1,000 mV).
- **Lean mixture.** A lean mixture leaves some oxygen in the exhaust stream that did not combine with the fuel. This leftover oxygen reduces the difference between the oxygen content of the exhaust compared to the oxygen content of the outside air. As a result, the sensor voltage is low or almost 0 volt.
- **O2S voltage above 450 mV** is produced by the sensor when the oxygen content in the exhaust is low. This is interpreted by the engine computer (PCM) as being a rich exhaust.



Figure 55–33 A typical zirconia oxygen sensor.

FREQUENTLY ASKED QUESTION ???

Where Is HO2S1?

Oxygen sensors are numbered according to their location in the engine. On a V-type engine, heated oxygen sensor number 1 (HO2S1) is located in the exhaust manifold on the side of the engine where the number one cylinder is located. See Figure 55–34.

- **O2S voltage below 450 mV** is produced by the sensor when the oxygen content is high. This is interpreted by the engine computer (PCM) as being a lean exhaust.

Titania Oxygen Sensors The titania (titanium dioxide) oxygen sensor does not produce a voltage but rather changes in resistance with the presence of oxygen in the exhaust. All titania oxygen sensors use a four-terminal variable resistance unit with a heating element. A titania sensor samples exhaust air only and uses a reference voltage from the PCM. Titania oxide oxygen sensors use a 14-mm thread and are not interchangeable with zirconia oxygen sensors. One volt is applied to the sensor and the changing resistance of the titania oxygen sensor changes the voltage of the sensor circuit. As with a zirconia oxygen sensor, the voltage signal is above 450 mV when the exhaust is rich, and low (below 450 mV) when the exhaust is lean.

Wide-Band Oxygen Sensors A **wide-band oxygen sensor,** also called a **lean air–fuel (LAF) ratio sensor** or a **linear air–fuel ratio sensor,** allows engines to operate as lean as 23:1 and still maintain closed-loop operation. This type of sensor usually uses five wires.

- One power wire
- One ground wire for the electric heater
- Three sensor wires

The three sensor wires are used to provide the PCM with a signal that more accurately reflects the oxygen content in the exhaust than a conventional oxygen sensor. A wide-band oxygen sensor can be best described as having two oxygen sensors mated together with a diffusion layer between the two components. Just as in a conventional zirconium dioxide oxygen sensor, current flows from one side to the other and produces a voltage. In a wide-band oxygen sensor, an oxygen pump uses a heated cathode and anode to pull oxygen from the exhaust into a diffusion gap. The diffusion layer and the oxygen sensor elements are electrically connected so that it takes a certain amount of current (in milliamperes) to maintain a balanced oxygen level in the diffusion layer. When the air–fuel mixture is perfectly balanced at 14.7:1, the sensor produces no output current. When the air–fuel mixture is rich, the sensor produces a negative current ranging from 0 to about 2 milliamps, which represents an air–fuel ratio of about 12:1. When the air–fuel ratio is lean, the sensor produces a positive current that ranges from 0 to 1.5 milliamperes as the mixture gets leaner up to about 22:1.

Testing a wide-band oxygen sensor is usually achieved using a scan tool. Most PCMs display the rich and lean status of the exhaust, plus many show the operation of the oxygen sensor in millivolts from 0 to 1,000 just as if the sensor were a conventional zirconia oxygen sensor.

Wide-band oxygen sensors, just like conventional zirconia oxygen sensors, can be fooled by exhaust leaks upstream of the sensor, as well as from ignition misfires.

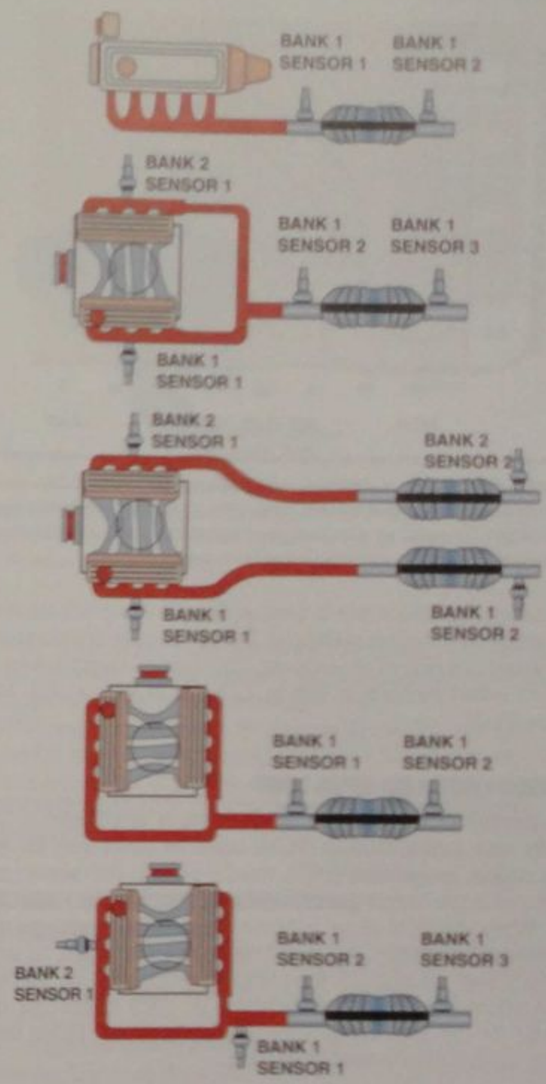


Figure 55–34 Number and label designations for oxygen sensors. Bank 1 is the bank where cylinder number 1 is located.

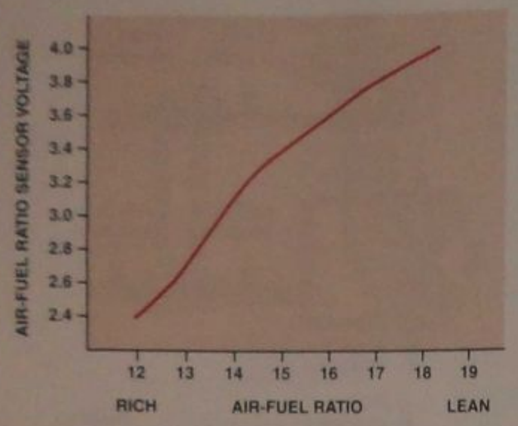


Figure 55–35 The output of a typical air–fuel mixture sensor showing that the voltage increases as the exhaust becomes leaner, which is opposite from normal oxygen sensors. The output of a wide-band oxygen sensor usually can not be read using a digital meter at the sensor, but instead a scan tool is needed.

A linear air–fuel sensor is used on some Toyota brand vehicles and produces a voltage reading of 2.2 to 4.2 volts depending on the oxygen content of the exhaust. This type of oxygen sensor is used to detect mixtures as rich as 12:1 and as lean as 18:1. See Figure 55–35.

CLOSED LOOP AND OPEN LOOP

The amount of fuel delivered to an engine is determined by the power train control module (PCM) based on inputs from the engine coolant temperature (ECT), throttle position (TP) sensor, and others until the oxygen sensor is capable of supplying a usable signal. When the PCM alone (without feedback) is determining the amount of fuel needed, it is called **open-loop operation.** As soon as the oxygen sensor (O2S) is capable of supplying rich and lean signals, adjustments by the computer can be made to fine-tune the correct air–fuel mixture. This checking and adjusting by the computer is called **closed-loop operation.**

PCM USES OF THE OXYGEN SENSOR

Fuel Control The upstream oxygen sensors are among the main sensor(s) used for fuel control while operating in closed loop. Before the oxygen sensors are hot enough to give accurate exhaust oxygen information to the computer, fuel control is determined by other sensors and the anticipated injector pulse width determined by those sensors. After the control system achieves closed-loop status, the oxygen sensor provides feedback with actual exhaust gas oxygen content.

Fuel Trim **Fuel trim** is a computer program that is used to compensate for a too rich or a too lean air–fuel exhaust as detected by the oxygen sensor(s). Fuel trim is necessary to keep the air–fuel mixture within limits to allow the catalytic converter to operate efficiently. If the exhaust is too lean or too rich for a long time, the catalytic converter can be damaged. The fuel trim numbers are determined from the signals from the oxygen sensor(s). If the engine has been operating too lean, short-term and long-term fuel time programming inside the PCM can cause an increase in the commanded injector pulse width to bring the air–fuel mixture back into the proper range. Fuel trim can be negative (subtracting fuel) or positive (adding fuel).

Diagnosis The oxygen sensors are used for diagnosis of other systems and components. For example, the exhaust gas recirculation (EGR) system is tested by the PCM by commanding the valve to open during the test. Some PCMs determine whether enough exhaust gas flows into the engine by looking at the oxygen sensor response (fuel trim numbers). The upstream and downstream oxygen sensors are also used to determine the efficiency of the catalytic converter. See Figure 55–36.

FREQUENTLY ASKED QUESTION ???

What Happens to the Bias Voltage?

Some vehicle manufacturers such as General Motors Corporation have the computer apply 450 mV (0.450 V) to the O2S signal wire. This voltage is called the **bias voltage** and represents the threshold voltage for the transition from rich to lean.

This bias voltage is displayed on a scan tool when the ignition switch is turned on with the engine off. When the engine is started, the O2S becomes warm enough to produce a usable voltage and bias voltage "disappears" as the O2S responds to a rich and lean mixture. What happened to the bias voltage that the computer applied to the O2S? The voltage from the O2S simply overcame the very weak voltage signal from the computer. This bias voltage is so weak that even a 20-megohm impedance DMM will affect the strength enough to cause the voltage to drop to 426 mV. Other meters with only 10 megohms of impedance will cause the bias voltage to read less than 400 mV.

Therefore, even though the O2S voltage is relatively low powered, it is more than strong enough to override the very weak bias voltage the computer sends to the O2S.

REAL WORLD FIX — The Oxygen Sensor Is Lying to You

A technician was trying to solve a driveability problem with a V-6 passenger car. The car idled roughly, hesitated, and accelerated poorly. A thorough visual inspection did not indicate any possible problems and there were no diagnostic trouble codes stored.

A check was made on the oxygen sensor activity using a DMM. The voltage stayed above 600 mV most of the time. If a large vacuum hose was removed, the oxygen sensor voltage would temporarily drop to below 450 mV and then return to a reading of over 600 mV. Remember:

- High O2S readings = rich exhaust (low O_2 content in the exhaust)
- Low O2S readings = lean exhaust (high O_2 content in the exhaust)

As part of a thorough visual inspection, the technician removed and inspected the spark plugs. All the spark plugs were white, indicating a lean mixture, not the rich mixture that the oxygen sensor was indicating. The high O2S reading signaled the computer to reduce the amount of fuel, resulting in an excessively lean operation.

After replacing the oxygen sensor, the engine ran great. But what killed the oxygen sensor? The technician finally learned from the owner that the head gasket had been replaced over a year ago. The phosphate and silicate additives in the antifreeze coolant had coated the oxygen sensor. Because the oxygen sensor was coated, the oxygen content of the exhaust could not be detected—the result: a false rich signal from the oxygen sensor.

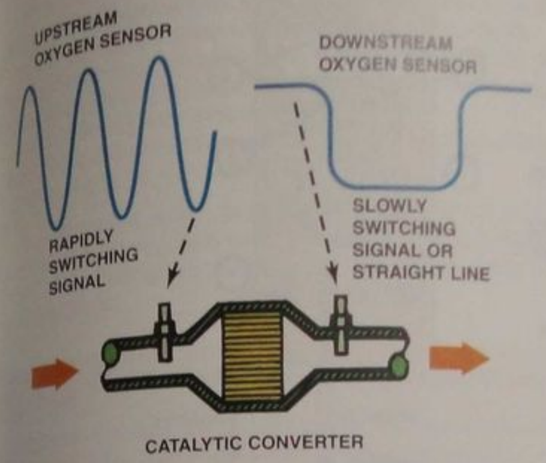


Figure 55–36 The OBD-II catalytic converter monitor compares the signals of the upstream and downstream oxygen sensor to determine converter efficiency.

REAL WORLD FIX — The Missing Ford Story

A four-cylinder Ford was being analyzed for poor engine operation. The engine ran perfectly during the following conditions:

1. With the engine cold or operating in open loop
2. With the engine at idle
3. With the engine operating at or near wide-open throttle

After hours of troubleshooting, the cause was found to be a poor ground connection for the oxygen sensor. The engine ran okay during times when the computer ignored the oxygen sensor. Unfortunately, the service technician did not have a definite plan during the diagnostic process and as a result checked and replaced many unnecessary parts. An oxygen sensor test early in the diagnostic procedure would have indicated that the oxygen (O2S) signal was not correct. The poor ground caused the oxygen sensor voltage level to be too high, indicating to the computer that the mixture was too rich. The computer then subtracted fuel which caused the engine to miss and run rough as the result of the now too lean air–fuel mixture.

TESTING AN OXYGEN SENSOR USING A DIGITAL VOLTMETER

The oxygen sensor can be checked for proper operation using a digital high-impedance voltmeter.

1. With the engine off, connect the red lead of the meter to the oxygen sensor signal wire. See Figure 55–37.
2. Start the engine and allow it to reach closed-loop operation.
3. In closed-loop operation, the oxygen sensor voltage should be constantly changing as the fuel mixture is being controlled.

The results should be interpreted as follows:

- If the oxygen sensor fails to respond, and its voltage remains at about 450 millivolts, the sensor may be defective and require replacement. Before replacing the oxygen sensor, check the manufacturers' recommended procedures.

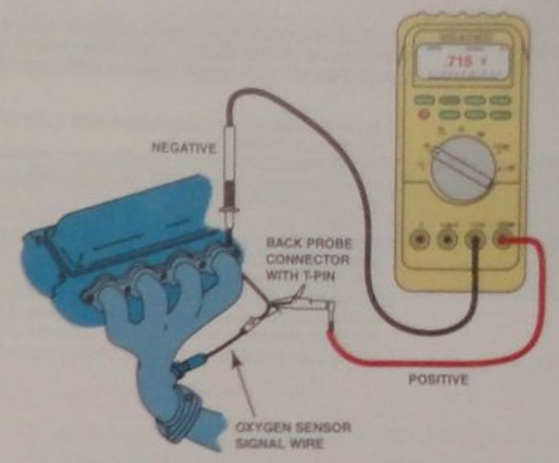


Figure 55–37 Testing an oxygen sensor using a DMM set on DC volts. With the engine operating in closed loop, the oxygen voltage should read over 800 mV and lower than 200 mV and be constantly fluctuating.

- If the oxygen sensor reads high all the time (above 550 millivolts), the fuel system could be supplying too rich a fuel mixture or the oxygen sensor may be contaminated.
- If the oxygen sensor voltage remains low (below 350 millivolts), the fuel system could be supplying too lean a fuel mixture. Check for a vacuum leak or partially clogged fuel injector(s). Before replacing the oxygen sensor, check the manufacturers' recommended procedures.

TESTING THE OXYGEN SENSOR USING THE MIN/MAX METHOD

A digital meter set on DC volts can be used to record the minimum and maximum voltage with the engine running. A good oxygen sensor should be able to produce a value of less than 300 millivolts and a maximum voltage above 800 millivolts. Replace any oxygen sensor that fails to go above 700 millivolts or lower than 300 millivolts. See Figure 55–38.

MIN/MAX Oxygen Sensor Test Chart

Minimum Voltage	Maximum Voltage	Average Voltage	Test Results
Below 200 mV	Above 800 mV	400 to 500 mV	Oxygen sensor is okay.
Above 200 mV	Any reading	400 to 500 mV	Oxygen sensor is defective.
Any reading	Below 800 mV	400 to 500 mV	Oxygen sensor is defective.
Below 200 mV	Above 800 mV	Below 400 mV	System is operating lean.*
Below 200 mV	Below 800 mV	Below 400 mV	System is operating lean. (Add propane to the intake air to see if the oxygen sensor reacts. If not, the sensor is defective.)
Below 200 mV	Above 800 mV	Above 500 mV	System is operating rich.
Above 200 mV	Above 800 mV	Above 500 mV	System is operating rich. (Remove a vacuum hose to see if the oxygen sensor reacts. If not, the sensor is defective.)

* Check for an exhaust leak upstream from the O2S or ignition misfire that can cause a false lean indication before further diagnosis.

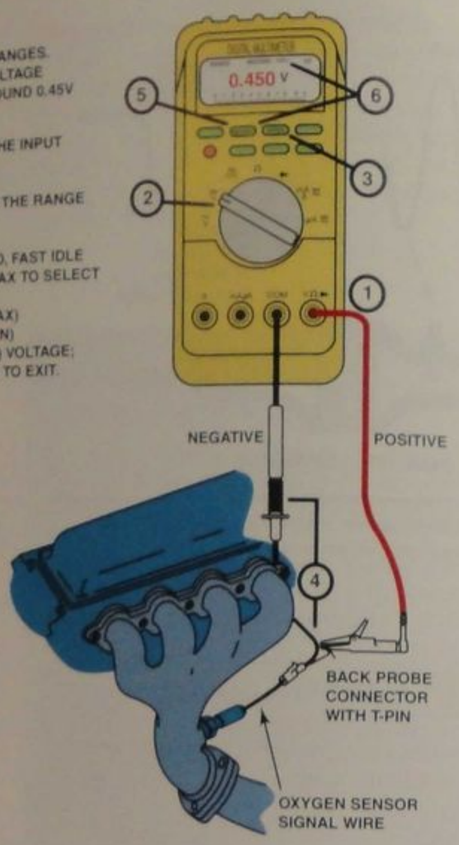


Figure 55–38 Using a digital multimeter to test an oxygen sensor using the min/max record function of the meter.

FREQUENTLY ASKED QUESTION ???

Why Does the Oxygen Sensor Voltage Read 5 Volts on Many Chrysler Vehicles?

Many Chrysler vehicles apply a 5-volt reference to the signal wire of the oxygen sensor. The purpose of this voltage is to allow the computer to detect if the oxygen sensor signal circuit is open or grounded.

- If the voltage on the signal wire is 4.5 volts or more, the computer assumes that the sensor is open.
- If the voltage on the signal wire is zero, the computer assumes that the sensor is shorted-to-ground.

If either condition exists, the computer can set a diagnostic trouble code (DTC).

TESTING AN OXYGEN SENSOR USING A SCAN TOOL

A good oxygen sensor should be able to sense the oxygen content and change voltage outputs rapidly. How fast an oxygen sensor switches from high (above 450 millivolts) to low (below 350 millivolts) is measured in oxygen sensor **cross counts.** Cross counts are the number of times an oxygen sensor changes voltage from high to low (from low to high voltage is not counted) in 1 second (or 1.25 second, depending on scan tool and computer speed).

NOTE: On a fuel-injected engine at 2000 engine RPM, 8 to 10 cross counts is normal.

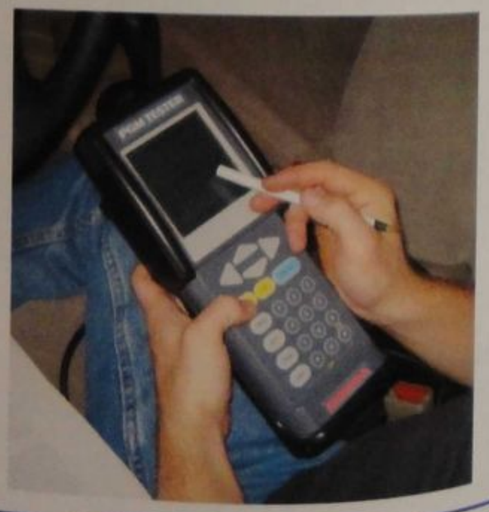


Figure 55–39 A Honda scan tool being used to diagnose the oxygen sensors.

Oxygen sensor cross counts can only be determined using a scan tool or other suitable tester that reads computer data. See Figure 55–39.

If the cross counts are low (or zero), the oxygen sensor may be contaminated, or the fuel delivery system is delivering a constant rich or lean air–fuel mixture. To test an engine using a scan tool, follow these steps:

1. Connect the scan tool to the DLC and start the engine.
2. Operate the engine at a fast idle (2500 RPM) for 2 minutes to allow time for the oxygen sensor to warm to operating temperature.
3. Observe the oxygen sensor activity on the scan tool to verify closed-loop operation. Select "snapshot" mode and hold the engine speed steady and start recording.
4. Play back snapshot and place a mark beside each range of oxygen sensor voltage for each frame of the snapshot.

A good oxygen sensor and computer system should result in most snapshot values at both ends (0 to 300 and 600 to 1,000 mV). If most of the readings are in the middle, the oxygen sensor is not working correctly.

Check for rapid switching from rich to lean and lean to rich and change between once every 2 seconds and five times per second (0.5 to 5.0 Hz). See Figures 55–41, 55–42, and 55–43.

NOTE: General Motors warns not to base the diagnosis of an oxygen sensor problem solely on its scope pattern. The varying voltage output of an oxygen sensor can easily be mistaken for a fault in the sensor itself, rather than a fault in the fuel delivery system.

TECH TIP ✓ The Key On, Engine Off Oxygen Sensor Test

This test works on General Motors vehicles and may work on others if the PCM applies a bias voltage to the oxygen sensors. Zirconia oxygen sensors become more electrically conductive as they get hot. To perform this test, be sure that the vehicle has not run for several hours.

Step #1 Connect a scan tool and get the display ready to show oxygen sensor data.

Step #2 Key the engine on *without* starting the engine. The heater in the oxygen sensor will start heating the sensor.

Step #3 Observe the voltage of the oxygen sensor. The applied bias voltage of 450 mV should slowly decrease for all oxygen sensors as they become more electrically conductive and other bias voltage is flowing to ground.

Step #4 A good oxygen sensor should indicate a voltage of less than 100 mV after 3 minutes. Any sensor that displays a higher-than-usual voltage or seems to stay higher longer than the others could be defective or skewed high.

TECH TIP ✓ Sensor or Wiring?

When troubleshooting a diagnostic trouble code, it is sometimes difficult to determine if the sensor itself is defective or its wiring and ground connections are defective. For example, when diagnosing an O2S code, perform the following to check the wiring:

1. Connect a scan tool and observe the O2S voltage with the ignition on (engine off).
2. Disconnect the O2S pigtail to open the circuit between the computer and the O2S. The scan tool should read 450 mV if the wiring is okay and the scan tool is showing the bias voltage.

NOTE: Some vehicle manufacturers do not apply a bias voltage to the O2S and the reading on the scan tool may indicate zero and be okay.

3. Ground the O2S wire from the computer. The scan tool should read 0 volts if the wiring is okay.

TESTING AN OXYGEN SENSOR USING A SCOPE

A scope can also be used to test an oxygen sensor. Connect the scope to the signal wire and ground for the sensor (if it is so equipped).

With the engine operating in closed loop, the voltage signal of the sensor should be constantly changing. See Figure 55–40.

O2S READINGS

An oxygen sensor reading that is low could be due to other things besides a lean air–fuel mixture. An oxygen sensor senses oxygen, not unburned gas, even though a high reading generally indicates a rich exhaust (lack of oxygen) and a low reading indicates a lean mixture (excess oxygen).

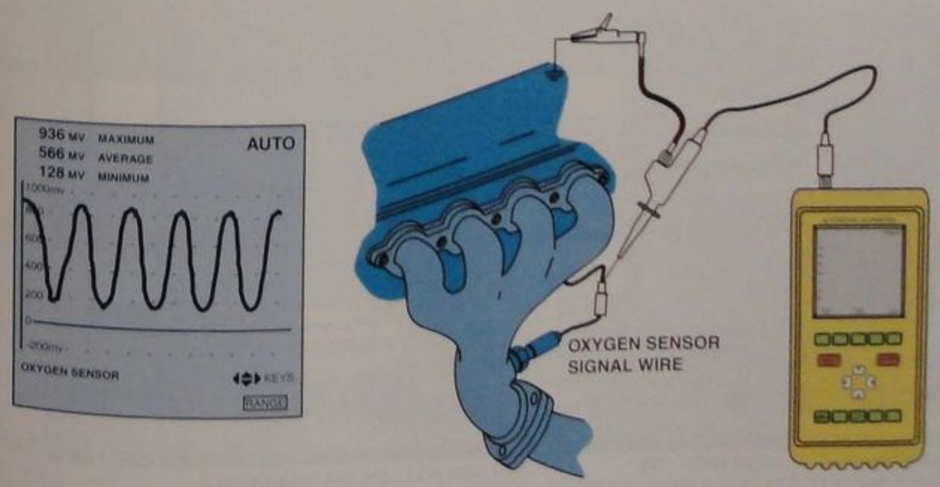


Figure 55–40 The waveform of a good oxygen sensor as displayed on a digital storage oscilloscope (DSO). Note that the maximum reading is above 800 mV and the minimum reading is less than 200 mV.

Lean Indications If an oxygen sensor reads low as a result of a lean mixture it can be caused by things such as:

- Vacuum leak
- Low fuel pump pressure
- Clogged fuel injector

Also sometimes the lean indication can be false.

False lean indications (low O2S readings) can be attributed to the following:

1. **Ignition misfire.** An ignition misfire due to a defective spark plug wire, fouled spark plug, and so forth, causes no burned air and fuel to be exhausted past the O2S. The O2S "sees" the oxygen (not the unburned gasoline) and the O2S voltage is low.
2. **Exhaust leak in front of the O2S.** An exhaust leak between the engine and the oxygen sensor causes outside oxygen to be drawn into the exhaust and past the O2S. This oxygen is "read" by the O2S and produces a lower-than-normal voltage. The computer interrupts the lower-than-normal voltage signal from the O2S as meaning that the air–fuel mixture is lean. The computer will cause the fuel system to deliver a richer air–fuel mixture.

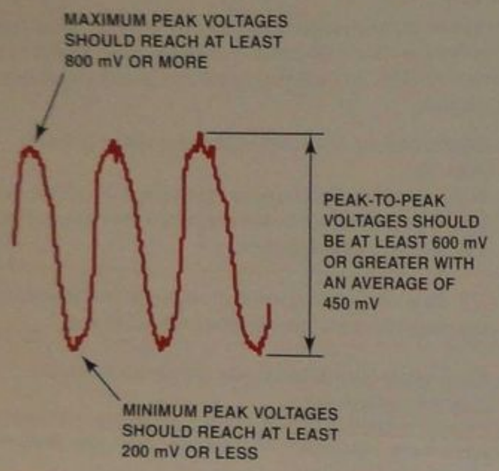


Figure 55–41 A typical good oxygen sensor waveform as displayed on a digital storage oscilloscope. Look for transitions that occur rapidly between 0.5 and 5.0 Hz.

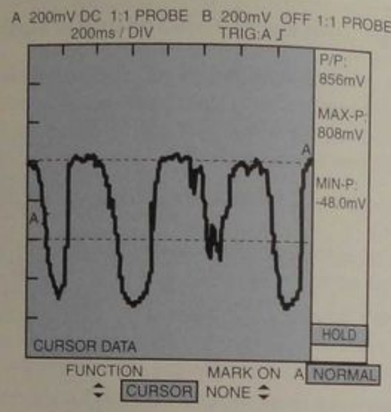


Figure 55–42 Using the cursors on the oscilloscope, the high- and low-oxygen sensor values can be displayed on the screen.

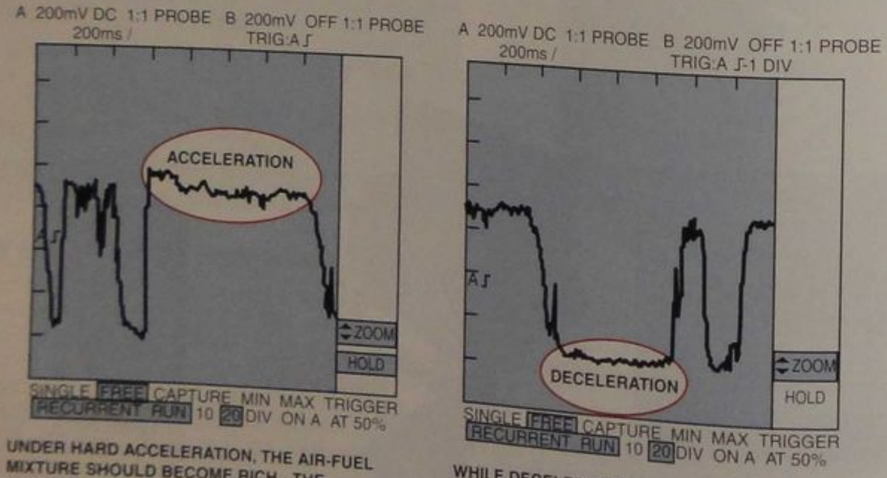


Figure 55–43 When the air–fuel mixture rapidly changes such as during a rapid acceleration, look for a raid response. The transition from low to high should be less than 100 ms

3. **A spark plug misfire represents a false lean signal to the oxygen sensor.** The computer does not know that the extra oxygen going past the oxygen sensor is not due to a lean air–fuel mixture. The computer commands a richer mixture, which could cause the spark plugs to foul, increasing the rate of misfirings.

Rich Indications An oxygen sensor reading that is high could be due to a rich air–fuel mixture caused by things such as:

- Excessive fuel pressure
- Leaking fuel injector
- Leaking fuel pressure regulator

When the O2S reads high as a result of other factors besides a rich mixture, it is sometimes called a **false rich indication.**

False rich indications (high O2S readings) can be attributed to the following:

1. Contaminated O2S due to additives in the engine coolant or due to silicon poisoning
2. A stuck-open EGR valve (especially at idle)
3. A spark plug wire too close to the oxygen sensor signal wire, which can induce a higher-than-normal voltage in the signal wire, thereby indicating to the computer a false rich condition
4. A loose oxygen sensor ground connection, which can cause a higher-than-normal voltage and a false rich signal
5. A break or contamination of the wiring and its connectors, which could prevent reference oxygen from reaching the oxygen sensor, resulting in a false rich indication (All oxygen sensors require an oxygen supply inside the sensor itself for reference to be able to sense exhaust gas oxygen.)

POST-CATALYTIC CONVERTER OXYGEN SENSOR TESTING

The oxygen sensor located behind the catalytic converter is used on OBD-II vehicles to monitor converter efficiency. A changing air–fuel mixture is required for the most efficient operation of the converter. If the converter is working correctly, the oxygen content after the converter should be fairly constant. See Figure 55–44.

OXYGEN SENSOR INSPECTION

Whenever an oxygen sensor is replaced, the old sensor should be carefully inspected to help determine the cause of the failure. This is an important step because if the cause of the failure is not discovered, it could lead to another sensor failure.

Inspection may reveal the following:

1. *Black sooty deposits,* which usually indicate a rich air–fuel mixture.
2. *White chalky deposits,* which are characteristic of silica contamination. Usual causes for this type of sensor failure include silica deposits in the fuel or a technician having used the wrong type of silicone sealant during the servicing of the engine.
3. *White sandy or gritty deposits,* which are characteristic of antifreeze (ethylene glycol) contamination. A defective cylinder head or intake manifold gasket could be the cause, or a cracked cylinder head or engine block. Antifreeze may also cause the oxygen sensor to become green as a result of the dye used in antifreeze. See Figure 55–45.
4. *Dark brown deposits,* which are an indication of excessive oil consumption. Possible causes include a defective positive crankcase ventilation (PCV) system or a mechanical engine problem such as defective valve stem seals or piston rings.

CAUTION: Do not spray any silicone spray near the engine where the engine vacuum could draw the fumes into the engine. This can also cause silica damage to the oxygen sensor. Also be sure that the silicone sealer used for gaskets is rated oxygen sensor safe.

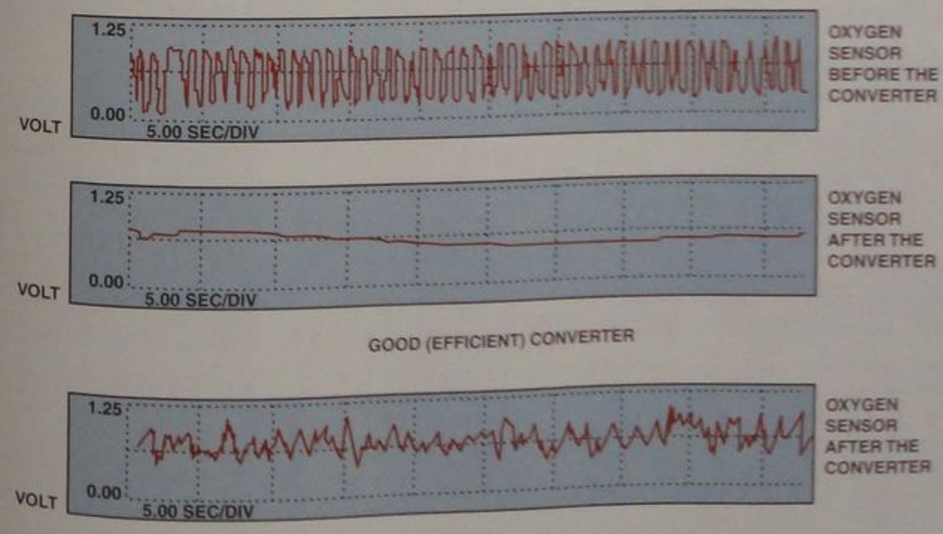


Figure 55–44 The post-catalytic converter oxygen sensor should display very little activity if the catalytic converter is efficient.



Figure 55–45 A contaminated oxygen sensor from an engine that had been operating with a defective cylinder head gasket that allowed antifreeze to get onto the sensor.

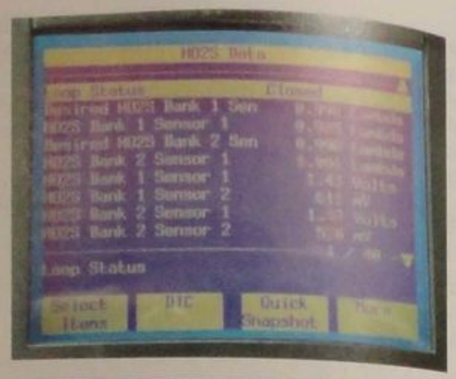


Figure 55–46 The target lambda on this vehicle is slightly lower than 1.0 indicating that the PCM is attempting to supply the engine with an air–fuel mixture that is slightly richer than stoichiometric.

FREQUENTLY ASKED QUESTION ???

What is Lambda?

An oxygen sensor is also called a lambda sensor because the voltage changes at the air–fuel ratio of 14.7:1, which is the stoichiometric rate for gasoline. If this mixture of gasoline and air is burned, all of the gasoline is burned and uses all of the oxygen in the mixture. This exact ratio represents a lambda of 1.0. If the mixture is richer (more fuel or less air), the number is less than 1.0, such as 0.850. If the mixture is leaner than 14.7:1 (less fuel or more air), the lambda number is higher than 1.0, such as 1.130. Often, the target lambda is displayed on a scan tool. See Figure 55–46.

OXYGEN SENSOR-RELATED DIAGNOSTIC TROUBLE CODES

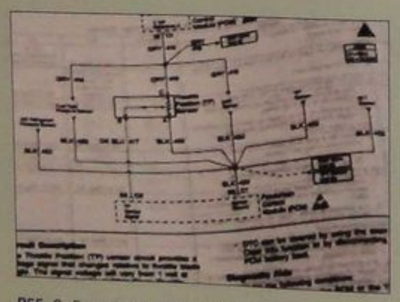
Diagnostic trouble codes (DTCs) associated with the oxygen sensor include:

Diagnostic Trouble Codes	Description	Possible Causes
P0131	Upstream HO2S grounded	• Exhaust leak upstream of HO2S (bank 1) • Extremely lean air–fuel mixture • HO2S defective or contaminated • HO2S signal wire shorted-to-ground
P0132	Upstream HO2S shorted	• Upstream HO2S (bank 1) shorted • Defective HO2S • Fuel-contaminated HO2S
P0133	Upstream HO2S slow response	• Open or short in heater circuit • Defective or fuel-contaminated HO2S • EGR or fuel-system fault

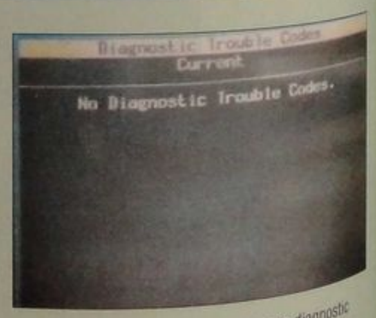
PHOTO SEQUENCE Throttle Position Sensor Diagnosis



P55–1 Besides a scan tool, other equipment that can be used to check a throttle position (TP) sensor includes a scope or graphing multimeter.

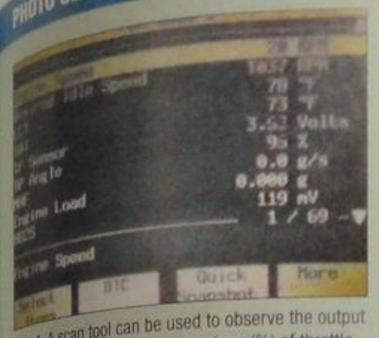


P55–2 Consult the factory service manual for the specifications and wire colors used for the TP sensor, as well as the recommended testing procedure.



P55–3 A scan tool display showing no diagnostic trouble codes (DTCs). A fault could still exist even though a diagnostic trouble code is not set—it depends on the type of fault and when it occurs.

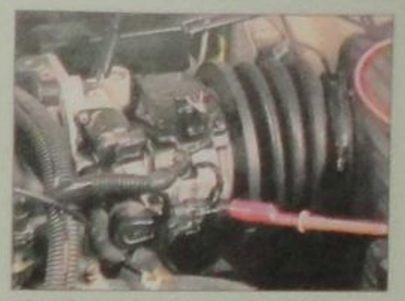
PHOTO SEQUENCE Throttle Position Sensor Diagnosis—continued



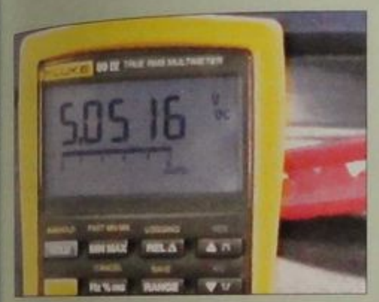
P55–4 A scan tool can be used to observe the output voltage and the circulated percentage (%) of throttle opening.



P55–5 Most throttle position sensors use a 5-volt reference voltage from the computer. To test that this signal is available at the sensor, carefully back-probe the 5-volt reference.



P55–6 Connect the red lead from the digital multimeter to the T-pin and attach the black meter lead to a good clean engine ground.



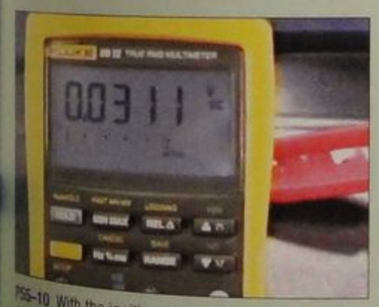
P55–7 Select DC volts and turn the ignition key on (engine off). The meter reads slightly over 5 volts, confirminging the computer is supplying the reference voltage to the TP sensor.



P55–8 To check the ground of the TP sensor, carefully back-probe the ground wire at the TP sensor connector and connect the red meter lead to the T-pin.



P55–9 Attach the black meter lead to a good, clean engine ground.



P55–10 With the ignition on (engine off) and the digital meter still set to read DC volts, read the voltage drop of the TP sensor ground. This TP sensor ground shows 31.1 mV (0.031 IV).



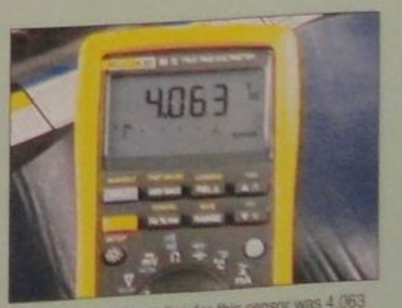
P55–11 To measure the signal voltage, back-probe the signal wire (dark blue on this General Motors vehicle).



P55–12 Select DC volts and manually range the meter. This fluke meter changes from the 4-volt scale to the 40-volt scale as the sensor voltage goes slightly higher than 4 volts.



P55–13 For best results, this test should be performed by depressing the accelerator pedal. This puts the same forces on the sensor as occurs during normal driving.



P55–14 The high reading for this sensor was 4.063 volts.



P55–15 Pushing the MIN-MAX button shows the minimum voltage the meter recorded during the test (0.399V).

(continued)

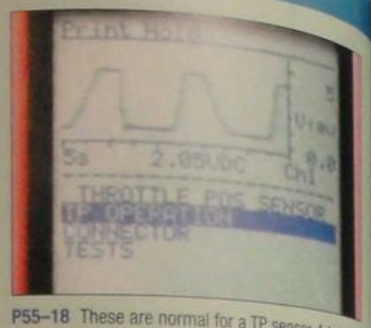
PHOTO SEQUENCE Throttle Position Sensor Diagnosis—continued



P55–16 A Snap-On Vantage graphing multimeter or digital storage oscilloscope can also be used to test a TP sensor. To test the sensor using the Snap-On Vantage, select TP sensor from the menu.



P55–17 The Vantage has a built-in database that can be accessed to show connector position and wire color information.

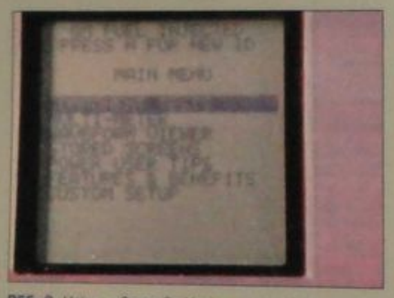


P55–18 These are normal for a TP sensor. A fault would show as a vertical line or dip in the waveform.

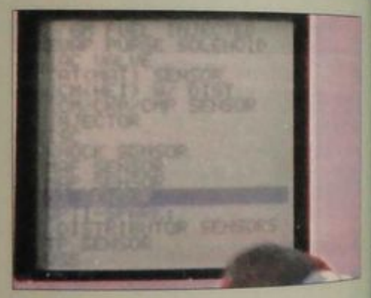
Oxygen Sensor Testing



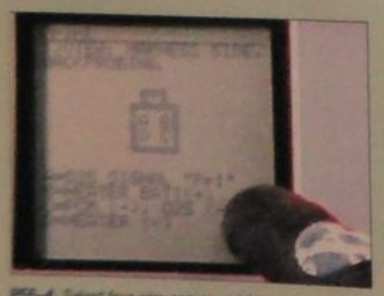
P55–1 Oxygen sensors can be tested using a digital multimeter or graphing multimeter using T-pins to back-probe the signal wire.



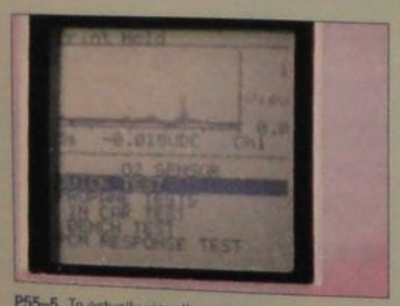
P55–2 Using a Snap-On Vantage, select "component tests" after selecting the vehicle manufacturer and year.



P55–3 Select "O2 sensor."



P55–4 Select four wire sensor and then "connector" to view a sample oxygen sensor connector and the color of the signal wire (purple on this General Motors vehicle).



P55–5 To actually view the voltage signal from the oxygen sensor on the graphing multimeter, select "quick test."

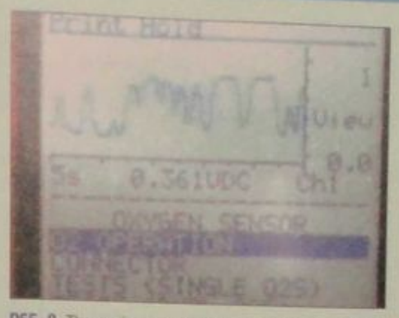


P55–6 A T-pin was used to back-probe the purple signal wire at the connector near the oxygen sensor. The red test lead from the meter attaches to the T-pin.

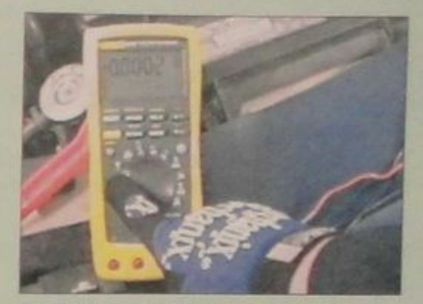
PHOTO SEQUENCE Oxygen Sensor Testing—continued



P55–7 The black meter lead is attached as a good, clean engine ground.



P55–8 The engine was started and allowed to operate until the oxygen sensor produced a changing voltage and closed-loop engine operation was achieved.



P55–9 A digital multimeter can also be used to check the operation of an oxygen sensor. Select "DC volts."



P55–10 Connect the red meter lead to the T-pin that is attached to the signal wire and attach the black meter lead to a good engine ground.



P55–11 Start the engine and select MIN/MAX.



P55–12 While the meter is recording, operate the engine for several minutes and then note the maximum reading (844.8 mV) which should be above 800 mV.



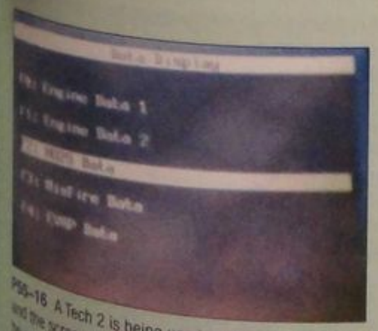
P55–13 Push the MIN/MAX button to view the minimum oxygen sensor voltage reading (59.1 mV). This minimum reading should be less than 200 mV.



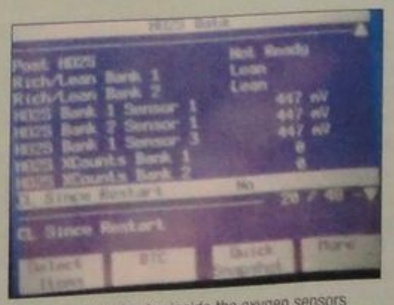
P55–14 Push the MIN/MAX button again to view the average oxygen sensor voltage reading. This reading (449.8 mV) is average and indicates that the engine is operating correctly.



P55–15 After testing, carefully remove the meter, test leads, and T-pin used for testing.



P55–16 A Tech 2 is being used on the OBD II vehicle and the screen showing oxygen sensor data should be collected before turning on the ignition (engine off).



P55–17 As the heater inside the oxygen sensors work, the sensors become more conductive to ground and the voltage should drop.



P55–18 After about three minutes, all sensors should show about the same low voltage.

SUMMARY

1. All temperature sensors decrease in resistance as the temperature increases. This is called negative temperature coefficient (NTC).
2. The ECT and IAT sensors can be tested visually, as well as by using a digital multimeter or a scan tool.
3. A throttle position (TP) sensor is a three-wire variable resistor called a potentiometer.
4. The three wires on the TP sensor include a 5-volt reference voltage from the PCM, plus the signal wire to the PCM, and a ground, which also goes to the PCM.
5. The TP sensor signal voltage should be about 0.5 volt at idle and increase to about 4.5 volts at wide-open throttle (WOT).
6. A TP sensor can be tested using a digital multimeter, a digital storage oscilloscope (DSO), or a scan tool.
7. Pressure below atmospheric pressure is called vacuum and is measured in inches of Mercury.
8. A manifold absolute pressure sensor uses a perfect vacuum (zero absolute pressure) in the sensor to determine the pressure.
9. Three types of MAP sensors include:
   - Silicon-diaphragm strain gauge
   - Capacitor-capsule design
   - Ceramic disc design
10. A MAP sensor is used to detect changes in altitude, as well as check other sensors and engine systems.
11. A MAP sensor can be tested by visual inspection, testing the output using a digital meter or scan tool.
12. A mass airflow sensor actually measures the density and amount of air flowing into the engine, which results in accurate engine control.
13. An air vane sensor measures the volume of the air, and the intake air temperature sensor is used by the PCM to calculate the mass of the air entering the engine.
14. A hot wire MAF sensor uses the electronics in the sensor itself to heat a wire 70°C above the temperature of the air entering the engine.
15. An oxygen sensor produces a voltage output signal based on the oxygen content of the exhaust stream.
16. If the exhaust has little oxygen, the voltage of the oxygen sensor will be close to 1 volt (1,000 mV) and close to zero if there is high-oxygen content in the exhaust.
17. Oxygen sensors can have one, two, three, four, or more wires, depending on the style and design.
18. A wide-band oxygen sensor, also called a lean air–fuel (LAF) or linear air–fuel ratio sensor, can detect air–fuel ratios from as rich as 12:1 to as lean as 18:1.

REVIEW QUESTIONS

1. How does a typical NTC temperature sensor work?
2. What temperature should be displayed on a scan tool if the ECT sensor is unplugged with the key on, engine off?
3. What are the three ways that temperature sensors can be tested?
4. What is the purpose of each of the three wires on a typical TP sensor?
5. What is the relationship among atmospheric pressure, vacuum, and boost pressure in PSI?
6. What are three types (construction) of MAP sensors?
7. What are three uses of a MAP sensor by the PCM?
8. How does a hot film MAF sensor work?
9. How is a MAF sensor tested?
10. What are the types of airflow sensors?
11. How does an oxygen sensor detect oxygen levels in the exhaust?
12. What are three basic designs of oxygen sensors and how many wires may be used for each?
13. What are three ways oxygen sensors can be tested?

CHAPTER QUIZ

1. Two technicians are discussing a stepped ECT circuit. Technician A says that the sensor used for a stepped circuit is different than one used in a non-stepped circuit. Technician B says that a stepped ECT circuit uses different internal resistance inside the PCM. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. When checking the ECT sensor with a scan tool, about what temperature should be displayed if the connector is removed from the sensor with the key on, engine off?
   a. 284°F (140°C)
   b. 230°F (110°C)
   c. 120°F (50°C)
   d. −40°F (−40°C)
3. Typical TP sensor voltage at idle is about _____.
   a. 2.50 to 2.80 volts
   b. 0.5 volt or 10% of WOT TP sensor voltage
   c. 1.5 to 2.8 volts
   d. 13.5 to 15.0 volts
4. A TP sensor is what type of sensor?
   a. Rheostat
   b. Voltage generating
   c. Potentiometer
   d. Piezoelectric
5. As the load on an engine increases, the manifold vacuum decreases and the manifold absolute pressure _____.
   a. Increases
   b. Decreases
   c. Changes with barometric pressure only (altitude or weather)
   d. Remains constant (absolute)
6. A fuel-injection system that does not use a sensor to measure the amount (or mass) of air entering the engine is usually called a(n) _____ type of system.
   a. Air vane-controlled
   b. Speed density
   c. Mass airflow
   d. Hot wire
7. The typical MAF reading on a scan tool with the engine at idle speed and normal operating temperature is _____.
   a. 1 to 3 grams per second
   b. 3 to 7 grams per second
   c. 8 to 12 grams per second
   d. 14 to 24 grams per second
8. The voltage output of a zirconia oxygen sensor when the exhaust stream is lean (excess oxygen) is _____.
   a. Relatively high (close to 1 volt)
   b. About in the middle of the voltage range
   c. Relatively low (close to 0 volt)
   d. Either a or b, depending on atmospheric pressure
9. A high O2S voltage could be due to _____.
   a. A rich exhaust
   b. A lean exhaust
   c. A defective spark plug wire
   d. Both a and c
10. An oxygen sensor is being tested using a Min-Max on a digital meter set to read the average. A good oxygen sensor should display what reading?
    a. 450 to 650 mV
    b. 450 mV
    c. 100 to 250 mV
    d. 650 to 950 mV

CHAPTER 56 Ignition System Components and Operation

OBJECTIVES: After studying Chapter 56, the reader will be able to: Prepare for ASE Engine Performance (A8) certification test content area "B" (Ignition System Diagnosis and Repair). • Explain how ignition coils create 40,000 volts. • Discuss crankshaft position sensor and pickup coil operation. • Describe the operation of waste-spark and coil-on-plug ignition systems.

KEY TERMS: bypass ignition • coil-on-plug (COP) ignition (also coil-by-plug, coil-near-plug, coil-over-plug) • compression-sensing ignition • detonation • distributor ignition (DI) • distributorless ignition system (DIS) • divorced coil • dwell • *e* coil • electromagnetic interference (EMI) • electronic control unit (ECU) • electronic ignition (EI) • electronic ignition system (EIS) • electronic spark timing (EST) • flyback voltage • Hall-effect switch • high energy ignition (HEI) • igniter • ignition coil • ignition control (IC) • ignition control module (ICM) • ignition timing • inductive reactance • initial timing • ion-sensing ignition • iridium spark plugs • knock sensor (KS) • magnetic pulse generator • magnetic sensor • married coil • mutual induction • optical sensors • paired cylinders • pickup coil (pulse generator) • ping • platinum spark plugs • polarity • primary ignition circuit • primary winding • saturation • Schmitt trigger • secondary ignition circuit • secondary winding • self-induction • spark knock • spark output (SPOUT) • switching • tapped transformer • transistor • triggering • true transformer • turn ratio • up-integrated ignition • waste-spark ignition

The ignition system includes those parts and wiring required to generate and distribute a high voltage to the spark plugs. A fault anywhere in the primary (low-voltage) ignition circuit can cause a no-start condition. A fault anywhere in the secondary (high-voltage) ignition circuit can cause engine missing, hesitation, stalling, or excessive exhaust emissions.

IGNITION SYSTEM OPERATION

The ignition system includes components and wiring necessary to create and distribute a high voltage (up to 40,000 volts or more). All ignition systems apply voltage close to battery voltage to the positive side of the ignition coil and pulse the negative side to ground. When the coil negative lead is grounded, the primary (low-voltage) circuit of the coil is complete and a magnetic field is created around the coil windings. When the circuit is opened, the magnetic field collapses and induces a high-voltage spark in the secondary winding of the ignition coil. Early ignition systems used a mechanically opened set of contact points to make and break the electrical connection to ground. Electronic ignition uses a sensor, such as a pickup coil and reluctor (trigger wheel), or trigger to signal an electronic module that makes and breaks the primary connection of the ignition coil.

NOTE: Distributor ignition (DI) is the term specified by the Society of Automotive Engineers (SAE) for an ignition system that uses a distributor. **Electronic ignition (EI)** is the term specified by the SAE for an ignition system that does not use a distributor.

IGNITION COILS

The heart of any ignition system is the **ignition coil.** The coil creates a high-voltage spark by electromagnetic induction. Many ignition coils contain two separate but electrically connected windings of copper wire. Other coils are true transformers in which the primary and secondary windings are not electrically connected. See Figure 56–1.

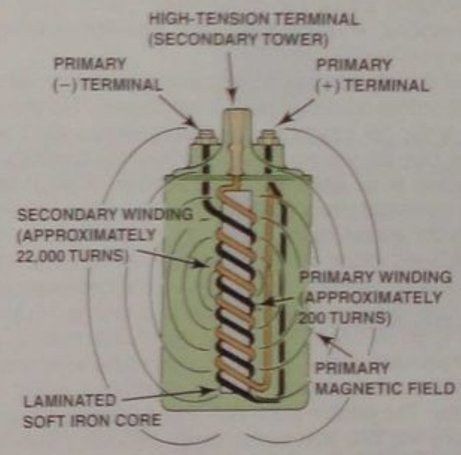


Figure 56–1 Internal construction of an oil-cooled ignition coil. Notice that the primary winding is electrically connected to the secondary winding. The polarity (positive or negative) of a coil is determined by the direction in which the coil is wound.

The center of an ignition coil contains a core of laminated soft iron (thin strips of soft iron). This core increases the magnetic strength of the coil. Surrounding the laminated core are approximately 20,000 turns of fine wire (approximately 42 gauge). These windings are called the **secondary** coil windings. Surrounding the secondary windings are approximately 150 turns of heavy wire (approximately 21 gauge). These windings are called the **primary** coil windings. The secondary winding has about 100 times the number of turns of the primary winding, referred to as the **turns ratio** (approximately 100:1). In many coils, these windings are surrounded with a thin metal shield and insulating paper and placed into a metal container. The metal container and shield help retain the magnetic field produced in the coil windings. The primary and secondary windings produce heat because of the electrical resistance in the turns of wire. Many coils contain oil to help cool the ignition coil. Other coil designs, such as

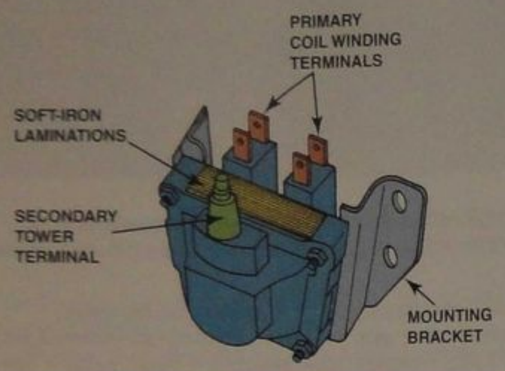


Figure 56–2 Typical air-cooled epoxy-filled E coil.



Figure 56–3 Cutaway of a General Motors Type II distributorless ignition coil. Note that the primary windings are inside of the secondary windings.

those used on GM's **high energy ignition (HEI)** systems, use an air-cooled, epoxy-sealed **E coil.** The E coil is so named because the laminated, soft-iron core is E-shaped, with the coil wire turns wrapped around the center "finger" of the E and the primary winding wrapped inside the secondary winding. See Figures 56–2 and 56–3.

The primary windings of the coil extend through the case of the coil and are labeled as positive and negative. The positive terminal of the coil attaches to the ignition switch, which supplies current from the positive battery terminal. The negative terminal is attached to an **ignition control module (ICM** or **igniter),** which opens and closes the primary ignition circuit by opening or closing the ground return path of the circuit. When the ignition switch is on, voltage should be available at *both* the positive terminal and the negative terminal of the coil if the primary windings of the coil have continuity. The labeling of positive (+) and negative (−) of the coil indicates that the positive terminal is *more* positive (closer to the positive terminal of the battery) than the negative terminal of the coil. This condition is called the coil **polarity.** The polarity of the coil must be correct to ensure that electrons will flow from the hot center electrode of the spark plug on DI systems. *The polarity of an ignition coil is determined by the direction of rotation of the coil windings.* The correct polarity is then indicated on the primary terminals of the coil. If the coil primary leads are reversed, the voltage required to fire the spark plugs is increased by 40%. The coil output voltage is directly proportional to the ratio of primary to secondary turns of wire used in the coil.

Self-Induction When current starts to flow into a coil, an opposing current is created in the windings of the coil. This opposing current generation is caused by **self-induction** and is called **inductive reactance.** Inductive reactance is similar to resistance because it opposes any changes (increase or decrease) in current flow in a coil. Therefore, when an ignition coil is first energized, there is a slight delay of approximately 0.01 second before the ignition coil reaches its maximum magnetic field strength. The point at which a coil's maximum magnetic field strength is reached is called **saturation.**

Mutual Induction In an ignition coil there are two windings, a primary and a secondary winding. When a *change* occurs in the magnetic field of one coil winding, a change also occurs in the other coil winding. Therefore, if the current is stopped from flowing (circuit is opened), the collapsing magnetic field cuts across the turns of the secondary winding and creates a high voltage in the secondary winding. This generation of an electric current in both coil windings is called **mutual induction.** The collapsing magnetic field also creates a voltage of up to 250 volts in the primary winding.

How Ignition Coils Create 40,000 Volts All ignition systems use electromagnetic induction to produce a high-voltage spark from the ignition coil. Electromagnetic induction means that a current can be created in a conductor (coil winding) by a moving magnetic field. The magnetic field in an ignition coil is produced by current flowing through the primary windings of the coil. The current for the primary winding is supplied through the ignition switch to the positive terminal of the ignition coil. The negative terminal is connected to the ground return through an electronic ignition module (igniter).

If the primary circuit is completed, current (approximately 2 to 6 A) can flow through the primary coil windings. This flow creates a strong magnetic field inside the coil. When the primary coil winding ground return path connection is opened, the magnetic field collapses and induces a voltage of from 250 to 400 volts in the primary winding of the coil and a high-voltage (20,000 to 40,000 volts) low-amperage (20 to 80 mA) current in the secondary coil windings. This high-voltage pulse flows through the coil wire (if the vehicle is so equipped), distributor cap, rotor, and spark plug wires to the spark plugs. For each spark that occurs, the coil must be charged with a magnetic field and then discharged. The ignition components that regulate the current in the coil primary winding by turning it on and off are known collectively as the **primary ignition circuit.** The components necessary to create and distribute the high voltage produced in the secondary windings of the coil are called the **secondary ignition circuit.** See Figure 56–4. These circuits include the following components.

Primary Ignition Circuit

1. Battery
2. Ignition switch
3. Primary windings of coil
4. Pickup coil (crank sensor)
5. Ignition module (igniter)

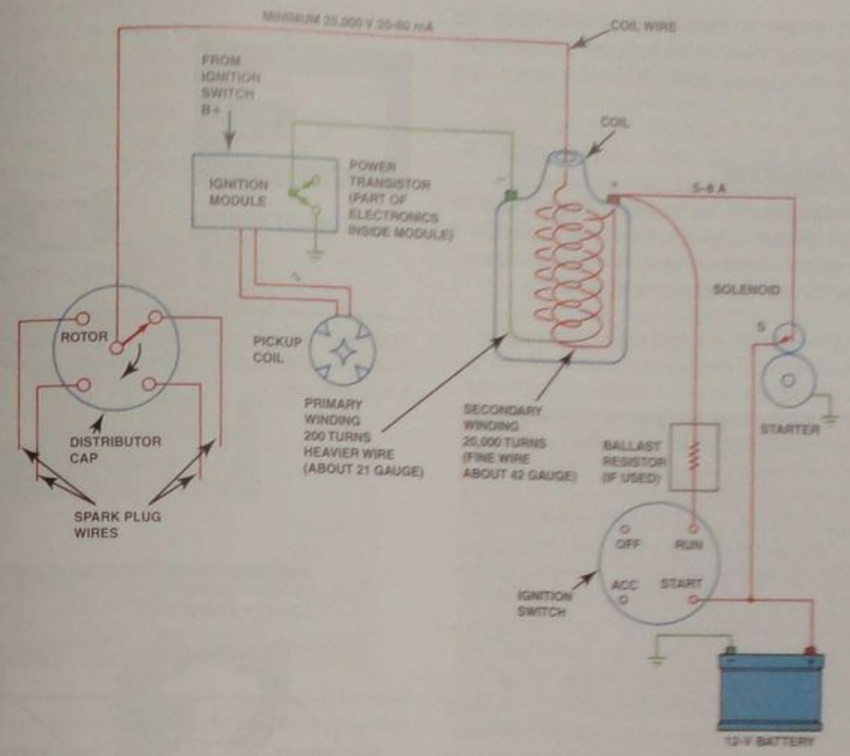


Figure 56–4 Typical primary and secondary electronic ignition using a ballast resistor and a distributor. To protect the ignition coil from overheating at lower engine speeds, many electronic ignitions do not use a ballast resistor but use electronic circuits within the module.

Secondary Ignition Circuit

1. Secondary windings of coil
2. Distributor cap and rotor (if the vehicle is so equipped)
3. Spark plug wires
4. Spark plugs

FREQUENTLY ASKED QUESTION ???

What Is a "Married" and "Divorced" Coil Design?

An ignition coil contains two windings, a primary winding and a secondary winding, and these windings can be either connected together at one end or kept separated.

- **Married.** A **married coil** design is also called a **tapped transformer** design. See Figure 56–5. The primary winding is electrically connected to the secondary winding. This method is commonly used in older distributor-type ignition system coils, as well as many coil-on-plug designs. The inductive kick, also called **flyback voltage,** created when the primary field collapses is used by the PCM to monitor secondary ignition performance.
- **Divorced.** A **divorced coil** design is also called a **true transformer** design and is used by most waste-spark ignition coils to keep both the primary and secondary winding separated.

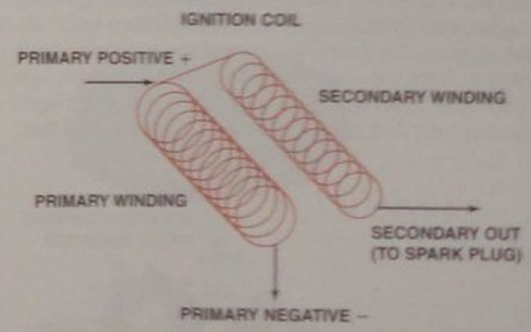


Figure 56–5 A tapped- (married) type ignition coil where the primary winding is tapped (connected) to the secondary winding.

IGNITION SWITCHING AND TRIGGERING

For any ignition system to function, the primary current must be turned on to charge the coil and off to allow the coil to discharge, creating a high-voltage spark. This turning on and off of the primary circuit is called **switching.** The unit that does the switching is an electronic switch, such as a power transistor. This power transistor can be located in any of the following locations:

- In the ignition control module (ICM)
- In the PCM (computer)

NOTE: On some coil-on-plug systems, the ICM is part of the ignition coil itself and is serviced as an assembly.

The device that signals the switching of the coil on and off or just on in most instances, is called the **trigger.** A trigger is typically a pickup coil in some distributor-type ignitions and a crankshaft

position sensor (CKP) on electronic (waste-spark and coil-on-plug) and many distributor-type ignitions. There are three types of devices used for triggering, including the magnetic sensor, Hall-effect switch, and optical sensor.

PRIMARY CIRCUIT OPERATION

To get a spark out of an ignition coil, the primary coil circuit must be turned on and off. This primary circuit current is controlled by a **transistor** (electronic switch) inside the ignition module or (igniter) that in turn is controlled by one of several devices, including:

- **Pickup coil (pulse generator)**—A simple and common ignition electronic switching device is the magnetic pulse generator system. Most manufacturers use the rotation of the distributor shaft to time the voltage pulses. The **magnetic pulse generator** is installed in the distributor housing. The pulse generator consists of a trigger wheel (reluctor) and a pickup coil. The pickup coil consists of an iron core wrapped with fine wire, in a coil at one end and attached to a permanent magnet at the other end. The center of the coil is called the pole piece. The pickup coil signal triggers the transistor inside the module and is also used by the computer for piston position information and engine speed (RPM). See Figures 56–6 and 56–7.
- **Hall-effect switch**—A **Hall-effect switch** also uses a stationary sensor and rotating trigger wheel (shutter). See Figure 56–8. Unlike the magnetic pulse generator, the Hall-effect switch requires a small input voltage to generate an output or signal voltage. Hall effect is the ability to generate a voltage signal in semiconductor material (gallium arsenate crystal) by passing current through it in one direction and applying a magnetic field to it at a right angle to its surface. If the input current is held steady and the magnetic field fluctuates, an output voltage is produced that changes in proportion to field strength. Most Hall-effect switches in distributors have a Hall element or device, a permanent magnet, and a rotating ring of metal blades (shutters) similar to a trigger wheel (another method uses a stationary sensor with a rotating magnet). Some blades are designed to hang down, typically found in Bosch and Chrysler systems; others may be on a separate ring on the distributor shaft, typically found in GM and Ford Hall-effect

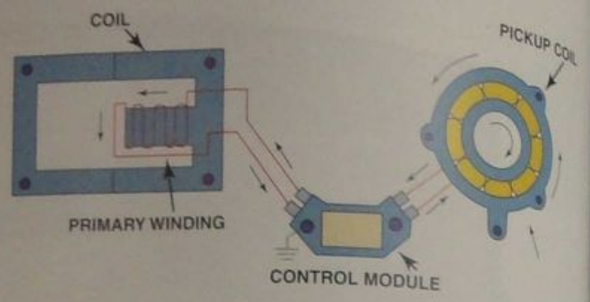


Figure 56–7 The varying voltage signal from the pickup coil triggers the ignition module. The ignition module grounds and ungrounds the primary winding of the ignition coil, creating a high-voltage spark.

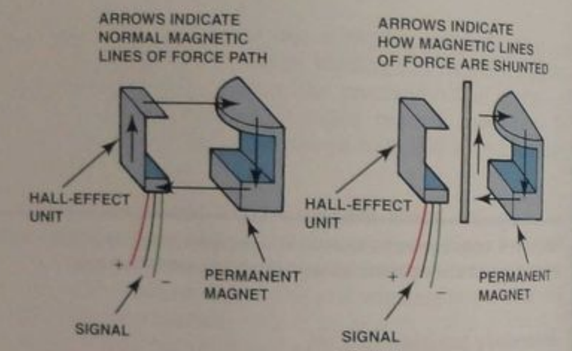


Figure 56–8 Hall-effect switches use metallic shutters to shunt magnetic lines of force away from a silicon chip and related circuits. All Hall-effect switches produce a square wave output for every accurate triggering.

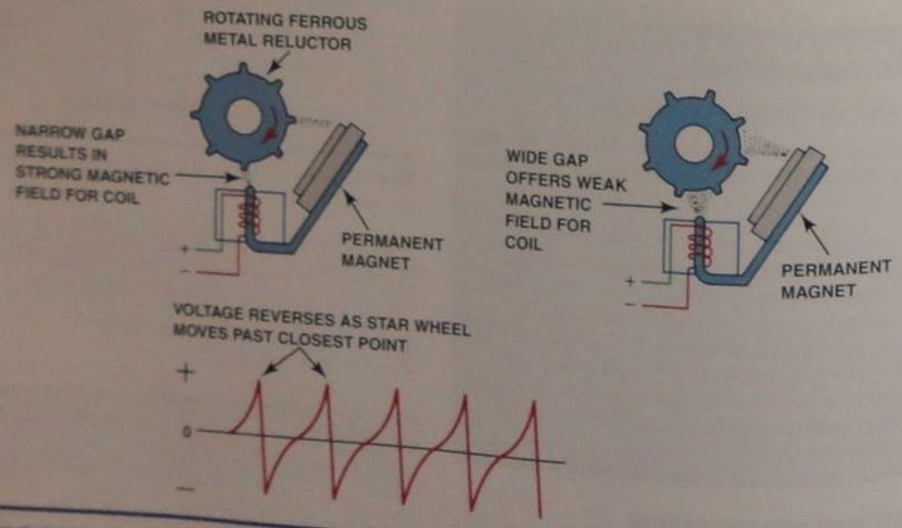


Figure 56–6 Operation of a typical pulse generator (pickup coil). At the bottom is a line drawing of a typical scope pattern of the output voltage of a pickup coil. The module receives this voltage from the pickup coil and opens the ground circuit to the ignition coil when the voltage starts down from its peak (just as the reluctor teeth start moving away from the pickup coil).

distributors. When the shutter blade enters the gap between the magnet and the Hall element, it creates a magnetic shunt that changes the field strength through the Hall element. This analog signal is sent to a **Schmitt trigger** inside the sensor itself, which converts the analog signal into a digital signal. A digital (on or off) voltage signal is created at a varying frequency to the ignition module or onboard computer. See Figures 56–9 and 56–10.

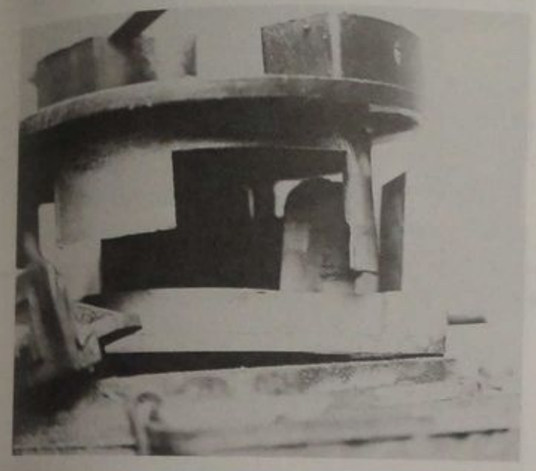


Figure 56–9 Shutter blade of a rotor as it passes between the sensing silicon chip and the permanent magnet.

- **Magnetic crankshaft position sensor**—This sensor uses the changing strength of the magnetic field surrounding a coil of wire to signal the module and computer. This signal is used by the electronics in the module and computer as to piston position and engine speed (RPM). See Figures 56–11 and 56–12.
- **Optical sensors**—These use light from a LED and a phototransistor to signal the computer. An interrupter disc between the LED and the phototransistor has slits that allow the light from the LED to trigger the phototransistor on the other side of the disc. Most **optical sensors** (usually located inside the distributor) use two rows of slits to provide individual cylinder recognition (low-resolution) and precise distributor angle recognition (high-resolution) signals. See Figure 56–13.

TECH TIP ✓ **Optical Distributors Do Not Like Light**

Optical distributors use the light emitted from LEDs to trigger phototransistors. Most optical distributors use a shield between the distributor rotor and the optical interrupter ring. Sparks jump the gap from the rotor tip to the distributor cap inserts. This shield blocks the light from the electrical arc from interfering with the detection of the light from the LEDs.

If this shield is not replaced during service, the light signals are reduced and the engine may not operate correctly. See Figure 56–14. This can be difficult to detect because nothing looks wrong during a visual inspection. Remember that all optical distributors must be shielded between the rotor and the interrupter ring.

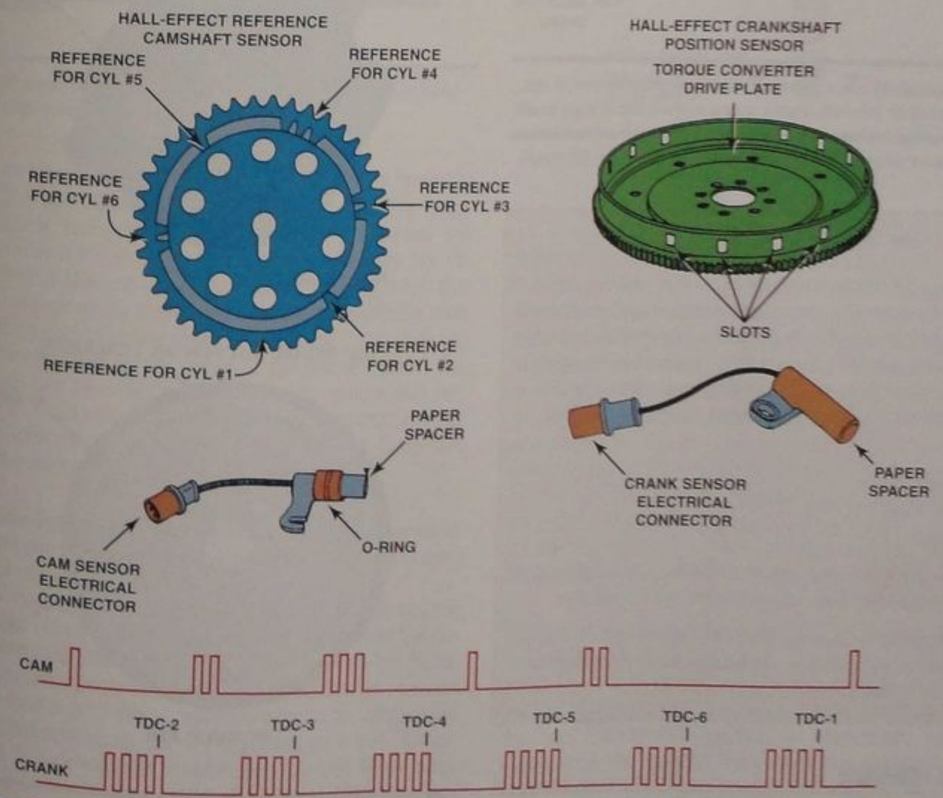


Figure 56–10 Some Hall-effect sensors look like magnetic sensors. This Hall-effect camshaft reference sensor and crankshaft position sensor have an electronic circuit built in that creates a 0- to 5-volt signal as shown at the bottom. These Hall-effect sensors have three wires: a power supply (8 volts) from the computer (controller); a signal (0 to 5 volts); and a signal ground.

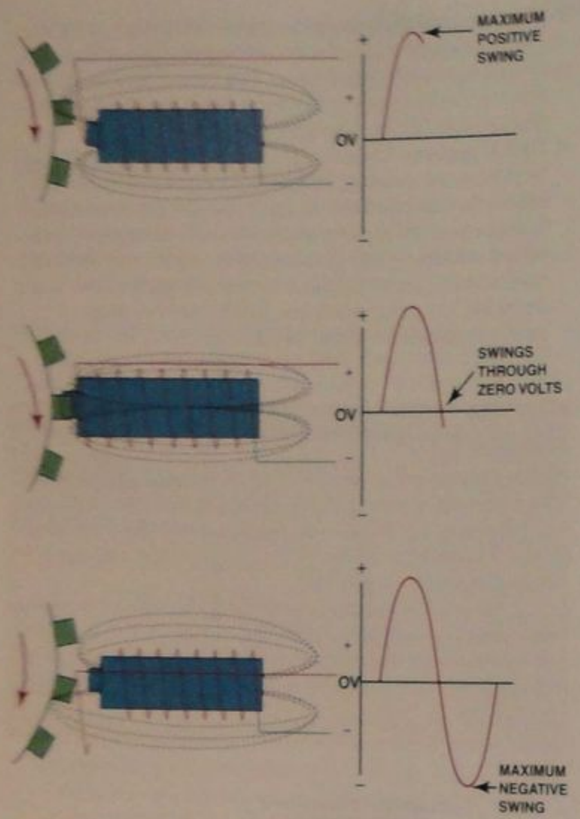


Figure 56–11 A magnetic sensor uses a permanent magnet surrounded by a coil of wire. The notches of the crankshaft (or camshaft) create a variable magnetic field strength around the coil. When a metallic section is close to the sensor, the magnetic field is stronger because metal is a better conductor of magnetic lines of force than air.

TECH TIP ✓ **The Tachometer Trick**

When diagnosing a no-start or intermittent missing condition, check the operation of the tachometer. If the tachometer does not indicate engine speed (no-start condition) or drops toward zero (engine missing), then the problem is due to a defect in the primary ignition circuit. The tachometer gets its signal from the pulsing of the primary winding of the ignition coil. The following components in the primary circuit could cause the tachometer to not work when the engine is cranking.

- Pickup coil
- Crankshaft position sensor
- Ignition module (igniter)
- Coil primary wiring

If the vehicle is not equipped with a tachometer, connect a handheld tachometer to the negative terminal of the coil. Remember the following:

- No tachometer reading means the problem is in the primary ignition circuit.
- Tachometer reading okay means the problem is in the secondary ignition circuit or is a fuel-related problem.

DISTRIBUTOR IGNITION

General Motors HEI Electronic Ignition As mentioned, high energy ignition (HEI) has been the standard equipment DI system on General Motors vehicles. Some models use an ignition

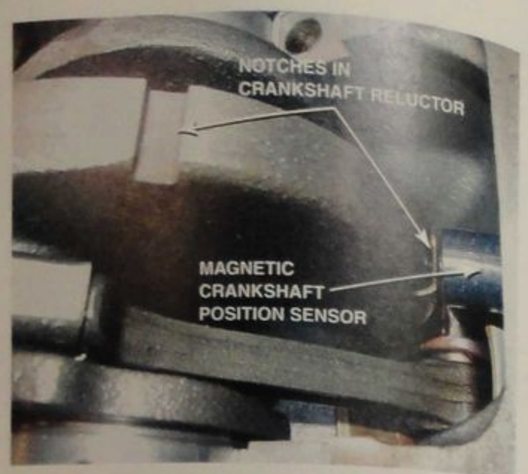
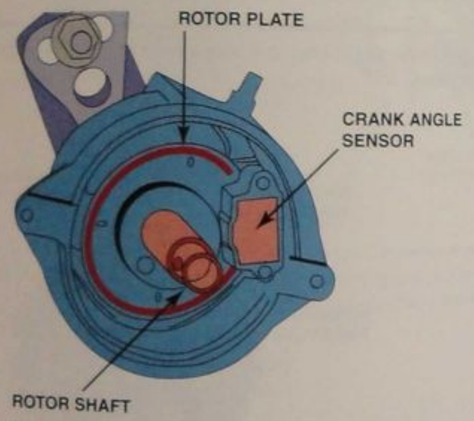


Figure 56–12 A typical magnetic crankshaft position sensor.



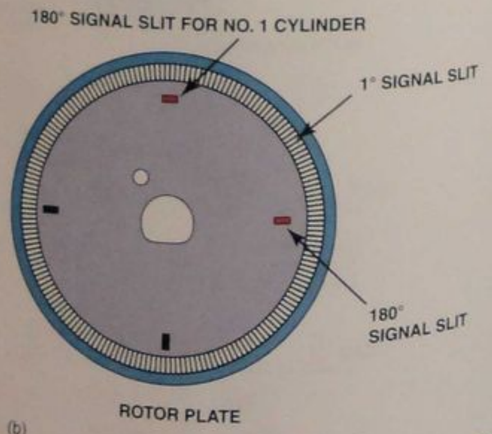


Figure 56–13 (a) Typical optical distributor. (b) Cylinder I slit signals the computer the piston position for cylinder I. The I-degree slits provide accurate engine speed information to the computer.

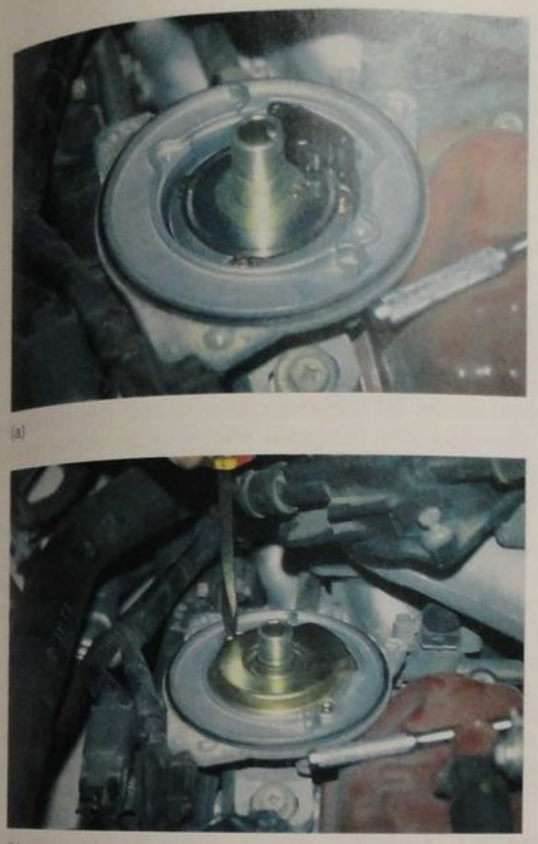


Figure 56–14 (a) An optical distributor on a Nissan 3.0 L V-6 shown with the light shield removed. (b) A light shield being installed before the rotor is attached.

coil inside the distributor cap and some use an externally mounted ignition coil. The operation of both styles is similar. The large-diameter distributor cap provides additional space between the spark plug connections to help prevent crossfire. See Figure 56–15. Most HEI distributors also use 8-mm-diameter spark plug wires that use female connections to the distributor cap towers. HEI coils must be replaced (if defective) with the exact replacement style. HEI coils differ and can be identified by the colors of the primary leads. The primary coil leads can be either white and red or yellow and red. The correct color of lead coil must be used for replacement. The colors of the leads indicate the direction in which the coil is wound, and therefore its polarity. See Figures 56–16 and 56–17.

Ford Electronic Ignition Ford electronic ignition systems all function similarly, even though over the years the system has been called by various names.

The EEC IV system uses the thick-film-integration (TFI) ignition system. This system uses a smaller control module attached to the distributor and uses an air-cooled epoxy E coil. See Figure 56–18. Thick-film integration means that all electronics are manufactured on small layers built up to form a thick film. Construction includes using pastes of different electrical resistances that are deposited on a thin, flat ceramic material by a process similar to silk-screen printing. These resistors are connected by tracks of palladium silver paste. Then the chips that form the capacitors, diodes, and integrated circuits are soldered directly to the palladium silver tracks. The thick-film manufacturing process is highly automated.

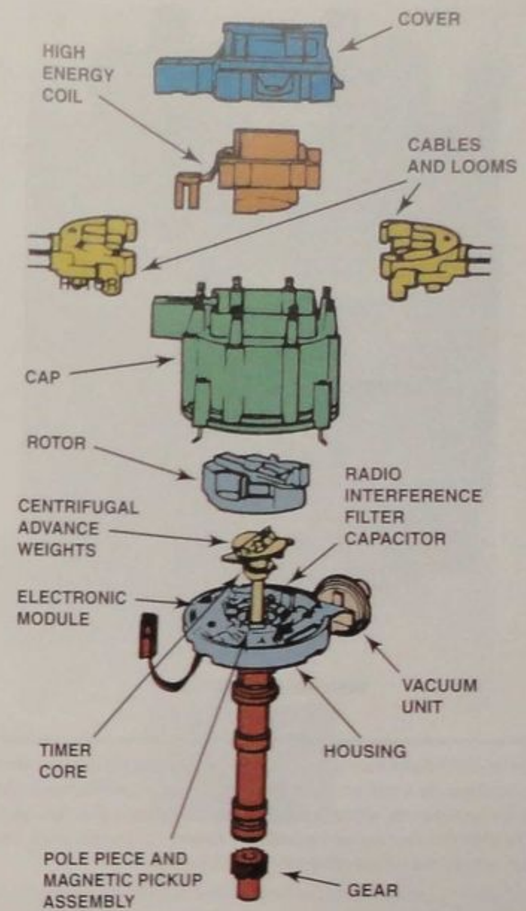


Figure 56–15 An HEI distributor.

Operation of Ford Distributor Ignition Ford DI systems function in basically the same way regardless of year and name. Under the distributor cap and rotor is a magnetic pickup assembly. This assembly produces a small alternating electrical pulse (approximately 1.5 volts) when the distributor armature rotates past the pickup assembly (stator). This low-voltage pulse is sent to the ignition module. The ignition module then switches (through transistors) off the primary ignition coil current. When the ignition coil primary current is stopped quickly, a high-voltage "spike" discharges from the coil secondary winding. The coil current is controlled in the module circuits by decreasing dwell (coil-charging time), depending on various factors determined by operating conditions. See Figure 56–19.

Chrysler Distributor Ignition Chrysler was the first domestic manufacturer to produce electronic ignition as standard equipment. The Chrysler system consists of a pulse generator unit in the distributor (pickup coil and reluctor). Chrysler's name for their electronic ignition is **electronic ignition system (EIS),** and the control unit (module) is called the **electronic control unit (ECU).**

The pickup coil in the distributor (pulse generator) generates the signal to open and close the primary coil circuit. See Figure 56–20.

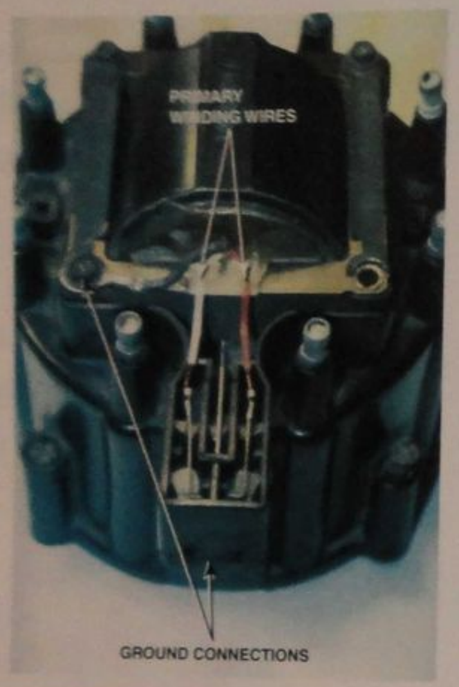


Figure 56–16 A typical General Motors HEI coil installed in the distributor cap. When the coil or distributor cap is replaced, check that the ground clip is transferred from the old distributor cap to the new. Without proper grounding, coil damage is likely. There are two designs of HEI coils. One uses red and white wire as shown, and the other design, which has reversed polarity, uses red and yellow wire for the coil primary.



Figure 56–17 This uses a remotely mounted ignition coil.

WASTE-SPARK IGNITION SYSTEMS

Waste-spark ignition is another name for **distributorless ignition system (DIS)** or **electronic ignition (EI)**. Waste-spark ignition was introduced in the mid-1980s and uses the onboard computer to fire the ignition coils. These systems were first used on some Saabs and General Motors engines. A four-cylinder engine uses two ignition coils and a six-cylinder engine uses three ignition coils. Each coil is a true transformer in which the primary winding and secondary winding are not electrically connected. Each end of the secondary winding is connected to a cylinder exactly opposite the other in the firing order, which is called a **paired cylinder.** See Figure 56–21. This means that *both* spark plugs fire at the same time (within nanoseconds of each other). When one cylinder (for example, 6) is on the compression stroke, the other cylinder (3) is on the exhaust stroke. This spark that occurs on the exhaust stroke is called the waste spark, because it does no useful work and is only used as a ground path for the secondary winding of the ignition coil. The voltage required to jump the spark plug gap on cylinder 3 (the exhaust stroke) is only 2 to 3 kV and provides the *ground circuit* for the secondary coil circuit. The remaining coil energy is used by the cylinder on the compression stroke. One spark plug of each pair always fires straight polarity and the other cylinder always fires reverse polarity. Spark plug life is not greatly affected by the reverse polarity. If there is only one defective spark plug wire or spark plug, two cylinders may be affected.

The coil polarity is determined by the direction the coil is wound (left-hand rule for conventional current flow) and cannot be changed. See Figure 56–22. Each spark plug for a particular cylinder always will be fired either with straight or reversed polarity, depending on its location in the engine and how the coils are wired. However, the compression and waste-spark condition flip-flops. When one cylinder is on compression, such as cylinder number 1, then the paired cylinder (number 4) is on the exhaust stroke. During the next rotation of the crankshaft, cylinder number 4 is on the compression stroke and cylinder number 1 is on the exhaust stroke.

Cylinder 1 Always fires straight polarity, one time, requiring 10 to 12 kV and one time, requiring 3 to 4 kV.

Cylinder 4 Always fires reverse polarity, one time, requiring 10 to 12 kV and one time, requiring 3 to 4 kV.

NOTE: With a distributor-type ignition system, the coil has two air gaps to fire: one between the rotor tip and the distributor insert (not under compression forces) and the other in the gap at the firing tip of the spark plug (under compression forces). A DIS also fires two gaps: one under compression (compression stroke plug) and one not under compression (exhaust stroke plug).

TECH TIP ✓ **Odds Fire Straight**

Waste-spark ignition systems fire two spark plugs at the same time. Most vehicle manufacturers use a waste-spark system that fires the odd-numbered cylinders (1, 3, and 5) by straight polarity (current flow from the top of the spark plug through the gap and to the ground electrode). The even-numbered cylinders (2, 4, and 6) are fired reverse polarity, meaning that the spark jumps from the side electrode to the center electrode. Some vehicle manufacturers equip their vehicles with platinum plugs with the expansive platinum alloy only on one electrode as follows:

- On odd-numbered cylinders (1, 3, 5), the platinum is on the center electrode.
- On even-numbered cylinders (2, 4, 6), the platinum is on the ground electrode.

Replacement spark plugs use platinum on both electrodes (double platinum) and can, therefore, be placed in any cylinder location.

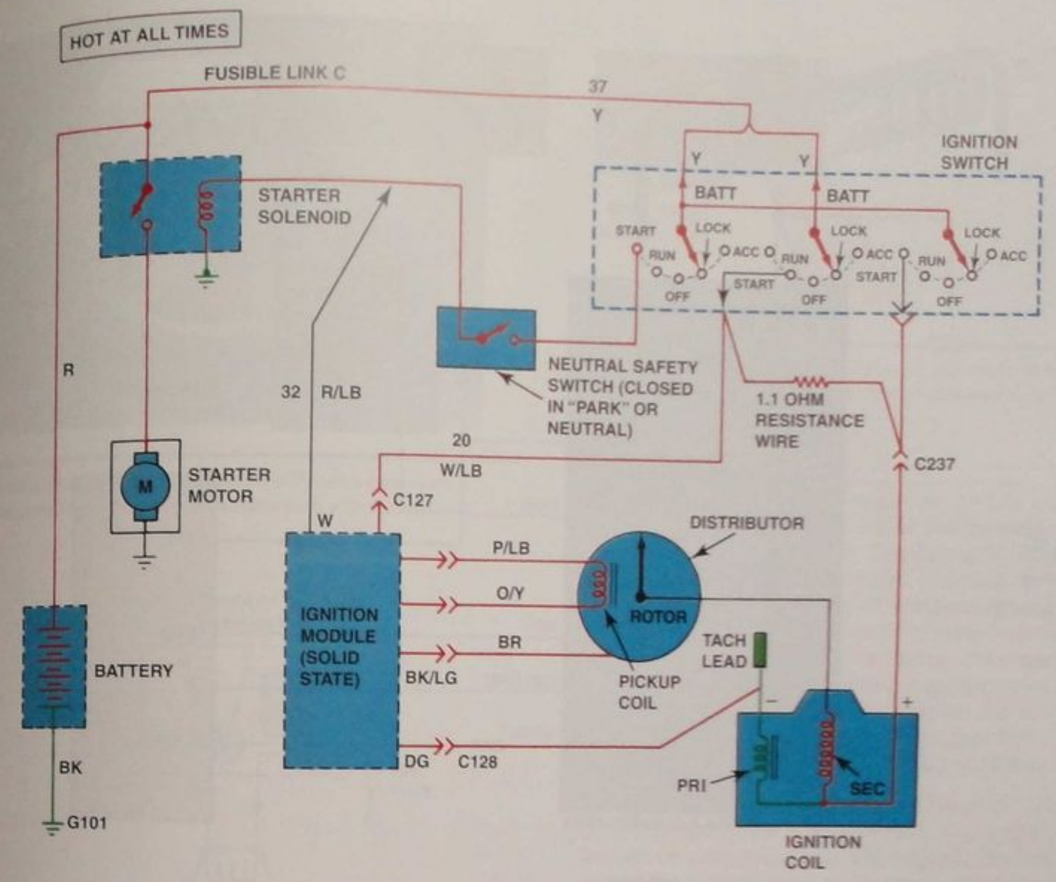


Figure 56–18 Wiring diagram of a typical Ford electronic ignition.

Waste-spark ignitions require a sensor (usually a crankshaft sensor) to trigger the coils at the correct time. See Figure 56–23. The crankshaft sensor cannot be moved to adjust ignition timing. Ignition timing is not adjustable. The slight adjustment of the crankshaft sensor is designed to position the sensor exactly in the middle of the rotating metal disc for maximum clearance. Some engines do not use a camshaft position sensor, but rather double Hall-effect crankshaft sensors and again, ignition timing is not adjustable.

IGNITION CONTROL CIRCUITS

Ignition control (IC) is the OBD-II terminology for the output signal from the PCM to the ignition system that controls engine timing. Previously, each manufacturer used a different term to describe this signal. For instance, Ford referred to this signal as **spark output (SPOUT)** and General Motors referred to this signal as **electronic spark timing (EST).** This signal is now referred to as the ignition control (IC) signal. The ignition control signal is usually a digital output that is sent to the ignition system as a timing signal. If the ignition system is equipped with an ignition module, then this signal is used by the ignition module to vary the timing as engine speed and load changes. If the PCM directly controls the coils, such as most coil-on-plug ignition systems, then this IC signal directly controls the coil primary and there is a separate IC signal for each ignition coil. The IC signal controls the time that the coil fires; it either advances or retards the timing. On many systems, this signal controls the duration of the primary current flow in the coil, which is referred to as the **dwell.**

BYPASS IGNITION CONTROL

A bypass-type ignition control means that the engine starts using the ignition module for timing control and then switches to the PCM for timing control after the engine starts. A **bypass ignition** is commonly used on General Motors engines equipped with distributor ignition (DI), as well as those equipped with waste-spark ignition. See Figure 56–24 on page 668. The bypass circuit includes four wires:

- **Tach reference (purple/white).** This wire comes from the ignition control (IC) module and is used by the PCM as engine speed information.
- **Ground (black/white).** This ground wire is used to ensure that both the PCM and the ignition control module share the same ground.
- **Bypass (tan/black).** This wire is used to conduct a 5-volt DC signal from the PCM to the ignition control module to switch the timing control from the module to the PCM.

NOTE: It is this bypass wire that is disconnected before the ignition timing can be set on many General Motors engines equipped with a distributor ignition.

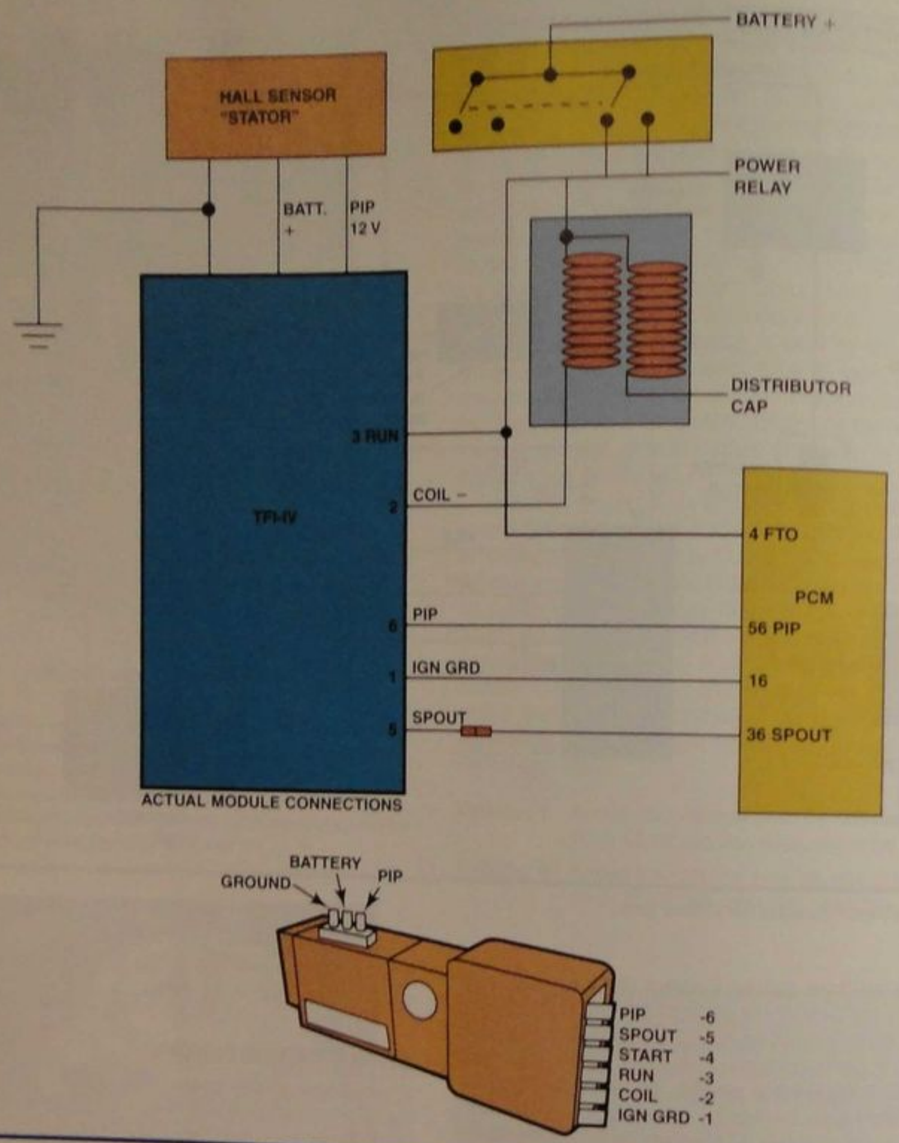


Figure 56–19 Schematic of a Ford TFI-IV ignition system. The SPOUT connector is unplugged when ignition timing is being set.

- **EST (ignition control) (white wire).** This is the ignition timing control signal from the PCM to the ignition control module.

Diagnosing a Bypass Ignition System One advantage of a bypass-type ignition is that the engine will run without the computer because the module can do the coil switching and can, through electronic circuits inside the module, provide for some spark advance as the engine speed increases. This is a safety feature that helps protect the catalytic converter if the ignition control from the PCM is lost. Therefore, if there is a problem, use a digital meter and check for the presence of 5 volts on the tan bypass wire. If there is not 5 volts present with the engine running, then the PCM or the wiring is at fault.

Up-Integrated Ignition Control Most coil-on-plug and many waste-spark-type ignition systems use the PCM for ignition timing control. This type of ignition control is called **up-integrated** because all timing functions are interpreted in the PCM, rather than being split between the ignition control module and the PCM. The ignition module, if even used, contains the power transistor for coil switching. The signal as to when the coil fires, is determined and controlled from the PCM.

Unlike a bypass ignition control circuit, it is not possible to separate the PCM from the ignition coil control to help isolate a fault.

COMPRESSION-SENSING IGNITION

Some waste-spark ignition systems, such as those used on Saturns, use the voltage required to fire the cylinders to determine cylinder position. It requires a higher voltage to fire a spark plug under compression than it does when the spark plug is being fired on the exhaust stroke. The electronics in the coil and the PCM can detect which of the two cylinders that are fired at the same time requires the higher voltage, which indicates the cylinder on the compression stroke. For example, a typical four-cylinder engine equipped with a waste-spark ignition system will fire both cylinders 1 and 4. If cylinder number 4 requires a higher voltage to fire, as determined by the electronics connected to the coil, then the PCM assumes that cylinder number 4 is on the compression stroke. Engines equipped with **compression-sensing ignition** systems, such as Saturns, do not require the use of a camshaft position sensor to determine cylinder number.



Figure 56–20 A Chrysler electronic ignition distributor. This unit is equipped with a vacuum advance mechanism that advances the ignition timing under light engine load conditions.

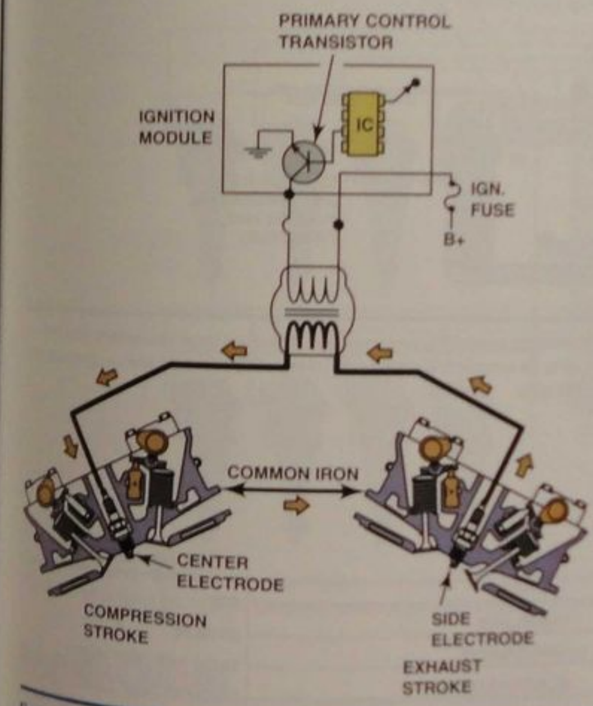


Figure 56–21 A waste-spark system fires one cylinder while its piston is on the compression stroke and into paired or companion cylinders while it is on the exhaust stroke. In a typical engine, it requires only about 2 to 3 kV to fire the cylinder on the exhaust strokes. The remaining coil energy is available to fire the spark plug under compression (typically about 8 to 12 kV).

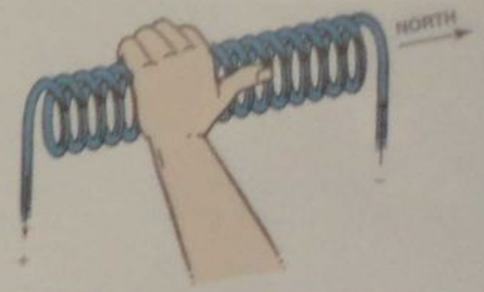


Figure 56–22 The left-hand rule states that if a coil is grasped with the left hand, the fingers will point in the direction of current flow and the thumb will point toward the north pole.

COIL-ON-PLUG IGNITION

Coil-on-plug (COP) ignition uses one ignition coil for each spark plug. This system is also called **coil-by-plug, coil-near-plug,** or **coil-over-plug** ignition. See Figures 56–25 and 56–26 on page 669. The coil-on-plug system eliminates the spark plug wires which are often sources of **electromagnetic interference (EMI)** that can cause problems to some computer signals. The vehicle computer controls the timing of the spark. Ignition timing also can be changed (retarded or advanced) on a cylinder-by-cylinder basis for maximum performance and to respond to knock sensor signals. See Figure 56–27 on page 669.

There are two basic types of coil-on-plug ignition including:

- **Two-wire**—This design uses the vehicle computer to control the firing of the ignition coil. The two wires include ignition voltage feed and the pulse ground wire, which is controlled by the computer. All ignition timing and dwell control are handled by the computer.
- **Three-wire**—This design includes an ignition module at each coil. The three wires include:
  - Ignition voltage
  - Ground
  - Pulse from the computer to the built-in module

General Motors vehicles use a variety of coil-on-plug-type ignition systems. Many V-8 engines use a coil-near-plug system with individual coils and modules for each individual cylinder that are placed on the valve covers. Short secondary ignition spark plug wires are used to connect the output terminal of the ignition coil to the spark plug.

Most newer Chrysler engines use coil-over-plug-type ignition systems. Each coil is controlled by the PCM, which can vary the ignition timing separately for each cylinder based on signals the PCM receives from the knock sensor(s). For example, if the knock sensor detects that a spark knock has occurred after firing cylinder 3, then the PCM will continue to monitor cylinder 3 and retard timing on just this one cylinder if necessary to prevent engine-damaging detonation.

SAFETY TIP **Never Disconnect a Spark Plug Wire When the Engine Is Running!**

Ignition systems produce a high-voltage pulse necessary to ignite a lean air-fuel mixture. If you disconnect a spark plug wire when the engine is running, this high-voltage spark could cause personal injury or damage to the ignition coil and/or ignition module.

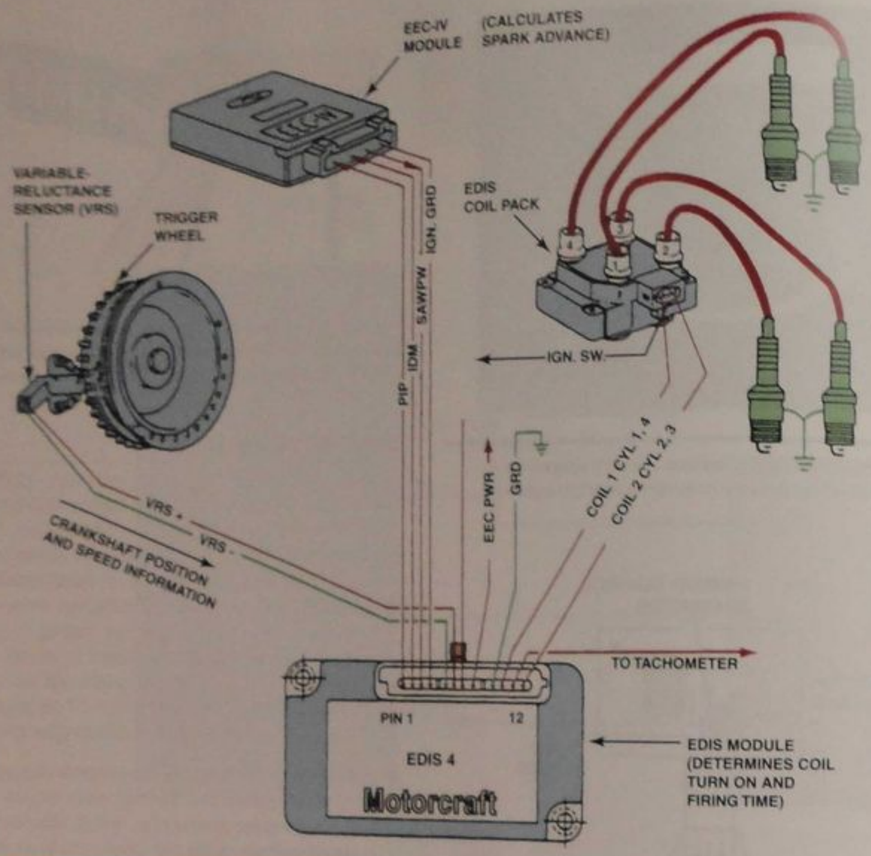


Figure 56–23 Typical Ford EDIS 4-cylinder ignition system. The crankshaft sensor, called a variable-reluctance sensor (VRS), sends crankshaft position and speed information to the EDIS module. A modified signal is sent to the computer as a profile ignition pickup (PIP) signal. The PIP is used by the computer to calculate ignition timing, and the computer sends a signal back to the EDIS module as to when to fire the spark plug. This return signal is called the spark angle word (SAW) signal.

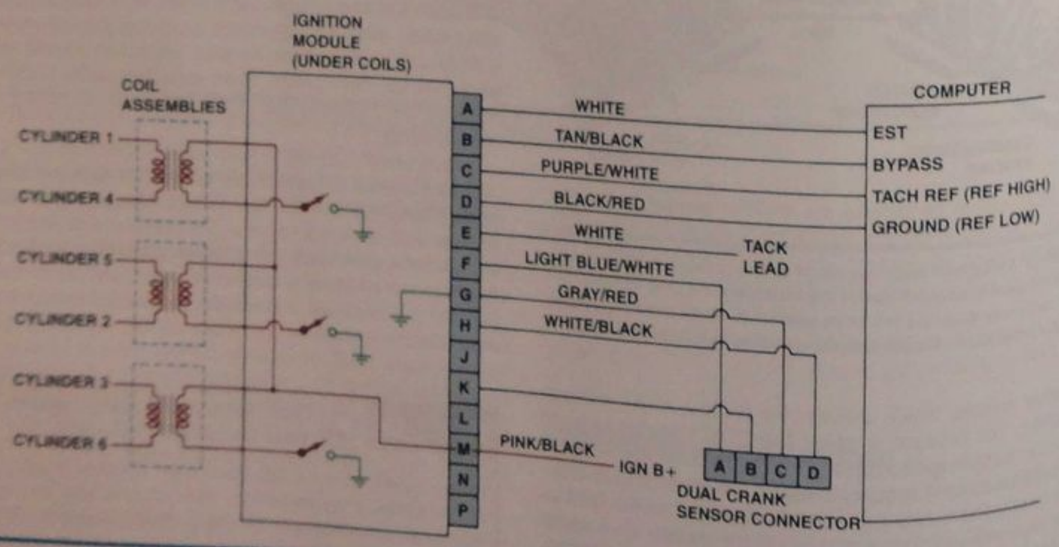


Figure 56–24 Typical wiring diagram of a V-6 distributorless (direct fire) ignition system.

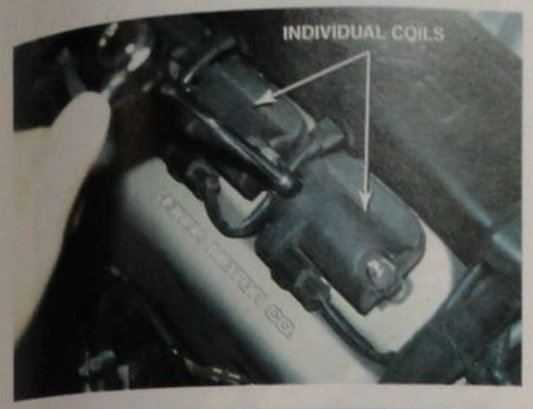


Figure 56–25 A coil-on-plug ignition system.

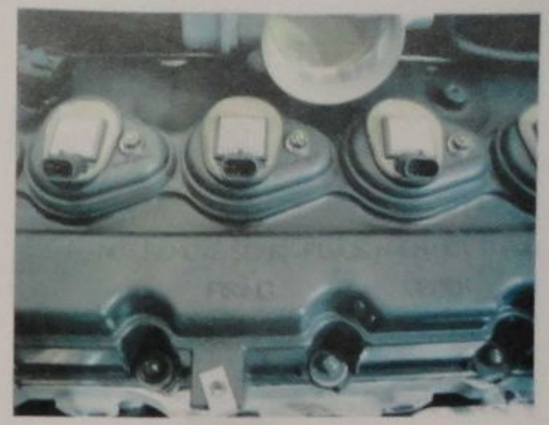


Figure 56–27 Individual coils with modules shown on the General Motors 4.2-L inline 6-cyliner light-truck engine. Note the aluminum cooling fins (heat sink) on top of each assembly.

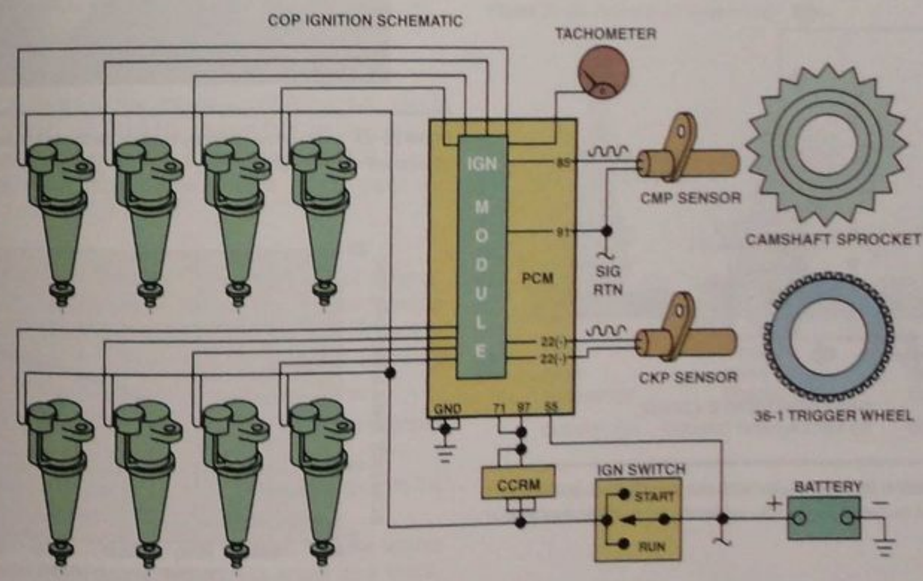


Figure 56–26 A typical coil-on-plug (COP) ignition system on a V-8 with a separate coil for each cylinder.

ION-SENSING IGNITION

In an **ion-sensing ignition** system, the spark plug itself becomes a sensor. The ignition control (IC) module applies a voltage of about 100 to 400 volts DC across the spark plug gap after the ignition event to sense the plasma inside the cylinder. See Figure 56–28. The coil discharge voltage (10 to 15 kV) is electrically isolated from the ion-sensing circuit. The combustion flame is ionized and will conduct some electricity, which can be accurately measured at the spark plug gap. The purpose of this circuit includes:

- Misfire detection (required by OBD-II regulations)
- Knock detection (eliminates the need for a knock sensor)
- Ignition timing control (to achieve the best spark timing for maximum power with lowest exhaust emissions)
- Exhaust gas recirculation (EGR) control
- Air–fuel ratio control on an individual cylinder basis

Ion-sensing ignition systems still function the same as conventional coil-on-plug designs, but the engine does not need to be equipped with a camshaft position sensor for misfire detection, or a knock sensor because both of these faults are achieved using the electronics inside the ignition control circuits.

IGNITION TIMING

Ignition timing refers to when the spark plug fires in relation to piston position. The time when the spark occurs depends on engine speed, and therefore, must be advanced (spark plugs fire some) as the engine rotates faster. The ignition in the cylinder takes a certain amount of time, usually 30 ms (3/1000 of a second). This burning time is relatively constant throughout the entire engine speed range. For maximum efficiency from the expanding gases inside the combustion chamber, the burning of the air–fuel

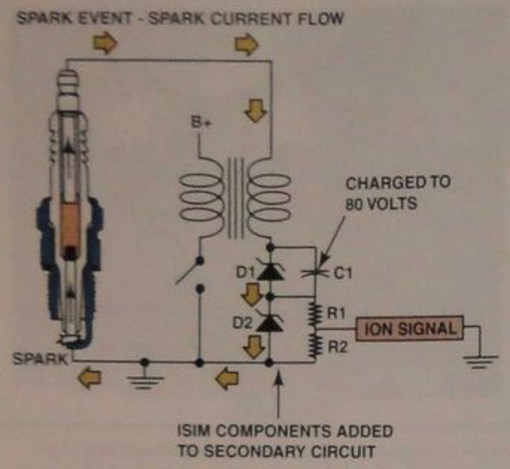


Figure 56–28 A DC voltage is applied across the spark plug gap after the plug fires and the circuit can determine if the correct air–fuel ratio was present in the cylinder and if knock occurred.

mixture should end by about 10° after top dead center (ATDC). If the burning of the mixture is still occurring after that point, the expanding gases do not exert much force on the piston because it is moving away from the gases (the gases are "chasing" the piston).

Therefore, to achieve the goal of having the air–fuel mixture be completely burned by the time the piston reaches 10° after top dead center, the spark must be advanced (occur sooner) as the engine speed increases. This timing advance is determined and controlled by the PCM on most vehicles. See Figure 56–29.

INITIAL TIMING

If the engine is equipped with a distributor, it may be possible to adjust the base or the **initial timing.** The initial timing is usually set to fire the spark plug between zero degrees (top dead center or TDC) or slightly before TDC (BTDC). Ignition timing does change as the timing chain or gear wears and readjustment is often necessary on high-mileage engines. See

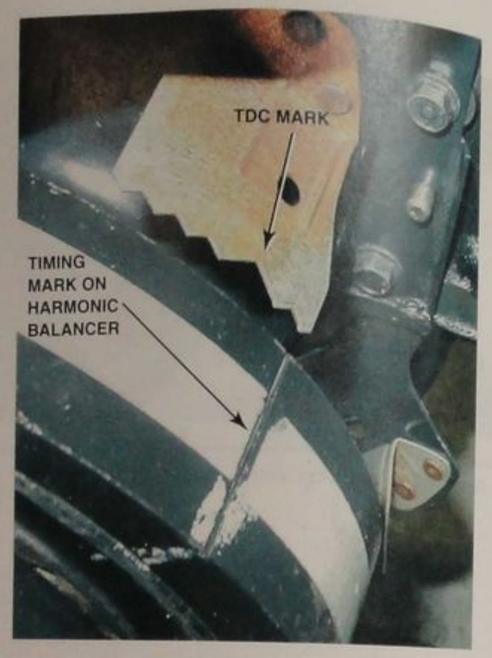


Figure 56–29 Ignition timing marks are found on the harmonic balancers that are equipped with distributor ignition.

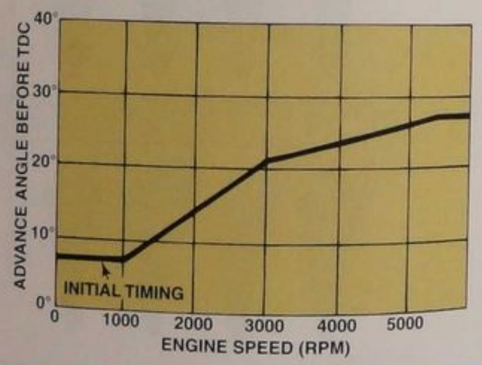


Figure 56–30 The initial timing is where the spark plug fires at idle speed. The computer then advances the timing based on engine speed and other factors.

Figure 56–30. Waste-spark and coil-on-plug ignitions cannot be adjusted.

KNOCK SENSORS

Knock sensors are used to detect abnormal combustion, often called **ping, spark knock,** or **detonation.** Whenever abnormal combustion occurs, a rapid pressure increase occurs in the cylinder, creating a vibration in the engine block. It is this vibration that is detected by the knock sensor. The signal from the knock sensor is used by the PCM to retard the ignition timing until the knock is eliminated, thereby reducing the damaging effects of the abnormal combustion on pistons and other engine parts.

Inside the knock sensor is a piezoelectric element that generates a voltage when pressure or a vibration is applied to the unit.

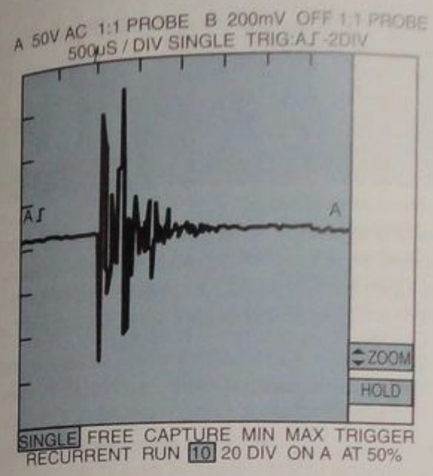


Figure 56–31 A typical waveform from a knock sensor during a spark knock event. This signal is sent to the computer which in turn retards the ignition timing. This timing retard is accomplished by an output command from the computer to either a spark advance control unit or directly to the ignition module.

The knock sensor is tuned to the engine knock frequency, which is a range from 5 kHz to 10 kHz, depending on the engine design. The voltage signal from the **knock sensor (KS)** is sent to the PCM. The PCM retards the ignition timing until the knocking stops.

Diagnosing the Knock Sensor If a knock sensor diagnostic trouble code (DTC) is present, follow the specified testing procedure in the service information. A scan tool can be used to check the operation of the knock sensor, using the following procedure.

Step #1 Start the engine and connect a scan tool to monitor ignition timing and/or knock sensor activity.

Step #2 Create a simulated engine knocking sound by tapping on the engine block or cylinder head with a soft-faced mallet.

Step #3 Observe the scan tool display. The vibration from the tapping should have been interpreted by the knock sensor as a knock, resulting in a knock sensor signal and a reduction in the spark advance.

A knock sensor also can be tested using a digital storage oscilloscope. See Figure 56–31.

NOTE: Some engine computers are programmed to ignore knock sensor signals when the engine is at idle speed to avoid having the noise from a loose accessory drive belt, or other accessory, interpreted as engine knock. Always follow the vehicle manufacturer's recommended testing procedure.

Replacing a Knock Sensor If replacing a knock sensor, be sure to purchase the exact replacement needed, because they often look the same, but the frequency range can vary according to engine design, as well as where it is located on the engine. Always tighten the knock sensor using a torque wrench and tighten to the specified torque to avoid causing damage to the piezoelectric element inside the sensor.

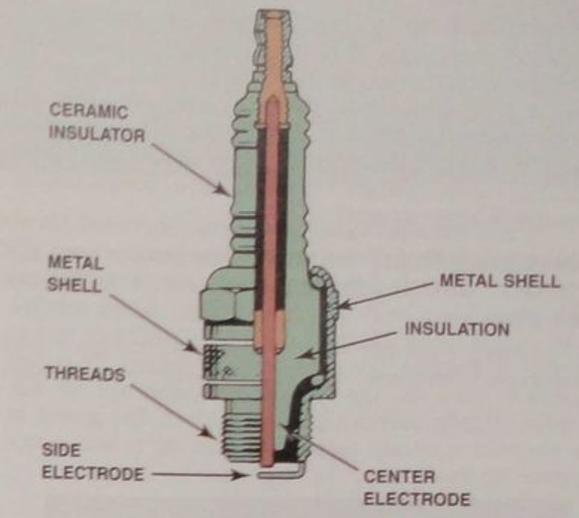


Figure 56–32 Parts of a typical spark plug.

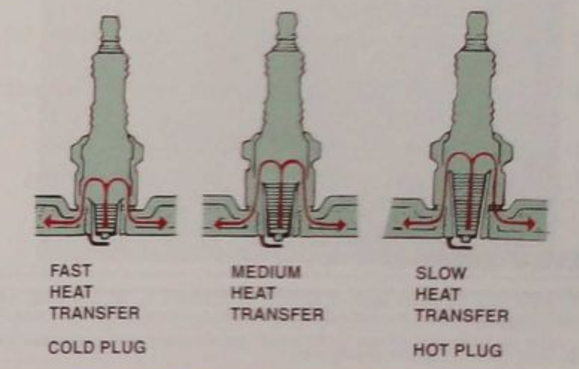


Figure 56–33 The heat range of a spark plug is determined by the distance the heat has to flow from the tip to the cylinder head.

SPARK PLUGS

Spark plugs are manufactured from ceramic insulators inside a steel shell. The threads of the shell are rolled and a seat is formed to create a gastight seal with the cylinder head. See Figure 56–32. The physical difference in spark plugs includes:

- **Reach.** This is the length of the threaded part of the plug.
- **Heat range.** The heat range of the spark plug refers to how rapidly the heat created at the tip is transferred to the cylinder head. A plug with a long ceramic insulator path will run hotter at the tip than a spark plug that has a shorter path because the heat must travel farther. See Figure 56–33.
- **Type of seat.** Some spark plugs use a gasket and others rely on a tapered seat to seal.

Resistor Spark Plugs Most spark plugs include a resistor in the center electrode, which helps to reduce electromagnetic noise or radiation from the ignition system. The closer the resistor is to the actual spark or arc, the more effective it becomes. The value of the resistor is usually between 2,500 ohms and 7,500 ohms.

Platinum Spark Plugs **Platinum spark plugs** have a small amount of the precious metal platinum welded onto the end of the center electrode, as well as on the ground or side electrode. Platinum is a grayish-white metal that does not react with oxygen and therefore, will not erode away as can occur with conventional nickel alloy spark plug electrodes. Platinum is also used as a catalyst in catalytic converters where it is able to start a chemical reaction without itself being consumed.

Iridium Spark Plugs Iridium is a white precious metal and is the most corrosion-resistant metal known. Most **iridium spark plugs** use a small amount of iridium welded onto the tip of a small center electrode 0.0015 to 0.002 inch (0.4 to 0.6 mm) in diameter. The small diameter reduces the voltage required to jump the gap between the center and the side electrode, thereby reducing possible misfires. The ground or side electrode is usually tipped with platinum to help reduce electrode gap wear.

SUMMARY

1. All inductive ignition systems supply battery voltage to the positive side of the ignition coil and pulse the negative side of the coil on and off to ground to create a high-voltage spark.
2. If an ignition system uses a distributor, it is a distributor ignition (DI) system.
3. If an ignition system does not use a distributor, it is called an electronic ignition (EI) system.
4. A waste-spark ignition system fires two spark plugs at the same time.
5. A coil-on-plug ignition system uses an ignition coil for each spark plug.

REVIEW QUESTIONS

1. How can 12 volts from a battery be changed to 40,000 volts for ignition?
2. How does a magnetic sensor work?
3. How does a Hall-effect sensor work?
4. How does a waste-spark ignition system work?

CHAPTER QUIZ

1. The primary (low-voltage) ignition system must be working correctly before any spark occurs from a coil. Which component is *not* in the primary ignition circuit?
   a. Spark plug wiring
   b. Ignition module (igniter)
   c. Pickup coil (pulse generator)
   d. Ignition switch
2. The ignition module has direct control over the firing of the coil(s) of an EI system. Which component(s) triggers (controls) the module?
   a. Pickup coil
   b. Computer
   c. Crankshaft sensor
   d. All of the above
3. Distributorless (waste-spark) ignition systems can be triggered by a _____.
   a. Hall-effect sensor
   b. Magnetic sensor
   c. Spark sensor
   d. Either a or b
4. HEI, Duraspark, and EIS are examples of _____.
   a. Waste-spark systems
   b. Coil-on-plug ignition systems
   c. Distributor ignition systems
   d. Pickup coil types
5. Coil polarity is determined by the _____.
   a. Direction of rotation of the coil windings
   b. Turn ratio
   c. Direction of laminations
   d. Saturation direction
6. Because of _____, an ignition coil cannot be fully charged (reach magnetic saturation) until after a delay of about 10 ms.
   a. Voltage drop across the ignition switch and related wiring
   b. Resistance in the coil windings
   c. Inductive reactance
   d. Saturation
7. The pulse generator _____.
   a. Fires the spark plug directly
   b. Signals the electronic control unit (module)
   c. Signals the computer that fires the spark plug directly
   d. Is used as a tachometer reference signal by the computer and has no other function
8. Two technicians are discussing distributor ignition. Technician A says that the pickup coil or optical sensor in the distributor is used to pulse the ignition module (igniter). Technician B says that some distributor ignition systems have the ignition coil inside the distributor cap. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A waste-spark-type ignition system _____.
   a. Fires two spark plugs at the same time
   b. Fires one spark plug with reverse polarity
   c. Fires one spark plug with straight polarity
   d. All of the above
10. Technician A says that a defective crankshaft position sensor can cause a no-spark condition. Technician B says that a faulty ignition control module can cause a no-spark condition. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 57

Ignition System Diagnosis and Service

OBJECTIVES: **After studying Chapter 57, the reader will be able to:** Prepare for ASE Engine Performance (A8) certification test content area "B" (Ignition System Diagnosis and Repair). • Describe the procedure used to check for spark. • Discuss what to inspect and look for during a visual inspection of the ignition system. • List the steps necessary to check and/or adjust ignition timing on engines equipped with a distributor. • Describe how to test the ignition system using an oscilloscope.

KEY TERMS: automatic shutdown (ASD) relay • base timing • burn kV • display • distributor cap • dwell section • firing line • firing order • intermediate oscillations • millisecond (ms) sweep • raster • remove and replace (R & R) • rotor gap • spark line • spark tester • superimposed • tracked coil • transistor-off point • transistor-on point

CHECKING FOR SPARK

In the event of a no-start condition, the first step should be to check for secondary voltage out of the ignition coil or to the spark plugs. If the engine is equipped with a separate ignition coil, remove the coil wire from the center of the distributor cap, install a **spark tester,** and crank the engine. See the Tech Tip "Always Use a Spark Tester." A good coil and ignition system should produce a blue spark at the spark tester. See Figures 57–1 and 57–2.

If the ignition system being tested does not have a separate ignition coil, disconnect any spark plug wire from a spark plug and, while cranking the engine, test for spark available at the spark plug wire, again using a spark tester.

NOTE: An intermittent spark should be considered a no-spark condition.

Typical causes of a no-spark (intermittent spark) condition include the following:

1. Weak ignition coil
2. Low or no voltage to the primary (positive) side of the coil
3. High resistance or open coil wire, or spark plug wire
4. Negative side of the coil not being pulsed by the ignition module
5. Defective pickup coil
6. Defective module

TECH TIP ✔ **Always Use a Spark Tester**

A spark tester looks like a spark plug except it has a recessed center electrode and no side electrode. The tester commonly has an alligator clip attached to the shell so that it can be clamped on a good ground connection on the engine. A good ignition system should be able to cause a spark to jump this wide gap at atmospheric pressure. Without a spark tester, a technician might assume that the ignition system is okay, because it can spark across a normal, grounded spark plug. The voltage required to fire a standard spark plug when it is out of the engine and not under pressure is about 3,000 volts or less. An electronic ignition spark tester requires a minimum of 25,000 volts to jump the 3/4-in. gap. Therefore, never assume that the ignition system is okay because it fires a spark plug—always use a spark tester. *Remember that an intermittent spark across a spark tester should be interpreted as a no-spark condition.*



Figure 57–1 A spark tester looks like a regular spark plug with an alligator clip attached to the shell. This tester has a specified gap that requires at least 25,000 volts (25 kV) to fire.



Figure 57–2 A close-up showing the recessed center electrode on a spark tester. It is recessed 3/8 in. into the shell and the spark must then jump another 3/8 in. to the shell for a total gap of 3/4 in.

ELECTRONIC IGNITION TROUBLESHOOTING PROCEDURE

When troubleshooting any electronic ignition system for no spark, follow these steps to help pinpoint the exact cause of the problem:

Step #1 Turn the ignition on (engine off) and, using either a voltmeter or a test light, test for battery voltage available at the positive terminal of the ignition coil. If the voltage is not available, check for an open circuit at the ignition switch or wiring. Also check the condition of the ignition fuse (if used).

NOTE: Many Chrysler group products use an **automatic shutdown (ASD) relay** to power the ignition coil. The ASD relay will not supply voltage to the coil unless the engine is cranking and the computer senses a crankshaft sensor signal. This little known fact has fooled many technicians.

Step #2 Connect the voltmeter or test light to the negative side of the coil and crank the engine. The voltmeter should fluctuate or the test light should blink, indicating that the primary coil current is being turned on and off. If there is no pulsing of the negative side of the coil, then the problem is a defective pickup, electronic control module, or wiring.

IGNITION COIL TESTING USING AN OHMMETER

If an ignition coil is suspected of being defective, a simple ohmmeter check can be performed to test the resistance of the primary and secondary winding inside the coil. For accurate resistance measurements, the wiring to the coil should be removed before testing. To test the primary coil winding resistance, take the following steps (Figure 57–3):

Step #1 Set the meter to read low ohms.

Step #2 Measure the resistance between the positive terminal and the negative terminal of the ignition coil. Most coils will give a reading between 1 and 3 ohms; however, some coils should indicate less than 1 ohm. Check the manufacturer's specifications for the exact resistance values.

To test the secondary coil winding resistance, follow these steps:

Step #1 Set the meter to read kilohms (kΩ).

Step #2 Measure the resistance between either primary terminal and the secondary coil tower. The normal resistance of most coils ranges between 6,000 and 30,000 ohms. Check the manufacturer's specifications for the exact resistance values.

NOTE: Many ignition coils use a screw that is inside the secondary tower of the ignition coil. If this screw is loose, an intermittent engine miss could occur. The secondary coil would also indicate high resistance if this screw was loose.

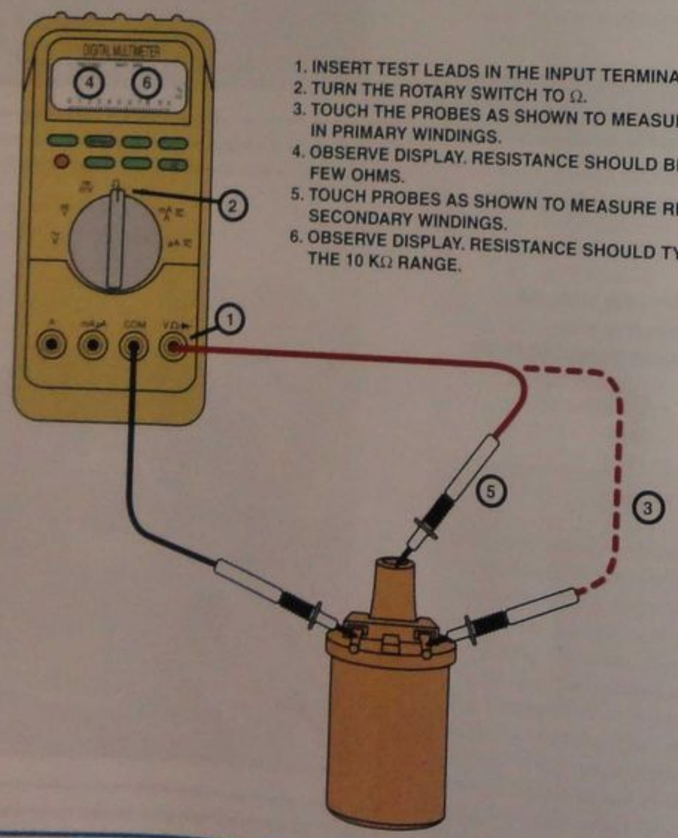


Figure 57–3 Checking an ignition coil using a multimeter set to read ohms.

PICKUP COIL TESTING

The pickup coil, located under the distributor cap on many electronic ignition engines, can cause a no-spark condition if defective. The pickup coil must generate an AC voltage pulse to the ignition module so that the module can pulse the ignition coil.

A pickup coil contains a coil of wire, and the resistance of this coil should be within the range specified by the manufacturer. See Figure 57–4. Some common specifications include the following:



Figure 57–4 Measuring the resistance of an HEI pickup coil using a digital multimeter set to the ohms position. The reading on the face of the meter is 0.796 kΩ or 796 ohms in the middle of the 500- to 1,500-ohm specifications.

Manufacturer	Pickup Coil Resistance (Ohms)
General Motors	500 to 1,500 (white and green leads)
Ford	400 to 1,000 (orange and purple leads)
Chrysler Brand	150 to 900 (orange and black leads)

Also check that the pickup coil windings are insulated from ground by checking for continuity using an ohmmeter. With one ohmmeter lead attached to ground, touch the other lead of the ohmmeter to the pickup coil terminal. The ohmmeter should read OL (over limit) with the ohmmeter set on the high scale. If the pickup coil resistance is not within the specified range, or if it has continuity to ground, replace the pickup coil assembly.

The pickup coil also can be tested for proper voltage output. During cranking, most pickup coils should produce a minimum of 0.25 volt AC. This can be tested with the distributor out of the vehicle by rotating the distributor drive gear by hand.

TESTING MAGNETIC SENSORS

First of all, magnetic sensors must be tested to see if they will stick to iron or steel, indicating that the magnetic strength of the sensors is okay. If the permanent magnet inside the sensor has cracked, the result is two weak magnets.

If the sensor is removed from the engine, hold a metal (steel) object against the end of the sensor. It should exert a strong magnetic pull on the steel object. If not, replace the sensor. Second, the sensor can be tested using a digital meter set to read AC volts. See Figure 57–5.

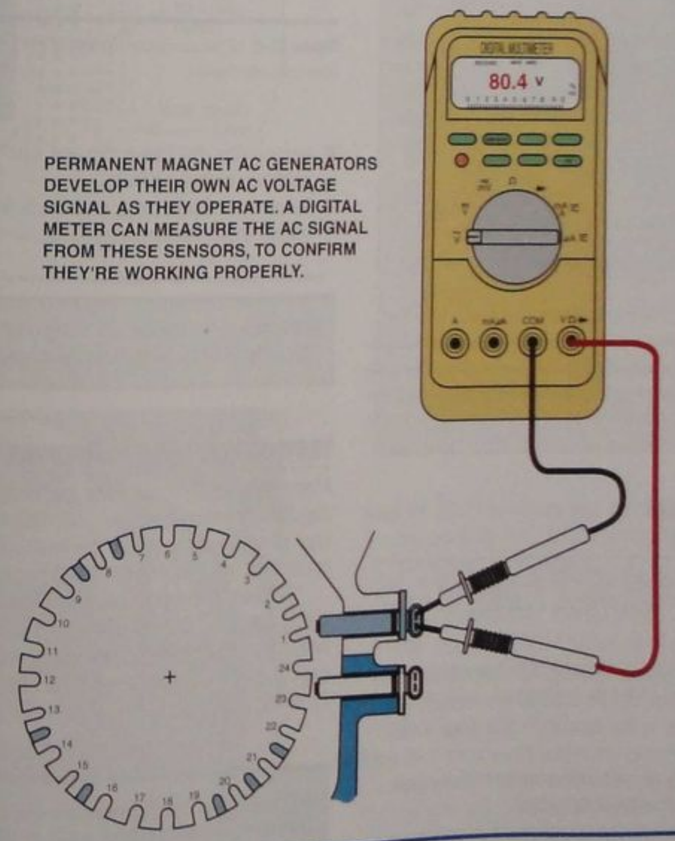


Figure 57–5 An AC voltage is produced by a magnetic sensor. Most sensors should produce at least 0.1 volt AC while the engine is cranking if the pickup wheel has many teeth. If the pickup wheel has only a few teeth, you may need to switch the meter to read DC volts and watch the display for a jump in voltage as the teeth pass the magnetic sensor.

TESTING HALL-EFFECT SENSORS

As with any other sensor, the output of the Hall-effect sensor should be tested first. Using a digital voltmeter, check for the presence of changing voltage (pulsed on and off or digital DC) when the engine is being cranked. The best test is to use an oscilloscope and observe the waveform. See Figure 57–6.

TESTING OPTICAL SENSORS

Optical sensors will not operate if dirty or covered in oil. Perform a thorough visual inspection and look for an oil leak that could cause dirty oil to get on the LED or phototransistor. Also be sure that the light shield is securely fastened and that the seal is lightproof. An optical sensor also can be checked using an oscilloscope. See Figure 57–7. Because of the speed of the engine and the number of slits in the optical sensor disk, a scope is one of the only tools that can capture useful information. For example, a Nissan has 360 slits and if it is running at 2000 RPM, a signal is generated 720,000 times per minute or 12,000 times per second.

TECH TIP ✔ **Bad Wire? Replace the Coil!**

When performing engine testing (such as a compression test), always ground the coil wire. Never allow the coil to discharge without a path to ground for the spark. High-energy electronic ignition systems can produce 40,000 volts or more of electrical pressure. If the spark cannot spark to ground, the coil energy can (and usually does) arc inside the coil itself, creating a low-resistance path to the primary windings or the steel laminations of the coil. See Figure 57–8. This low-resistance path is called a **track** and could cause an engine miss under load even though all of the remaining component parts of the ignition system are functioning correctly. Often these tracks do not show up on any coil test, including most scopes. Because the track is a lower-resistance path to ground than normal, it requires that the ignition system be put under a load for it to be detected, and even then, the problem (engine missing) may be intermittent.

Therefore, when disabling an ignition system, perform one of the following procedures to prevent possible ignition coil damage:

1. Remove the power source wire from the ignition system to prevent any ignition operation.
2. On distributor-equipped engines, remove the secondary coil wire from the center of the distributor cap and connect a jumper wire between the disconnected coil wire and a good engine ground. This ensures that the secondary coil energy will be safely grounded and prevents high-voltage coil damage.

IGNITION SYSTEM DIAGNOSIS USING VISUAL INSPECTION

One of the first steps in the diagnosis process is to perform a thorough visual inspection of the ignition system, including the following items:

- Check all spark plug wires for proper routing. All plug wires should be in the factory wiring separator and be clear of any metallic object that could cause damage to the insulation and cause a short-to-ground fault.
- Check that all spark plug wires are securely attached to the spark plugs and to the distributor cap or ignition coil(s).
- Check that all spark plug wires are clean and free from excessive dirt or oil. Check that all protective covers normally covering the coil and/or distributor cap are in place and not damaged.

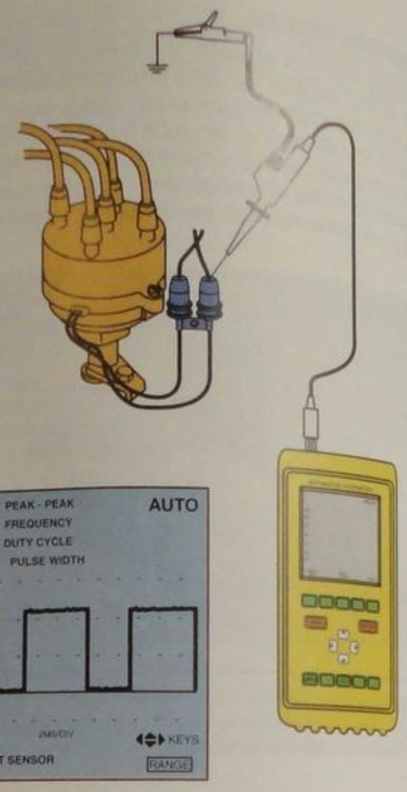


Figure 57–6 (a) The connection required to test a Hall-effect sensor. (b) A typical waveform from a Hall-effect sensor.

- Remove the distributor cap and carefully check the cap and distributor rotor for faults.
- Remove the spark plugs and check for excessive wear or other visible faults. Replace if needed.

NOTE: According to research conducted by General Motors, about one-fifth (20%) of all faults are detected during a *thorough visual inspection!*

TESTING FOR POOR PERFORMANCE

Many diagnostic equipment manufacturers offer methods for testing distributorless ignition systems on an oscilloscope. If using this type of equipment, follow the manufacturer's recommended procedures and interpretation of the specific test results.

A simple method of testing distributorless (waste-spark systems) ignition with the engine off involves removing the spark plug wires (or connectors) from the spark plugs (or coils or distributor cap) and installing short lengths (2 inches) of rubber vacuum hose in series.

NOTE: For best results, use rubber hose that is electrically conductive. Measure the vacuum hose with an ohmmeter. Suitable vacuum hose should give a reading of less than 10,000 ohms (10 kΩ) for a length of about 2 inches. See Figures 57–9 and 57–10.

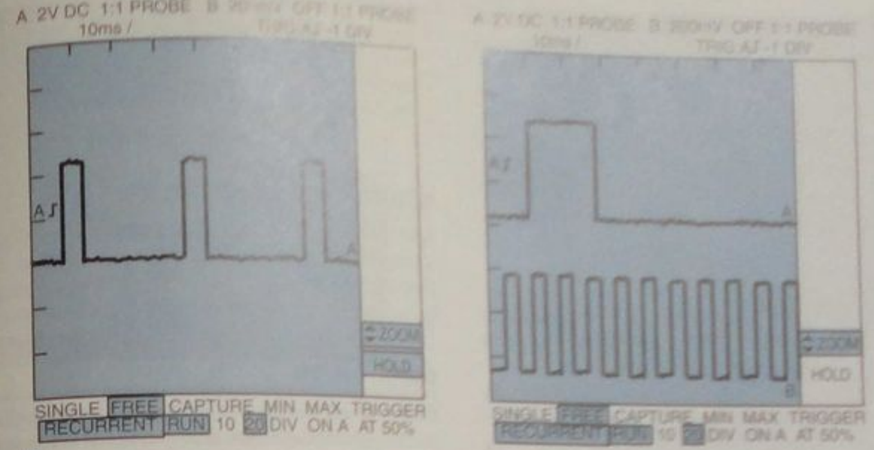


Figure 57–7 (a) The low-resolution signal has the same number of pulses as the engine has cylinders. (b) A dual-trace pattern showing both the low-resolution signal and the high-resolution signals that usually represent 1 degree of rotation.

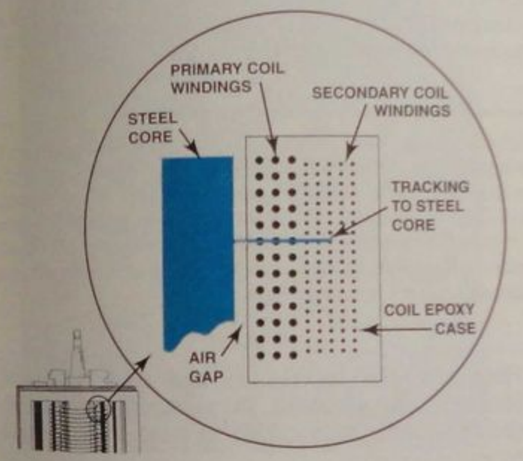


Figure 57–8 A track inside an ignition coil is not a short, but rather it is a low-resistance path or hole that has been burned through from the secondary wiring to the steel core.



Figure 57–9 A GM type 2 distributorless ignition system (DIS) can be checked by unplugging both spark plug wires from one ignition coil and starting the engine. The spark should be able to jump the 1-in. (25-mm) distance between the terminals of the coil. No damage to the coil (or module) results because a spark occurs and does not find ground elsewhere.

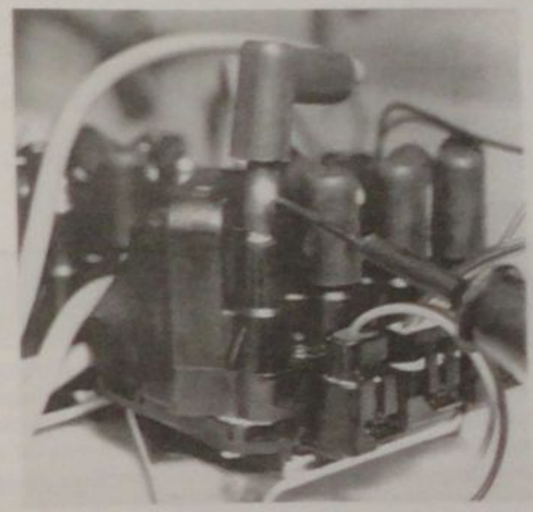


Figure 57–10 Using a vacuum hose and a grounded test light to ground one cylinder at a time on a DIS. This works on all types of ignition systems and provides a method for grounding out one cylinder at a time without fear of damaging any component.

Step #1 Start the engine and ground out each cylinder one at a time by touching the tip of a grounded test light to the rubber vacuum hose. Even though the computer will increase idle speed and fuel delivery to compensate for the grounded spark plug wire, a technician should watch for a change in the operation of the engine. If no change is observed or heard, the cylinder being grounded is obviously weak or defective. Check the spark plug wire or connector with an ohmmeter to be certain of continuity.

Step #2 Check all cylinders by grounding them out one at a time. If one weak cylinder is found (very little RPM drop), check the other cylinder using the same ignition coil (except on engines that use an individual coil for each cylinder). If both cylinders are affected, the problem could be an open spark plug wire, defective spark plug, or defective ignition coil.

Step #3 To help eliminate other possible problems and determine exactly what is wrong, switch the suspected ignition coil to another position (if possible).

- If the problem now affects the other cylinders, the ignition coil is defective and must be replaced.
- If the problem does not "change positions" with changing the position of the ignition coil, the control module affecting the suspected coil or either cylinder's spark plug or spark plug wire could be defective.

TESTING FOR A NO-START CONDITION

A no-start condition (with normal engine cranking speed) can be the result of either no spark or no fuel delivery.

Computerized engine control systems use the ignition primary pulses as a signal to inject fuel—a port or throttle-body injection (TBI) style of fuel—injection system. If there is no pulse, then there is no squirt of fuel. To determine exactly what is wrong, follow these steps:

Step #1 Test the output signal from the crankshaft sensor. Most computerized engines with distributorless ignitions use a crankshaft position sensor. These sensors are either the Hall-effect type or the magnetic type. The sensors must be able to produce either a sine or a digital signal. A meter set on AC volts should read a voltage across the sensor leads when the engine is being cranked. If there is no AC voltage output, replace the sensor.

Step #2 If the sensor tests okay in step 1, check for a changing AC voltage signal at the ignition module.

NOTE: Step 2 checks the wiring between the crankshaft position sensor and the ignition control module.

Step #3 If the ignition control module is receiving a changing signal from the crankshaft position sensor, it must be capable of switching the power to the ignition coils on and off. Remove a coil or coil package, and with the ignition switched to on (run), check for voltage at the positive terminal of the coil(s).

NOTE: Several manufacturers program the current to the coils to be turned off within several seconds of the ignition being switched to on if no pulse is received by the computer. This circuit design helps prevent ignition coil damage in the event of a failure in the control circuit or driver error, by keeping the ignition switch on (run) without operating the starter (start position). Some Chrysler engines do not supply power to the positive (+) side of the coil until a crank pulse is received by the computer which then energizes the coil(s) and injectors through the automatic shutdown (ASD) relay.

Step #4 If the module is not pulsing the negative side of the coil or not supplying battery voltage to the positive side of the coil, replace the ignition control module.

NOTE: Before replacing the ignition control module, be certain that it is properly grounded (where applicable) and that the module is receiving ignition power from the ignition circuit.

CAUTION: Most distributorless (waste-spark) ignition systems can produce 40,000 volts or more, with energy levels high enough to cause personal injury. Do not open the circuit of an electronic ignition secondary wire, because damage to the system (or to you) can occur.

IGNITION SYSTEM SERVICE

Most specifications are now commonly called *performance specifications*. Even though many electronic engine analyzers can help pinpoint suspected problem areas, close visual inspection of the distributor cap, rotor, spark plugs, and spark plug wires is still important.

FIRING ORDER

Firing order means the order that the spark is distributed to the correct spark plug at the right time. The firing order of an engine is determined by crankshaft and camshaft design. The firing order is determined by the location of the spark plug wires in the distributor cap of an engine equipped with a distributor. The firing order is often cast into the intake manifold for easy reference, as shown in Figure 57–11. Service information also shows the firing order and the direction of the distributor rotor rotation, as well as the location of the spark plug wires on the distributor cap.

CAUTION: Ford V-8s use two different firing orders depending on whether the engine is high output (HO) or standard. Using the incorrect firing order can cause the engine to backfire and could cause engine damage or personal injury. General Motors V-6s use different firing orders and different locations for cylinder 1 between the 60-degree V-6 and the 90-degree V-6. Using the incorrect firing order or cylinder number location chart could result in poor engine operation or a no-start condition.

Firing order is also important for waste-spark-type distributorless (direct-fire) ignition systems. The spark plug wire can often be installed on the wrong coil pack that can create a no-start condition or poor engine operation.

SECONDARY IGNITION INSPECTION

Inspect a **distributor cap** for a worn or cracked center carbon insert, excessive side insert wear or corrosion, cracks, or carbon tracks, and check the towers for burning or corrosion by removing spark plug wires from the distributor cap one at a time. Remember, a defective distributor cap affects starting and engine performance, especially in high-moisture conditions. If a carbon track is detected, it is most



Figure 57–11 The firing order is cast or stamped on the intake manifold on most engines that have a distributor ignition.



Figure 57–12 Note where the high-voltage spark jumped through the plastic rotor to arc to the distributor shaft. Always check for a defective spark plug(s) when a defective distributor cap or rotor is discovered. If a spark cannot jump to a spark plug, it tries to find a ground path wherever it can.

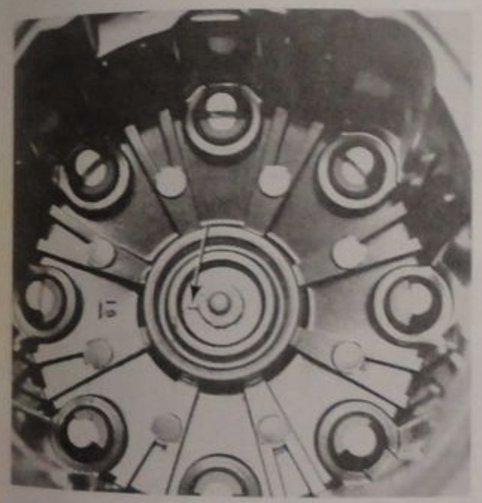


Figure 57–13 Carbon track in a distributor cap. These faults are sometimes difficult to see and can cause intermittent engine missing. The usual cause of a tracked distributor cap or coil, if it is distributorless ignition) is a defective (open) spark plug wire.

usually the result of a high-resistance or open spark plug wire. Replacement of a distributor cap because of a carbon track without checking and replacing the defective spark plug wire(s) often will result in the new distributor cap failing in a short time. It is recommended that the distributor cap and rotor be inspected every year and replaced if defective. The rotor should be replaced every time the spark plugs are replaced, because all ignition current flows through the rotor. General distributor caps should only need replacement after every three or four years of normal service. See Figures 57–12 and 57–13. Check ignition coils of waste-spark and coil-on-plug systems for signs of carbon tracks (black lines) or corrosion. See Figure 57–14.

SPARK PLUG WIRE INSPECTION

Spark plug wires should be visually inspected for cuts or defective insulation and checked for resistance with an ohmmeter. Good spark plug wires should measure less than 10,000 ohms per foot of length. See Figures 57–15 and 57–16. Faulty spark plug wire insulation can cause hard starting or no starting in damp weather conditions.



Figure 57–14 Corroded terminals on a waste-spark coil can cause misfire diagnostic trouble codes to be set.

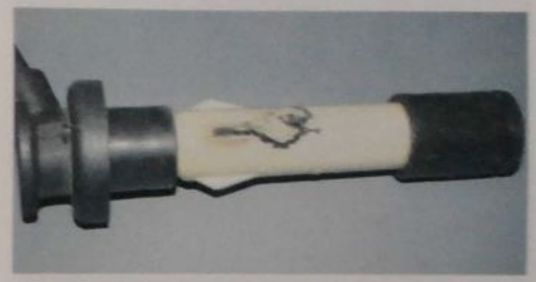


Figure 57–15 This spark plug boot on an overhead camshaft engine has been arcing to the valve cover causing a misfire to occur.

TECH TIP ✓ **Spark Plug Wire Pliers Are a Good Investment**

Spark plug wires are often difficult to remove. Using a good-quality spark plug wire plier, such as shown in Figure 57–17, saves time and reduces the chance of harming the wire during removal.

TECH TIP ✓ **Route the Wires Right!**

High voltage is present through spark plug wires when the engine is running. Surrounding the spark plugs is a magnetic field that can affect other circuits or components of the vehicle. For example, if a spark plug wire is routed too closely to the signal wire from a mass airflow (MAF) sensor, the induced signal from the ignition wire could create a false MAF signal to the computer. The computer, not able to detect that the signal was false, would act on the MAF signal and command the appropriate amount of fuel based on the false MAF signal.

To prevent any problems associated with high-voltage spark plug wires, be sure to route them as manufactured using all the factory holding brackets and wiring combs. See Figure 57–18. If the factory method is unknown, most factory service information shows the correct routing.



Figure 57–16 Measuring the resistance of a spark plug wire with a multimeter set to the ohms position. The reading of 16.03 kΩ (16,030 ohms) is okay because the wire is about 2 feet long. Maximum allowable resistance for a spark plug wire this long would be 20 kΩ (20,000 ohms).



Figure 57–17 Spark plug wire boot pliers is a handy addition to any tool box.



Figure 57–18 Always take the time to install spark plug wires back into the original holding brackets (wiring combs).

SPARK PLUG SERVICE

Spark plugs should be inspected when an engine performance problem occurs and should be replaced at specified intervals to ensure proper ignition system performance. Most spark plugs have a service life of over 20,000 miles (32,000 kilometers). Platinum-tipped



Figure 57–19 When removing spark plugs, it is wise to arrange them so that they can be compared and any problem can be identified with a particular cylinder.



Figure 57–20 A spark plug thread chaser is a low-cost tool that hopefully will not be used often, but is necessary to use to clean the threads before new spark plugs are installed.



Figure 57–21 Since 1991, General Motors engines have been equipped with slightly (1/8 in. or 3 mm) longer spark plugs. This requires that a longer spark plug socket should be used to prevent the possibility of cracking a spark plug during installation. The longer socket is shown next to a normal 5/8-in. spark plug socket.

original equipment spark plugs have a typical service life of 60,000 to 100,000 miles (100,000 to 160,000 kilometers). Used spark plugs should *not* be cleaned and reused unless absolutely necessary. The labor required to **remove and replace (R & R)** spark plugs is the same whether the spark plugs are replaced or cleaned. Although cleaning spark plugs often restores proper engine operation, the service life of cleaned spark plugs is definitely shorter than that of new spark plugs. *Platinum-tipped spark plugs should not be regapped!* Using a gapping tool can break the platinum after it has been used in an engine.

Be certain that the engine is cool before removing spark plugs, especially on engines with aluminum cylinder heads. To help prevent dirt from getting into the cylinder of an engine while removing a spark plug, use compressed air or a brush to remove dirt from around the spark plug before removal. See Figures 57–19 through 57–21.

Spark Plug Inspection Spark plugs are the windows to the inside of the combustion chamber. A thorough visual inspection of the spark plugs often can lead to the root cause of an engine performance problem. Two indications on spark plugs and their possible root causes in engine performance include the following:

1. **Carbon fouling.** If the spark plug(s) has *dry black carbon* (soot), the usual causes include:
   - Excessive idling
   - Slow-speed driving under light loads that keeps the spark plug temperatures too low to burn off the deposits
   - Overrich air–fuel mixture
   - Weak ignition system output
2. **Oil fouling.** If the spark plug has *wet, oily* deposits with little electrode wear, oil may be getting into the combustion chamber from the following:
   - Worn or broken piston rings
   - Defective or missing valve stem seals

NOTE: If the deposits are heavier on the side of the plug facing the intake valve, the cause is usually due to excessive valve stem clearance or defective intake valve stem seals.

When removing spark plugs, place them in order so that they can be inspected to check for engine problems that might affect one or more cylinders. All spark plugs should be in the same condition, and the color of the center insulator should be light tan or gray. If all the spark plugs are black or dark, the engine should be checked for conditions that could cause an overly rich air–fuel mixture or possible oil burning. If only one or a few spark plugs are black, check those cylinders for proper firing (possible defective spark plug wire) or an engine condition affecting only those particular cylinders. See Figures 57–22 through 57–25.

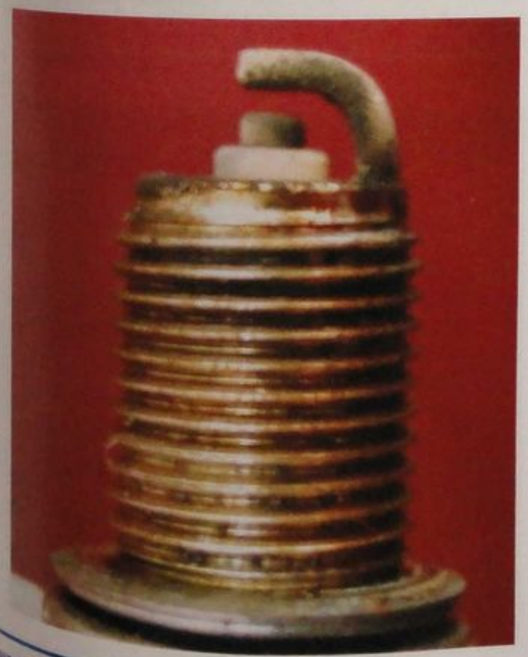


Figure 57–22 An extended-reach spark plug that shows normal wear. The color and condition indicate that the cylinder is operating correctly.



Figure 57–23 Spark plug removed from an engine after a 500-mile race. Note the clipped side (ground) electrode. The electrode design and narrow (0.025 in.) gap are used to ensure that a spark occurs during extremely high engine speed operation. The color and condition of the spark plug indicate that near-perfect combustion has been occurring.



Figure 57–24 Typical worn spark plug. Notice the rounded center electrode. The deposits indicate a possible oil usage problem.

If all spark plugs are white, check for possible overadvanced ignition timing or a vacuum leak causing a lean air–fuel mixture. If only one or a few spark plugs are white, check for a vacuum leak affecting the fuel mixture only to those particular cylinders.

NOTE: The engine computer "senses" rich or lean air–fuel ratios by means of input from the oxygen sensor. If one cylinder is lean, the computer may make all other cylinders richer to compensate.

Inspect all spark plugs for wear by first checking the condition of the center electrode. As a spark plug wears, the center electrode becomes rounded. If the center electrode is rounded, higher ignition



Figure 57–25 New spark plug that was fouled by a too-rich air–fuel mixture. The engine from which this spark plug came had a defective (stuck partially open) injector on this one cylinder only.

system voltage is required to fire the spark plug. When installing spark plugs, always use the correct tightening torque to ensure proper heat transfer from the spark plug shell to the cylinder head. See the following table.

Spark Plug	Torque with Torque Wrench (in lb-ft)		Torque without Torque Wrench (in turns)	
	Cast-iron Head	Aluminum Head	Cast-iron Head	Aluminum Head
Gasket				
14 mm	26–30	18–22	1/4	1/4
18 mm	32–38	28–34	1/4	1/4
Tapered seat				
14 mm	7–15	7–15	1/16 (snug)	1/16 (snug)
18 mm	15–20	15–20	1/16 (snug)	1/16 (snug)

NOTE: General Motors does not recommend the use of antiseize compound on the threads of spark plugs being installed in an aluminum cylinder head, because the spark plug will be overtightened. This excessive tightening torque places the threaded portion of the spark plug too far into the combustion chamber where carbon can accumulate and result in the spark plugs being difficult to remove. If antiseize compound is used on spark plug threads, reduce the tightening torque by 40%. Always follow the vehicle manufacturer's recommendations.

TECH TIP ✔ **Two-Finger Trick**

To help prevent overtightening a spark plug when a torque wrench is not available, simply use two fingers on the ratchet handle. Even the strongest service technician cannot overtighten a spark plug by using two fingers.

TECH TIP ✔ **Use Original Equipment Manufacturer's Spark Plugs**

A technician at an independent service center replaced the spark plugs in a Pontiac with new Champion brand spark plugs of the correct size, reach, and heat range. When the customer returned to pay the bill, he inquired as to the brand name of the replacement parts used for the tune-up. When told that Champion spark plugs were used, he stopped signing his name on the check he was writing. He said that he owned 1,000 shares of General Motors stock and he owned two General Motors vehicles and he expected to have General Motors parts used in his General Motors vehicles. The service manager had the technician replace the spark plugs with AC brand spark plugs because this brand was used in the engine when the vehicle was new. Even though most spark plug manufacturers produce spark plugs that are correct for use, many customers prefer that original equipment manufacturer (OEM) spark plugs be used in their engines.

QUICK AND EASY SECONDARY IGNITION TESTS

Engine running problems often are caused by defective or out-of-adjustment ignition components. Many ignition problems involve the high-voltage secondary ignition circuit. Following are some quick and easy secondary ignition tests.

Test 1 If there is a crack in a distributor cap, coil, or spark plug, or if there is a defective spark plug wire, a spark may be visible at night. Because the highest voltage is required during partial throttle acceleration, the technician's assistant should accelerate the engine slightly with the gear selector in drive or second gear (if manual transmission) and the brake firmly applied. If any spark is visible or a "snapping" sound is heard, the location should be closely inspected and the defective parts replaced. A blue glow or "corona" around the shell of the spark plug is normal and not an indication of a defective spark plug.

Test 2 For intermittent problems, use a spray bottle to apply a water mist to the spark plugs, distributor cap, and spark plug wires. See Figure 57–26. With the engine running, the water may cause an arc through any weak insulating materials and cause the engine to miss or stall.



Figure 57–26 A water spray bottle is an excellent diagnostic tool to help find a intermittent engine miss caused by a break in a secondary ignition circuit component.

HINT: Adding a little salt or liquid soap to the water makes the water more conductive and also makes it easier to find those hard-to-diagnose intermittent ignition faults.

Test 3 To determine if the rough engine operation is due to secondary ignition problems, connect a 12-volt test light to the negative side (sometimes labeled "tach") of the coil. Connect the other lead of the test light to the positive lead of the coil. With the engine running, the test light should be dim and steady in brightness. If there is high resistance in the secondary circuit (such as that caused by a defective spark plug wire), the test light will pulse brightly at times. If the test light varies noticeably, this indicates that the secondary voltage cannot find ground easily and is feeding back through the primary windings of the coil. This feedback causes the test light to become brighter.

IGNITION TIMING

Ignition timing should be checked and adjusted according to the manufacturer's specifications and procedures for best fuel economy and performance and lowest exhaust emissions. Generally, for testing, engines must be at idle with computer engine controls put into **base timing,** the timing of the spark before the computer advances the timing. To be assured of the proper ignition timing, follow exactly the timing procedure indicated on the under-hood emission (VECI) decal. See Figure 57–27 for a typical ignition timing plate and mark.

If the ignition timing is too far *advanced*, for example, if it is set at 12 degrees before top dead center (BTDC) instead of 8 degrees BTDC, the following symptoms may occur:

1. Engine ping or spark knock may be heard, especially while driving up a hill or during acceleration.
2. Cranking (starting) may be slow and jerky, especially when the engine is warm.
3. The engine may overheat.

If the ignition timing is too far *retarded*, for example, if it is set at 4 degrees BTDC instead of 8 degrees BTDC, the following symptoms may occur:

1. The engine may lack power and performance.
2. The engine may require a long period of starter cranking before starting.
3. Poor fuel economy may result.
4. The engine may overheat.



Figure 57–27 Typical timing marks. The numbers of the degrees are on the stationary plate and the notch is on the harmonic balancer.

Pretiming Checks Before the ignition timing is checked or adjusted, the following items should be checked to ensure accurate timing results:

1. The engine should be at normal operating temperature (the upper radiator hose should be hot and pressurized).
2. The engine should be at the correct timing RPM (check the specifications).
3. The vacuum hoses should be removed, and the hose from the vacuum advance unit on the distributor (if the vehicle is so equipped) should be plugged unless otherwise specified.
4. If the engine is computer equipped, check the timing procedure specified by the manufacturer. This may include disconnecting a "set timing" connector wire, grounding a diagnostic terminal, disconnecting a four-wire connector, or similar procedure.

NOTE: General Motors specifies many different timing procedures depending on the engine, type of fuel system, and type of ignition system. Always consult the emission decal under the hood or service information for the exact procedure to follow.

TECH TIP ✔ **"Turn the Key" Test**

If the ignition timing is correct, a warm engine should start immediately when the ignition key is turned to the start position. If the engine cranks a long time before starting, the ignition timing may be retarded. If the engine cranks slowly, the ignition timing may be too far advanced. However, if the engine starts immediately, the ignition timing, although it may not be exactly set according to specification, is usually adjusted fairly close to specifications. When a starting problem is experienced, check the ignition timing first, before checking the fuel system or the cranking system for a possible problem. This procedure can be used to help diagnose a possible ignition timing problem quickly without tools or equipment.

Timing Light Connections For checking or adjusting ignition timing, make the timing light connections as follows:

1. Connect the timing light battery leads to the vehicle battery: the red to the positive terminal and the black to the negative terminal.
2. Connect the timing light high-tension lead to spark plug cable 1.

Determining Cylinder 1 The following will help in determining cylinder 1.

1. **Four- or six-cylinder engines.** On all inline four- and six-cylinder engines, cylinder 1 is the *most forward* cylinder.
2. **V-6 or V-8 engines.** Most V-type engines use the left front (driver's side) cylinder as cylinder 1, except for Ford engines and some Cadillacs, which use the right front (passenger's side) cylinder.
3. **Sideways (transverse) engines.** Most front-wheel-drive vehicles with engines installed sideways use the cylinder to the far right (passenger's side) as cylinder 1 (plug wire closest to the drive belt[s]).

Follow this rule of thumb: If cylinder 1 is unknown for a given type of engine, it is the *most forward* cylinder as viewed from above (except in Pontiac V-8 engines). See Figure 57–28 for typical cylinder 1 locations.

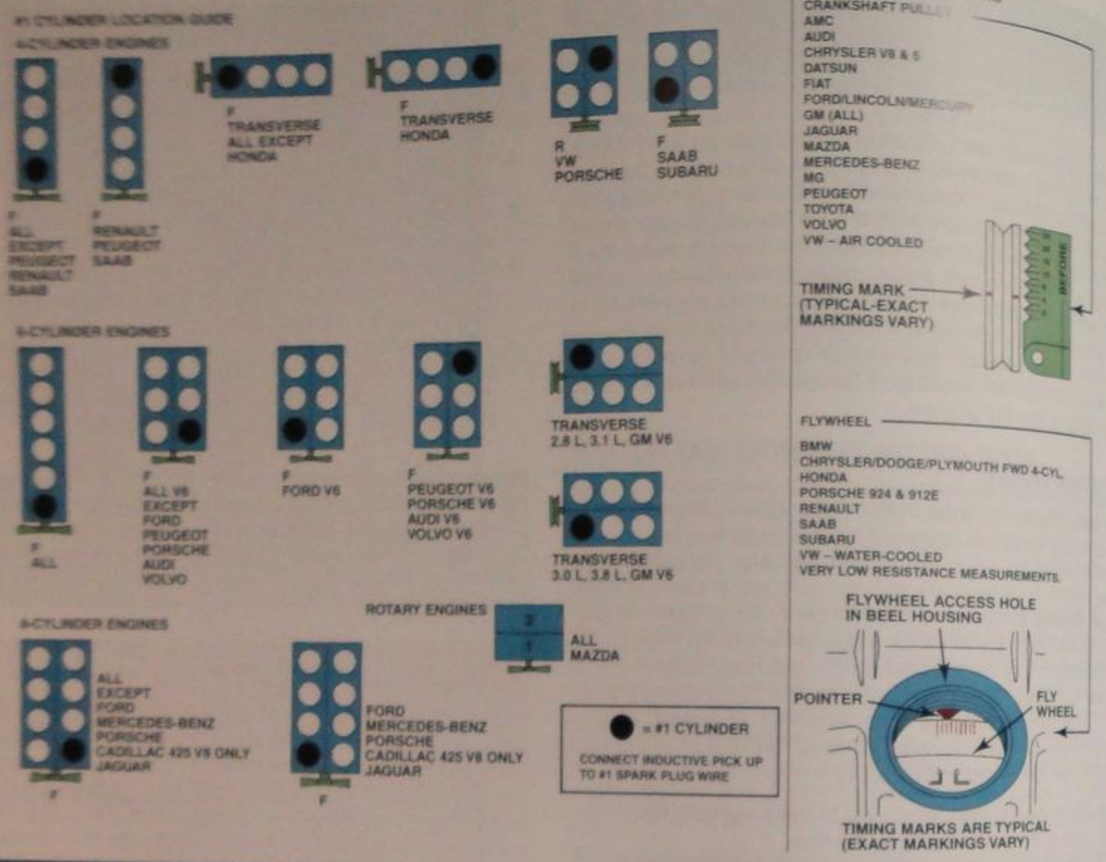


Figure 57–28 Cylinder 1 and timing mark location guide.

NOTE: Some engines are not timed off of cylinder 1. For example, Jaguar inline six-cylinder engines before 1988 used cylinder 6, but the cylinders were numbered from the firewall (bulkhead) forward. Therefore, cylinder 6 was the most forward cylinder. Always check for the specifications and procedures for the vehicle being tested.

NOTE: If cylinder 1 is difficult to reach, such as up against the bulkhead (firewall) or close to an exhaust manifold, simply use the opposite cylinder as the firing order (paired cylinder). The timing light will not detect the difference and will indicate the correct position of the timing mark in relation to the pointer or degree mark.

Checking or Adjusting Ignition Timing Use the following steps for checking or adjusting ignition timing:

1. Start the engine and adjust the speed to that specified for ignition timing.
2. With the timing light aimed at the stationary timing pointer, observe the position of the timing mark on the vibration damper with the light flashing. Refer to the manufacturer's specifications or underhood decal for the correct setting. See Figure 57–29.

NOTE: If the timing mark appears ahead of the pointer in relation to the direction of crankshaft rotation, the timing is advanced. If the timing mark appears behind the pointer in relation to the direction of crankshaft rotation, the timing is retarded.

3. To adjust timing, loosen the distributor locking bolt or nut and turn the distributor housing until the timing mark is in correct alignment. Turn the distributor housing in the direction of rotor rotation to retard the timing and against rotor rotation to advance the timing.
4. After adjusting the timing to specifications, carefully tighten the distributor locking bolt. Sometimes it is necessary to readjust the timing after the initial setting because the distributor may rotate slightly when the hold-down bolt is tightened.

TECH TIP ✓ **Two Marks Are the Key to Success**

When a distributor is removed from an engine, always mark the direction the rotor is pointing to ensure that the distributor is reinstalled in the correct position. Because of the helical cut on the distributor drive gear, the rotor rotates as the distributor is being removed from the engine. To help reinstall a distributor without any problems, simply make another mark where the rotor is pointing just as the distributor is lifted out of the engine. Then to reinstall, simply line up the rotor to the second mark and lower the distributor into the engine. The rotor should then line up with the original mark as a double check.



Figure 57–29 (a) Typical SPOUT connector as used on many Ford engines equipped with distributor ignition (DI). (b) The connector must be opened (disconnected) to check and/or adjust the ignition timing. On DIS/EDIS systems, the connector is called SPOUT/SAW (spark output/spark angle word).

SCOPE-TESTING THE IGNITION SYSTEM

Any automotive scope with the correct probes or adapters will show an ignition system pattern. All ignition systems must charge and discharge an ignition coil. With the engine off, most scopes will display a horizontal line. With the engine running, this horizontal (zero) line is changed to a pattern that will have sections both above and below the zero line. Sections of this pattern that are above the zero line indicate that the ignition coil is discharging. Sections of the scope pattern below the zero line indicate charging of the ignition coil. The height of the scope pattern indicates voltage. The length (from left to right) of the scope pattern indicates time. See Figures 57–30 and 57–31 for typical scope hookups.

Firing Line The leftmost vertical (upward) line is called the **firing line.** The height of the firing line should be between 5,000 and 15,000 volts (5 and 15 kV) with not more than a 3 kV difference between the highest and the lowest cylinder's firing line. See Figures 57–32 and 57–33.

The height of the firing line indicates the *voltage* required to fire the spark plug. It requires a high voltage to make the air inside the cylinder electrically conductive (to ionize the air). A higher than normal height (or height higher than that of other cylinders) can be caused by one or more of the following:

1. Spark plug gapped too wide
2. Lean fuel mixture
3. Defective spark plug wire

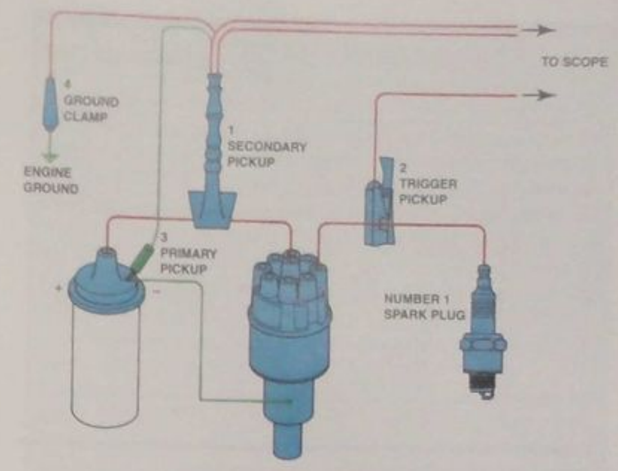


Figure 57–30 Typical engine analyzer hookup that includes a scope display. (1) Coil wire on top of the distributor cap if integral type of coil; (2) number 1 spark plug connection; (3) negative side of the ignition coil; (4) ground (negative) connection of the battery.

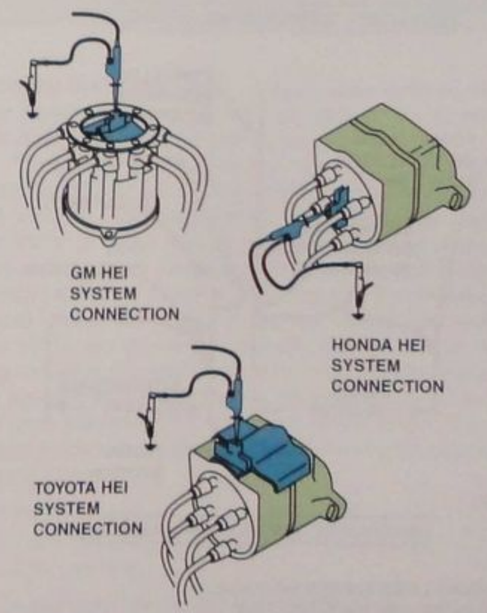


Figure 57–31 Clip-on adapters are used with an ignition system that uses an integral ignition coil.

If the firing lines are higher than normal for *all* cylinders, then possible causes include one or more of the following:

1. Worn distributor cap and/or rotor (if the vehicle is so equipped)
2. Excessive wearing of all spark plugs
3. Defective coil wire (the high voltage could still jump across the open section of the wire to fire the spark plugs)

Spark Line The **spark line** is a short horizontal line immediately after the firing line. The height of the spark line represents the voltage required to maintain the spark across the spark plug after the spark has started. The height of the spark line should be one-fourth of the height of the firing line (between 1.5 and 2.5 kV). The length

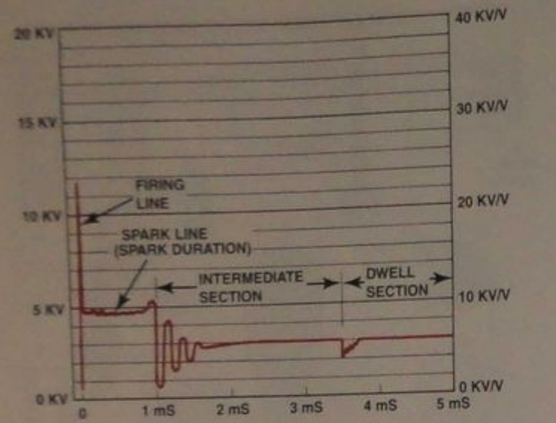


Figure 57–32 Typical secondary ignition oscilloscope pattern.

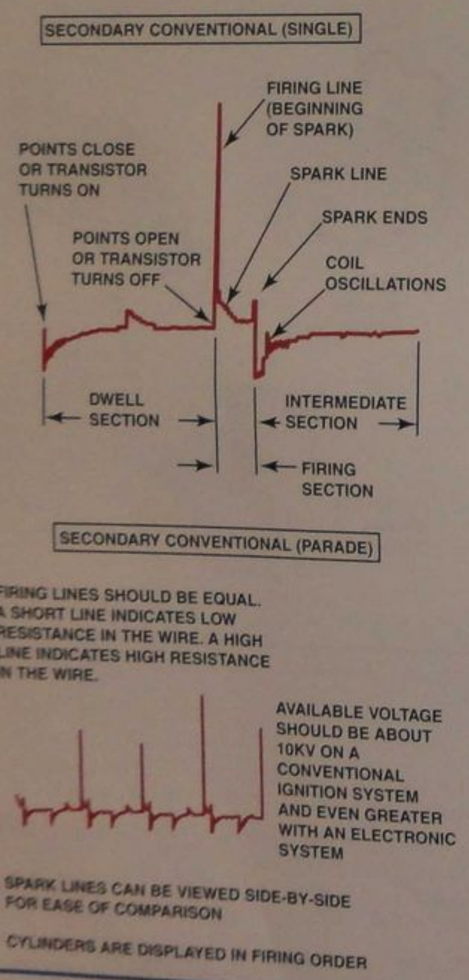


Figure 57–33 A single cylinder is shown at the top and a four-cylinder engine at the bottom.

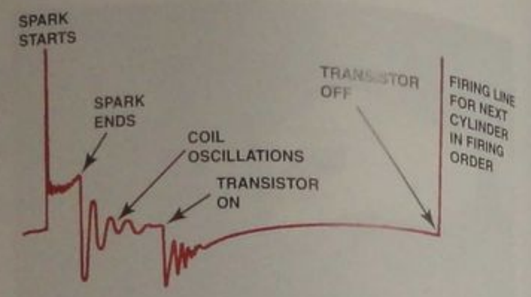


Figure 57–34 Drawing shows what is occurring electrically at each part of the scope pattern.

(from left to right) of the line represents the length of time for which the spark lasts (duration or burn time). The spark duration should be between 0.8 and 2.2 milliseconds (usually between 1.0 and 2.0 ms). The spark stops at the end (right side) of the spark line, as shown in Figure 57–34.

Intermediate Oscillations After the spark has stopped, some energy remains in the coil. This remaining energy dissipates in the coil windings and the entire secondary circuit. The **intermediate oscillations** are also called the "ringing" of the coil as it is pulsed.

The secondary pattern amplifies any voltage variation occurring in the primary circuit because of the turns ratio between the primary and secondary windings of the ignition coil. A correctly operating ignition system should display five or more "bumps" (oscillations) (three or more for a GM HEI system).

Transistor-On Point After the intermediate oscillations, the coil is empty (not charged), as indicated by the scope pattern being on the zero line for a short period. When the transistor turns on an electronic system, the coil is being charged. Note that the charging of the coil occurs slowly (coil-charging oscillations) because of the inductive reactance of the coil.

Dwell Section Dwell is the amount of time that the current is charging the coil from the **transistor-on point** to the **transistor-off point.** At the end of the **dwell section** is the beginning of the next firing line. This point is called "transistor off" and indicates that the primary current of the coil is stopped, resulting in a high-voltage spark out of the coil.

Pattern Selection Ignition oscilloscopes use three positions to view certain sections of the basic pattern more closely. These three positions are as follows:

1. **Superimposed.** This **superimposed** position is used to look at differences in patterns between cylinders in all areas except the firing line. There are no firing lines illustrated in superimposed positions. See Figure 57–35.
2. **Raster (stacked).** Cylinder 1 is at the bottom on most scopes. Use the **raster** (stacked) position to look at the spark line length and transistor-on point. The raster pattern shows all areas of the scope pattern except the firing lines. See Figure 57–36.
3. **Display (parade). Display** (parade) is the only position in which firing lines are visible. The firing line section for cylinder 1 is on the far right side of the screen, with the remaining portions of the pattern on the left side. This selection is used to compare the height of firing lines among all cylinders. See Figure 57–37.

Reading the Scope on Display (Parade) Start the engine and operate at approximately 1000 RPM to ensure a smooth and

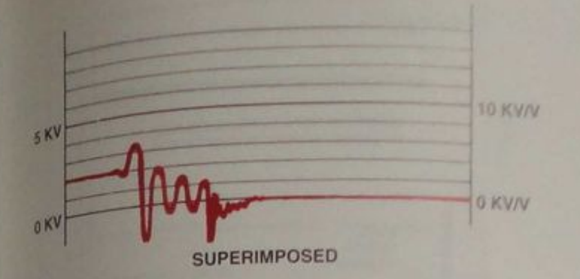


Figure 57–35 Typical secondary ignition pattern. Note the lack of firing lines on superimposed pattern.

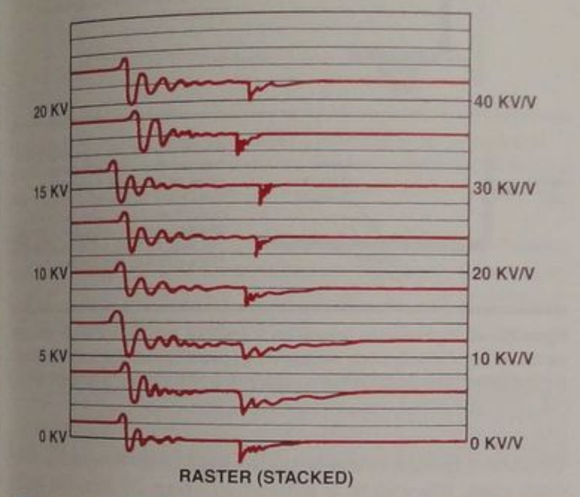


Figure 57–36 Raster is the best scope position to view the spark lines of all the cylinders to check for differences. Most scopes display the cylinder 1 at the bottom. The other cylinders are positioned by firing order above cylinder 1.

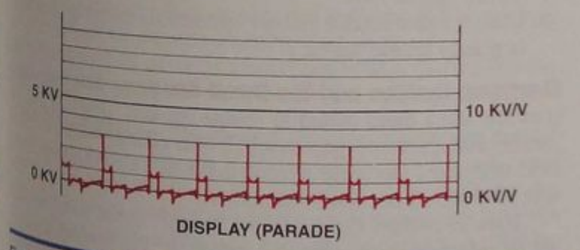


Figure 57–37 Display is the only position to view the firing lines of all cylinders. Cylinder 1 is displayed on the left (except for its firing line, which is shown on the right). The cylinders are displayed from left to right by firing order.

accurate scope pattern. Firing lines are visible only on the display (parade) position. The firing lines should all be 5 to 15 kV in height and be within 3 kV of each other. If one or more cylinders have high firing lines, this could indicate a defective (open) spark plug wire, a spark plug gapped too far, or a lean fuel mixture affecting only those cylinders.

A lean mixture (not enough fuel) requires a higher voltage to ignite because there are fewer droplets of fuel in the cylinder for the spark to use as "stepping stones" for the voltage to jump across. Therefore, a lean mixture is less conductive than a rich mixture.

REAL WORLD FIX — **A Technician's Toughie**

A vehicle ran poorly, yet its scope patterns were "perfect." Remembering that the scope indicates only that a spark has occurred (not necessarily inside the engine), the technician grounded one spark plug wire at a time using a vacuum hose and a test light. Every time a plug wire was grounded, the engine ran worse, until the last cylinder was checked. When the last spark plug wire was grounded, the engine ran the same. The technician checked the spark plug wire with an ohmmeter; it tested within specifications (less than 10,000 ohms per foot of length). The technician also removed and inspected the spark plug. The spark plug looked normal. The spark plug was reinstalled and the engine tested again. The test had the same results as before—the engine seemed to be running on seven cylinders, yet the scope pattern was perfect.

The technician then replaced the spark plug for the affected cylinder. The engine ran correctly. Very close examination of the spark plug showed a thin crack between the wire terminal and the shell of the plug. Why didn't the cracked plug show on the scope? The scope simply indicated that a spark had occurred. The scope cannot distinguish between a spark inside the engine and a spark outside the engine. In this case, the voltage required to travel through the spark plug crack to ground was about the same voltage required to jump the spark plug electrodes inside the engine. The spark that occurred across the cracked spark plug, however, may have been visible at night with the engine running.

Reading the Spark Lines Spark lines can easily be seen on either superimposed or raster (stacked) position. On the raster position, each individual spark line can be viewed.

The spark lines should be level and one-fourth as high as the firing lines (1.5 to 2.5 kV, but usually less than 2 kV). The spark line voltage is called the **burn kV.** The *length* of the spark line is the critical factor for determining proper operation of the engine because it represents the spark duration or burn time. There is only a limited amount of energy in an ignition coil. If most of the energy is used to ionize the air gaps of the rotor and the spark plug, there may not be enough energy remaining to create a spark duration long enough to completely burn the air–fuel mixture. Many scopes are equipped with a **millisecond (ms) sweep.** This means that the scope will sweep only that portion of the pattern that can be shown during a 5- or 25-ms setting. Following are guidelines for spark line length:

- 0.8 ms—too short
- 1.5 ms—average
- 2.2 ms—too long

If the spark line is too short, possible causes include the following:

1. Spark plug(s) gap is too wide
2. Rotor tip to distributor cap insert distance gap is too wide (worn cap or rotor)
3. High-resistance spark plug wire
4. Air–fuel mixture too lean (vacuum leak, broken valve spring, etc.)

If the spark line is too long, possible causes include the following:

1. Fouled spark plug(s)
2. Spark plug(s) gap is too narrow
3. Shorted spark plug or spark plug wire

Many scopes do not have a millisecond scale. Some scopes are labeled in degrees and/or percentage (%) of dwell. The following chart can be used to determine acceptable spark line length.

Normal Spark Line Length (at 700 to 1200 RPM)

Number of Cylinders	Milliseconds	Percentage (%) of Dwell Scale	Degrees (°)
4	1.0–2.0	3–6	3–5
6	1.0–2.0	4–9	2–5
8	1.0–2.0	6–13	3–6

Spark Line Slope Downward-sloping spark lines indicate that the voltage required to maintain the spark duration is decreasing during the firing of the spark plug. This downward slope usually indicates that the spark energy is finding ground through spark plug deposits (the plug is fouled) or other ignition problems. See Figure 57–38.

An upward-sloping spark line usually indicates a mechanical engine problem. A defective piston ring or valve would tend to seal better in the increasing pressures of combustion. As the spark plug fires, the effective increase in pressures increases the voltage required to maintain the spark, and the height of the spark line rises during the duration of the spark. See Figure 57–39.

An upward-sloping spark line can also indicate a lean air–fuel mixture. Typical causes include:

1. Clogged injector(s)
2. Vacuum leak
3. Sticking intake valve

See Figure 57–40 for an example showing the relationship between the firing line and the spark line.

Reading the Intermediate Section The intermediate section should have three or more oscillations (bumps) for a correctly operating ignition system. Because approximately 250 volts are in the primary ignition circuit when the spark stops flowing across the spark plugs, this voltage is reduced by about 75 volts per oscillation. Additional resistances in the primary circuit would decrease the number of oscillations. If there are fewer than three oscillations, possible problems include the following:

1. Shorted ignition coil
2. Loose or high-resistance primary connections on the ignition coil or primary ignition wiring

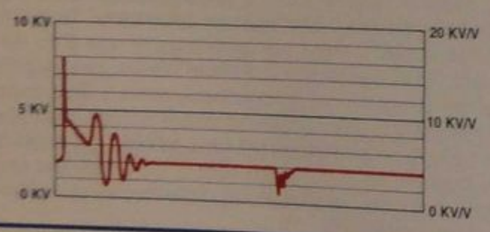


Figure 57–38 A downward-sloping spark line usually indicates high secondary ignition system resistance or an excessively rich air–fuel mixture.

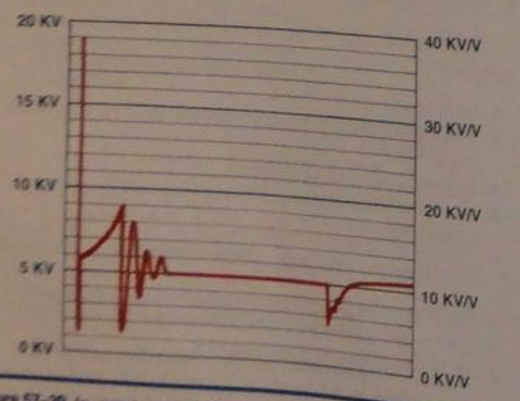


Figure 57–39 An upward-sloping spark line usually indicates a mechanical engine problem or a lean air–fuel mixture.

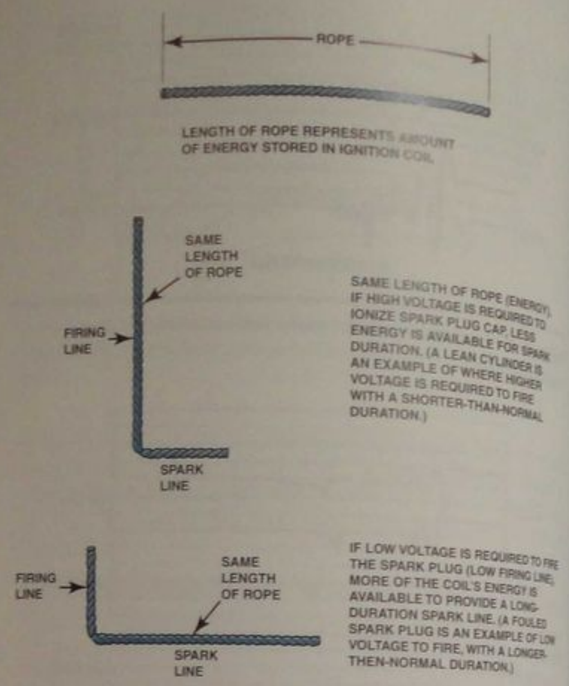


Figure 57–40 The relationship between the height of the firing line and length of the spark line can be illustrated using a rope. Because energy cannot be destroyed, the stored energy in an ignition coil must dissipate totally, regardless of engine operating conditions.

Electronic Ignition and the Dwell Section Electronic ignitions also use a dwell period to charge the coil. Dwell is not adjustable with electronic ignition, but it does change with increasing RPM with many electronic ignition systems. This change in dwell with RPM should be considered normal.

Many EI systems also produce a "hump" in the dwell section, which reflects a current-limiting circuit in the control module. These current-limiting humps may have slightly different shapes depending on the exact module used. For example, the humps produced by various GM HEI modules differ slightly.

Dwell Variation (Electronic Ignition) A worn distributor gear, worn camshaft gear, or other distributor problem may cause engine performance problems, because the signal created in the distributor will be affected by the inaccurate distributor operation. However, many electronic ignitions vary the dwell electronically in the module to maintain acceptable current flow levels through the ignition coil and module without the use of a ballast resistor.

NOTE: Distributorless ignition systems also vary dwell time electronically within the engine computer or ignition module.

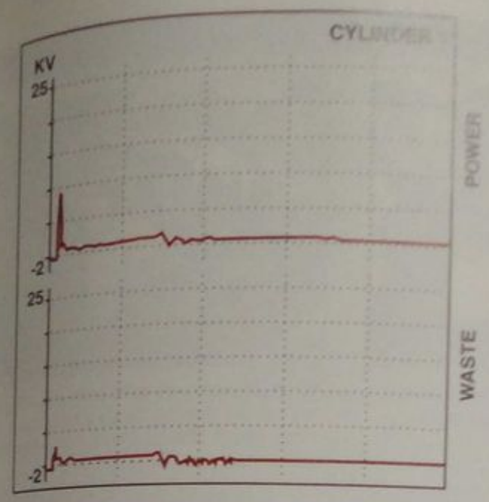


Figure 57–41 A dual-trace scope pattern showing both the power and the waste spark from the same coil (cylinders 1 and 6). Note that the firing line is higher on the cylinder that is under compression (power); otherwise, both patterns are almost identical.

Coil Polarity With the scope connected and the engine running, observe the scope pattern in the superimposed mode. If the pattern is upside down, the primary wires on the coil may be reversed, causing the coil polarity to be reversed.

NOTE: Check the scope hookup and controls before deciding that the coil polarity is reversed.

Acceleration Check With the scope selector set on the display (parade) position, rapidly accelerate the engine (gear selector in park or neutral with the parking brake on). The results should be interpreted as follows:

1. All firing lines should rise evenly (not to exceed 75% of maximum coil output) for properly operating spark plugs.
2. If the firing lines on one or more cylinders fail to rise, this indicates fouled spark plugs.

Rotor Gap Voltage The **rotor gap** voltage test measures the voltage required to jump the gap (0.030 to 0.050 in. or 0.8 to 1.3 mm) between the rotor and the inserts (segments) of the distributor cap. Select the display (parade) scope pattern and remove a spark plug wire using a jumper wire to provide a good ground connection. Start the engine and observe the height of the firing line for the cylinder being tested. Because the spark plug wire is connected directly to ground, the firing line height on the scope will indicate the voltage required to jump the air gap between the rotor and the distributor cap insert. The normal rotor gap voltage is 3 to 7 kV, and the voltage should not exceed 8 kV. If the rotor gap voltage indicated is near or above 8 kV, inspect and replace the distributor cap and/or rotor as required.

SCOPE-TESTING A WASTE-SPARK IGNITION SYSTEM

A handheld digital storage oscilloscope can be used to check the pattern of each individual cylinder. Some larger scopes can be connected to all spark plug wires and therefore are able to display both power and waste-spark waveforms. See Figure 57–41. Because the waste-spark does not require as high a voltage level as the cylinder on the power stroke, the waste form will be normally lower.

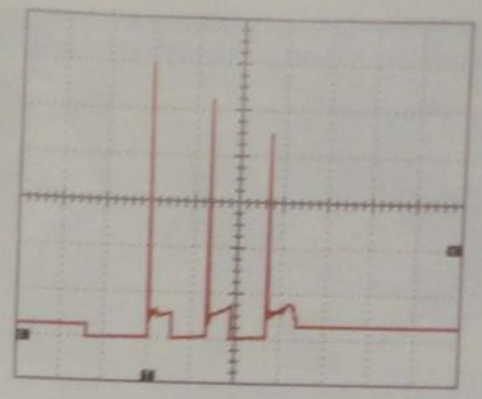


Figure 57–42 A secondary waveform of a Ford 4.6 liter V-8, showing three sparks occurring at idle speed.

SCOPE-TESTING A COIL-ON-PLUG IGNITION SYSTEM

On a coil-on-plug (COP) type of ignition system, each individual coil can be shown on a scope and using the proper cables and adapters, the waveform for all of the cylinders can be viewed at the same time. Always follow the scope equipment manufacturer's instructions. Many Ford coil-on-plug systems use a triple-strike secondary spark event. The spark plugs are fired three times when the engine is at idle speed to improve idle quality and to reduce exhaust emissions. Above certain engine speeds, the ignition system switches to a single-fire event. See Figure 57–42.

IGNITION SYSTEM TROUBLESHOOTING GUIDE

The following list will assist technicians in troubleshooting ignition system problems.

Problem	Possible Causes and/or Solutions
No spark out of the coil	• Possible open in the ignition switch circuit • Possible defective ignition module (if electronic ignition coil) • Possible defective pickup coil or Hall-effect switch (if electronic ignition) • Possible shorted condenser
Weak spark out of the coil	• Possible high-resistance coil wire or spark plug wire • Possible poor ground between the distributor or module and the engine block
Engine misfire	• Possible defective (open) spark plug wire • Possible worn or fouled spark plugs • Possible defective pickup coil • Possible defective module • Possible poor electrical connections at the pickup coil and/or module

SUMMARY

1. A thorough visual inspection should be performed on all ignition components when diagnosing an engine performance problem.
2. Platinum spark plugs should not be regapped after use in an engine.
3. A secondary ignition scope pattern includes a firing line, spark line, intermediate oscillations, and transistor-on and transistor-off points.
4. The slope of the spark line can indicate incorrect air–fuel ratio or other engine problems.

PHOTO SEQUENCE Ignition System Diagnosis



P57–1 The tools and supplies needed to test for a fault in the secondary ignition system.



P57–2 The first step in the diagnosis of the ignition system is to check for adequate voltage from the coil(s).



P57–3 Attach a spark tester to the end of the spark plug wire and then clip the spark tester to a good engine ground. Start the engine and observe the spark tester.



P57–4 Engine faults as well as ignition system faults can often be detected by using a tester capable of measuring spark plug firing voltage such as this unit from Snap-On tools.



P57–5 Start the engine and rotate the thumb wheel until the red light emitting diode (LED) just flickers off and then read the firing voltage on the display.



P57–6 The cylinder indicated a firing voltage of about 8 kV for the inverted spark on another cylinder. This cylinder is firing in the opposite polarity of the other cylinder (inverted).



P57–7 Another tester that can be used is one from OTC tools. To use this tester, connect the ground clip to a good engine ground and connect the test probe around a spark plug wire.



P57–8 Start the engine and select "spark kV." This is the voltage required to fire the spark plugs; this display indicates 16.4 kV.



P57–9 Move the selector to read "burn kV." The reading indicated 1.9 kV. This is the voltage necessary to keep the spark firing after it has been started. It should be less than 2 kV for most vehicles.



P57–10 Move the selector to "burn time." The reading is 1.2 mS (milliseconds). This is the duration of the spark and it should be between 1 and 2 mS.



P57–11 Ground out a cylinder one at a time and observe if the engine speed or idle quality is affected. If one cylinder does not respond then this test can help pinpoint a fault in a particular cylinder.



P57–12 Use a grounded test light and touch the section of rubber hose with the tip. The high voltage will travel through the test light to ground and not fire the spark plug.

REVIEW QUESTIONS

1. Why should a spark tester be used to check for spark rather than a standard spark plug?
2. How do you test a pickup coil for resistance and AC voltage output?
3. What harm can occur if the engine is cranked or run with an open (defective) spark plug wire?
4. What are the sections of a secondary ignition scope pattern?
5. What can the slope of the spark line indicate about the engine?

CHAPTER QUIZ

1. Technician A says that the firing line shows the voltage that is required to fire the spark plug. Technician B says that spark line shows the duration of the spark inside the cylinder. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that a defective spark plug wire can cause an engine miss. Technician B says that a defective pickup coil wire can cause an engine miss. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. The _____ sends a pulse signal to an electronic ignition module.
   a. Ballast resistor
   b. Pickup coil
   c. Ignition coil
   d. Condenser
4. Typical primary coil resistance specifications usually range from _____ ohms.
   a. 100 to 450
   b. 500 to 1,500
   c. 1 to 3
   d. 6,000 to 30,000
5. Typical secondary coil resistance specifications usually range from _____ ohms.
   a. 100 to 450
   b. 500 to 1,500
   c. 1 to 3
   d. 6,000 to 30,000
6. Technician A says that an engine will not start and run if the ignition coil is tracked. Technician B says that one wire of any pickup coil must be grounded. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Technician A says that a GM HEI distributor rotor can burn through and cause an engine miss during acceleration. Technician B says that a defective spark plug wire can cause an engine miss during acceleration. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. The secondary ignition circuit can be tested using _____.
   a. An ohmmeter
   b. A test light
   c. An ammeter
   d. Both a and b
9. Two technicians are discussing a no-start (no-spark) condition. Technician A says that an open pickup coil could be the cause. Technician B says that a defective ignition control module (ICM) could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Which sensor produces a square wave signal?
    a. Magnetic sensor
    b. Hall-effect sensor
    c. Pickup coil
    d. Both b and c

CHAPTER 58 Fuel Pumps, Lines, and Filters

OBJECTIVES: After studying Chapter 58, the reader will be able to: Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Describe how to check an electric fuel pump for proper pressure and volume delivery. • Explain how to check a fuel-pressure regulator. • Describe how to test fuel injectors. • Explain how to diagnose electronic fuel-injection problems.

KEY TERMS: accumulator • baffle • check valve • delivery system • filter basket • gerotor • hydrokinetic pump • inertia switch • onboard refueling vapor recovery (ORVR) • peripheral pump • residual or rest pressure • roller cell • rotary vane pump • side-channel pump • turbine pump • vacuum lock • vapor lock • volatile organic compound (VOC)

FUEL DELIVERY SYSTEM

Creating and maintaining a correct air–fuel mixture requires a properly functioning fuel and air **delivery system.** Fuel delivery (and return) systems use many if not all of the following components to make certain that fuel is available under the right conditions to the fuel-injection system:

- Fuel storage tank, filler neck, and gas cap
- Fuel tank pressure sensor
- Fuel pump
- Fuel filter(s)
- Fuel delivery lines and fuel rail
- Fuel-pressure regulator
- Fuel return line

FUEL TANKS

A vehicle fuel tank is made of corrosion-resistant steel or polyethylene plastic. Some models, such as sport utility vehicles (SUVs) and light trucks, may have an auxiliary fuel tank.

Tank design and capacity are a compromise between available space, filler location, fuel expansion room, and fuel movement. Some later-model tanks deliberately limit tank capacity by extending the filler tube neck into the tank low enough to prevent complete filling, or by providing for expansion room. See Figure 58–1. A vertical **baffle** in this same tank limits fuel sloshing as the vehicle moves.

Regardless of size and shape, all fuel tanks incorporate most if not all of the following features:

- Inlet or filler tube through which fuel enters the tank
- Filler cap with pressure holding and relief features
- An outlet to the fuel line leading to the fuel pump or fuel injector
- Fuel pump mounted within the tank
- Tank vent system
- Fuel pickup tube and fuel level sending unit

Tank Location and Mounting Most vehicles use a horizontally suspended fuel tank, usually mounted below the rear of the floor pan, just ahead of or behind the rear axle. Fuel tanks are located there so that frame rails and body components protect the tank in the event of a crash. To prevent squeaks, some models have insulated strips cemented on the top or sides of the tank wherever it contacts the underbody.

Fuel inlet location depends on the tank design and filler tube placement. It is located behind a filler cap and is often a hinged door in the outer side of either rear fender panel.

Generally, a pair of metal retaining straps holds a fuel tank in place. Underbody brackets or support panels hold the strap ends using bolts. The free ends are drawn underneath the tank to hold it in place, then bolted to other support brackets or to a frame member on the opposite side of the tank.

Filler Tubes Fuel enters the tank through a large tube extending from the tank to an opening on the outside of the vehicle. See Figure 58–2.

Effective in 1993, federal regulations require manufacturers to install a device to prevent fuel from being siphoned through the filler neck. Federal authorities recognized methanol as a poison, and methanol used in gasoline is a definite health hazard. Additionally, gasoline is a suspected carcinogen (cancer-causing agent). To prevent siphoning, manufacturers welded a filler-neck check-ball tube in fuel tanks. To drain check-ball-equipped fuel tanks, a technician must disconnect the check-ball tube at the tank and attach a siphon directly to the tank. See Figure 58–3.

Onboard refueling vapor recovery (ORVR) systems have been developed to reduce evaporative emissions during refueling. See Figure 58–4. These systems add components to the filler neck and the tank. One ORVR system utilizes a tapered filler neck with a smaller diameter tube and a check valve. When fuel flows down the neck, it opens the normally closed check valve. The vapor passage to the charcoal canister is opened. The diameter size neck and the opened air passage allow fuel and vapor to flow rapidly into the tank and the canister respectively. When the fuel has reached a predetermined level, the check valve closes, and the fuel tank pressure increases. This forces the nozzle to shut off, thereby preventing the tank from being overfilled.

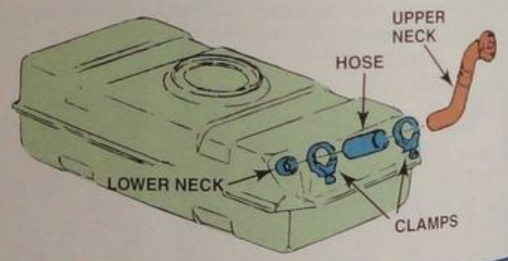


Figure 58–2 A three-piece filler tube assembly.

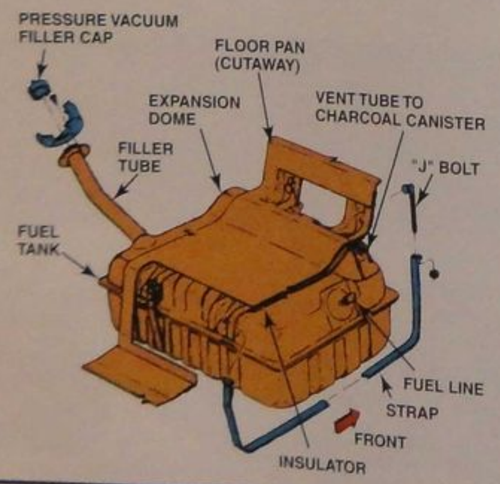


Figure 58–1 A typical fuel tank installation.



Figure 58–3 A view of a typical filler tube with the fuel tank removed. Notice the ground strap used to help prevent the buildup of static electricity as the fuel flows into the plastic tank. The check ball looks exactly like a ping-pong ball.



Figure 58–4 Vehicles equipped with onboard refueling vapor recovery usually have a reduced-size fill tube.

Pressure-Vacuum Filler Cap Fuel and vapors are sealed in the tank by the safety filler cap. The safety cap must release excess pressure or excess vacuum. Either condition could cause fuel tank damage, fuel spills, and vapor escape. Typically, the cap will release if the pressure is over 1.5 to 2.0 PSI (10 to 14 kPa) or if the vacuum is 0.15 to 0.30 PSI (1 to 2 kPa).

Fuel Pickup Tube The fuel pickup tube is usually a part of the fuel sender assembly or the electric fuel pump assembly. Since dirt and sediment eventually gather on the bottom of a fuel tank, the fuel pickup tube is fitted with a filter sock or strainer to prevent contamination from entering the fuel lines. The woven plastic strainer also acts as a water separator by preventing water from being drawn up with the fuel. The filter sock usually is designed to filter out particles that are larger than 70 to 100 microns, or 30 microns if a gerotor-type fuel pump is used. One micron is 0.000039 in. See Figure 58–5.

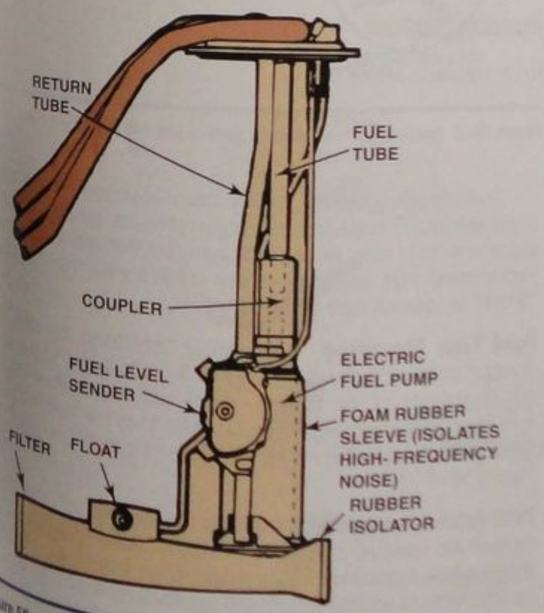


Figure 58–5 The fuel pickup tube is part of the fuel sender and pump assembly.

Note: The human eye cannot see anything smaller than about 40 microns.

The filter is made from woven Saran resin (copolymer of vinylidene chloride and vinyl chloride). The filter blocks any water that may be in the fuel tank, unless it is completely submerged in water. In that case, it will allow water through the filter. This filter should be replaced whenever the fuel pump is replaced.

Tank Venting Requirements Fuel tanks must be vented to prevent a **vacuum lock** as fuel is drawn from the tank. As fuel is used and its level drops in the tank, the space above the fuel increases. As the air in the tank expands to fill this greater space, its pressure drops. Without a vent, the air pressure inside the tank would drop below atmospheric pressure, developing a vacuum which prevents the flow of fuel. Under extreme pressure variance, the tank could collapse. Venting the tank allows outside air to enter as the fuel level drops, preventing a vacuum from developing.

An EVAP system vents gasoline vapors from the fuel tank directly to a charcoal-filled vapor storage canister, and uses an unvented filler cap. Many filler caps contain valves that open to relieve pressure or vacuum above specified safety levels. Systems that use completely sealed caps have separate pressure and vacuum relief valves for venting.

Because fuel tanks are not vented directly to the atmosphere, the tank must allow for fuel expansion, contraction, and overflow that can result from changes in temperature or overfilling. One way is to use a dome in the top of the tank. Many General Motors vehicles use a design that includes a vertical sloshing baffle which reserves up to 12% of the total tank capacity for fuel expansion.

Rollover Leakage Protection All vehicles have one or more devices to prevent fuel leaks in case of vehicle rollover or a collision in which fuel may spill.

Variations of the basic one-way **check valve** may be installed in any number of places between the fuel tank and the engine. The valve may be installed in the fuel return line, vapor vent line, or fuel tank filler cap.

In addition to the rollover protection devices, some vehicles use devices to ensure that the fuel pump shuts off when an accident occurs. Some pumps depend upon an oil pressure or an engine speed signal to continue operating; these pumps turn off whenever the engine dies. On some air vane sensors, a microswitch is built into the sensor to switch on the fuel pump as soon as intake airflow causes the vane to lift from its rest position. See Figure 58–6.

Ford vehicles use an **inertia switch.** See Figure 58–7. The inertia switch is installed in the rear of the vehicle between the electric fuel pump and its power supply. With any sudden impact, such as a jolt from another vehicle in a parking lot, the inertia switch opens and shuts off power to the fuel pump. The switch must be reset manually by pushing a button to restore current to the pump.

FUEL LINES

Fuel and vapor lines made of steel, nylon tubing, or fuel-resistant rubber hoses connect the parts of the fuel system. Fuel lines supply fuel to the throttle body or fuel rail. They also return excess fuel and vapors to the tank. Depending on their function, fuel and vapor lines may be either rigid or flexible.

Fuel lines must remain as cool as possible. If any part of the line is located near too much heat, the gasoline passing through it vaporizes and **vapor lock** occurs. When this happens, the fuel pump supplies only vapor that passes into the injectors. Without liquid gasoline, the engine stalls and a hot restart problem develops.

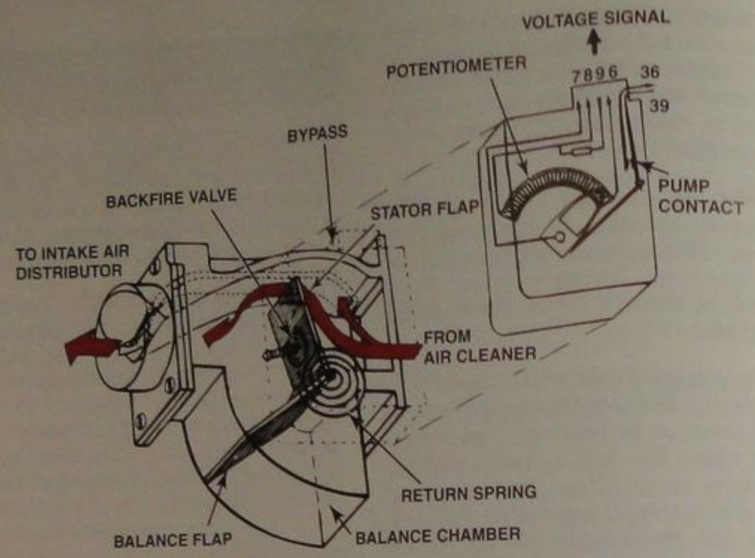


Figure 58–6 On some vehicles equipped with an airflow sensor, a switch is used to energize the fuel pump. In the event of a collision, the switch opens and the fuel flow stops.

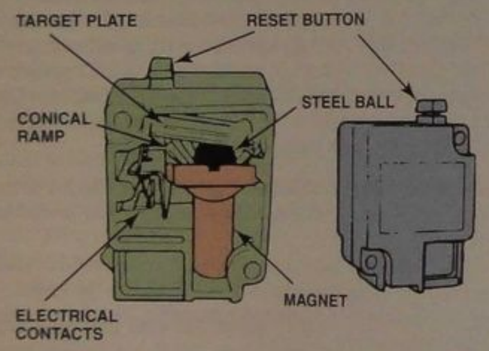


Figure 58–7 Ford uses an inertia switch to turn off the electric fuel pump in an accident.

The fuel delivery system supplies 10 to 15 PSI (69 to 103 kPa) or up to 35 PSI (241 kPa) to many throttle-body injection units and up to 50 PSI (345 kPa) for multiport fuel-injection systems. Fuel-injection systems retain residual or rest pressure in the lines for a half hour or longer when the engine is turned off to prevent hot engine restart problems. Higher-pressure systems such as these require special fuel lines.

Rigid Lines All fuel lines fastened to the body, frame, or engine are made of seamless steel tubing. Steel springs may be wound around the tubing at certain points to protect against impact damage.

Only steel tubing, or that recommended by the manufacturer, should be used when replacing rigid fuel lines. *Never substitute copper or aluminum tubing for steel tubing.* These materials do not withstand normal vehicle vibration and could combine with the fuel to cause a chemical reaction.

Flexible Lines Most fuel systems use synthetic rubber hose sections where flexibility is needed. Short hose sections often connect steel fuel lines to other system components. The fuel delivery hose inside diameter (ID) is generally larger (3/16 to 3/8 inches or 8 to 10 millimeters) than the fuel return hose ID (1/4 inches or 6 millimeters).

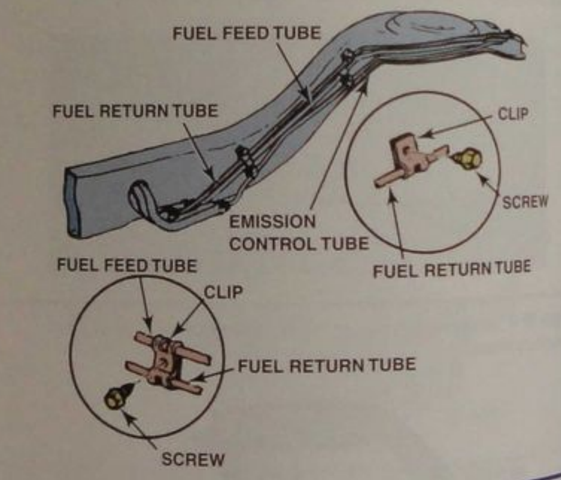


Figure 58–8 Fuel lines are routed along the frame or body and secured with clips.

Fuel-injection systems require special-composition reinforced hoses specifically made for these higher-pressure systems. Similarly, vapor vent lines must be made of materials that resist fuel vapors. Replacement vent hoses are usually marked with the designation "EVAP" to indicate their intended use.

Fuel Line Mounting Fuel supply lines from the tank to a throttle body or fuel rail are routed to follow the frame along the underbody of the vehicle. Vapor and return lines may be routed with the fuel supply line. All rigid lines are fastened to the frame rail or underbody with screws and clamps, or clips. See Figure 58–8.

Fuel-Injection Lines and Clamps Hoses used for fuel-injection systems are made of materials with high resistance to oxidation and deterioration. Replacement hoses for injection systems should always be equivalent to original equipment manufacturer (OEM) hoses.

Screw-type clamps are essential on injected engines and should have rolled edges to prevent hose damage.

CAUTION: *Do not use spring-type clamps on fuel-injected engines—they cannot* withstand the fuel pressures involved.

Fuel-Injection Fittings and Nylon Lines Because of their operating pressures, fuel-injection systems often use special kinds of fittings to ensure leakproof connections. Some high-pressure fittings on GM vehicles with port fuel-injection systems use O-ring seals instead of the traditional flare connections. When disconnecting such a fitting, inspect the O-ring for damage and replace it if necessary. *Always* tighten O-ring fittings to the specified torque value to prevent damage.

Other manufacturers also use O-ring seals on fuel line connections. In all cases, the O-rings are made of special materials that withstand contact with gasoline and oxygenated fuel blends. Some manufacturers specify that the O-rings be replaced every time the fuel system connection is opened. When replacing one of these O-rings, a new part specifically designed for fuel system service must be used.

Ford also uses spring-lock connectors to join male and female ends of steel tubing. See Figure 58–9. The coupling is held together by a garter spring inside a circular cage. The flared end of the female fitting slips behind the spring to lock the coupling together.

General Motors has used nylon fuel lines with quick-connect fittings at the fuel tank and fuel filter since the early 1990s. Like the GM threaded couplings used with steel lines, nylon line couplings use internal O-ring seals. Unlocking the metal connectors requires a special quick-connector separator tool; plastic connectors can be released without the tool. See Figures 58–10 and 58–11.

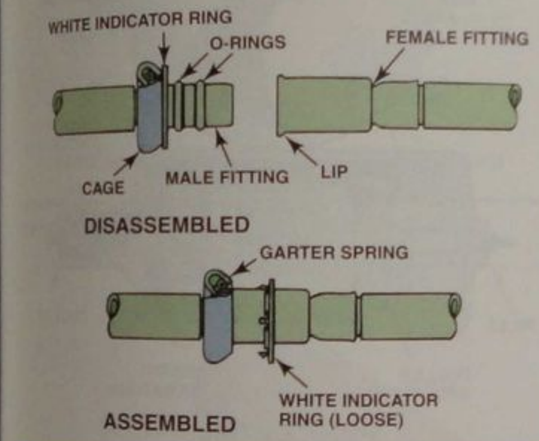


Figure 58–9 Some Ford metal line connections use spring-locks and O-rings.

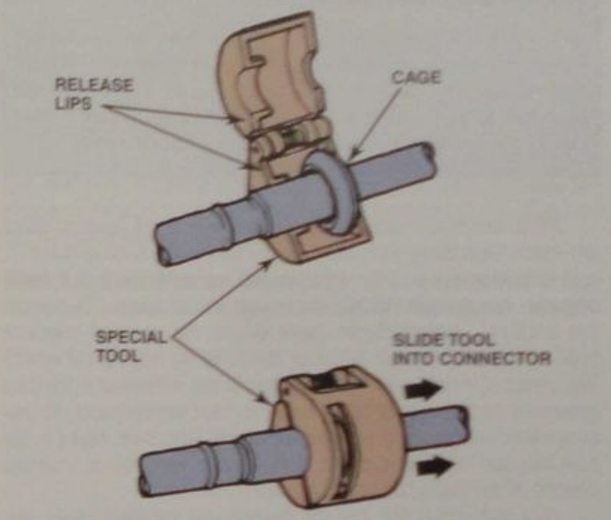


Figure 58–10 Ford spring-lock connectors require a special tool for disassembly.

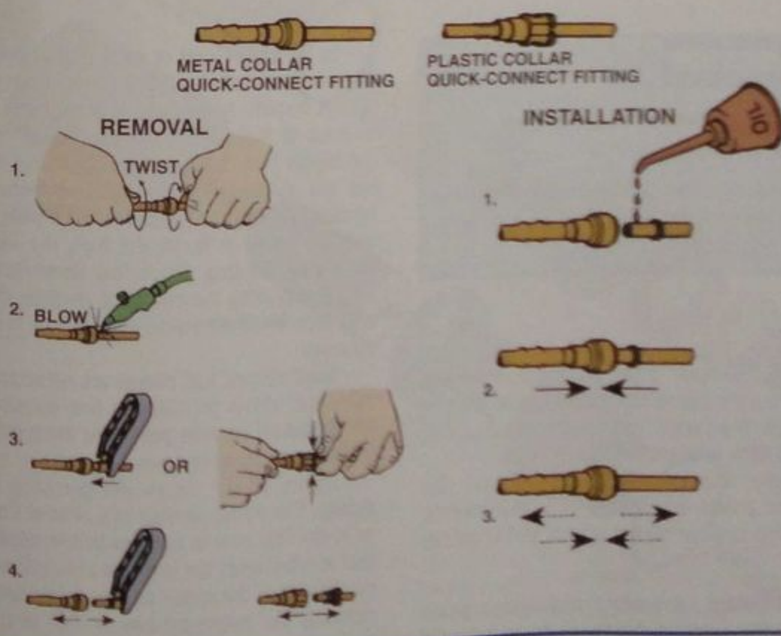


Figure 58–11 Typical quick-connect steps.

Fuel Line Layout Fuel pressures have tended to become higher to prevent vapor lock, and a major portion of the fuel routed to the fuel-injection system returns to the tank by way of a fuel return line or return-type systems. This allows better control, within limits, of heat absorbed by the gasoline as it is routed through the engine compartment. Throttle-body and multiport injection systems have typically used a pressure regulator to control fuel pressure in the throttle body or fuel rail, and also allow excess fuel not used by the injectors to return to the tank. However, the warmer fuel in the tank may create problems, such as an excessive rise in fuel vapor pressures in the tank.

FREQUENTLY ASKED QUESTION ???

Just How Much Fuel Is Recirculated?

Approximately 80% of the available fuel-pump volume is released to the fuel tank bypassing the fuel-pressure regulator at idle speed. As an example, a passenger vehicle cruising down the road at 60 mph gets 30 mpg. With a typical return-style fuel system pumping about 30 gallons per hour from the tank, it would therefore burn 2 gallons per hour, and return about 28 gallons per hour to the tank!

With late-model vehicles, there has been some concern about too much heat being sent back to the fuel tank, causing rising in-tank temperatures and increases in fuel vaporization and **volatile organic compound (VOC)** (hydrocarbon) emissions. To combat this problem, manufacturers have placed the pressure regulator back by the tank instead of under the hood on mechanical return-less systems. In this way, returned fuel is not subjected to the heat generated by the engine and the underhood environment. To prevent vapor lock in these systems, pressures have been raised in the fuel rail, and injectors tend to have smaller openings to maintain control of the fuel spray under pressure.

Not only must the fuel be filtered and supplied under adequate pressure, but there must also be a consistent *volume* of fuel to assure smooth engine performance even under the heaviest of loads.

FREQUENTLY ASKED QUESTION ???

How Can an Electric Pump Work Inside a Gas Tank and Not Cause a Fire?

Even though fuel fills the entire pump, no burnable mixture exists inside the pump because there is no air and no danger of commutator brush arcing, igniting the fuel.

ELECTRIC FUEL PUMPS

The electric fuel pump is a pusher unit. When the pump is mounted in the tank, the entire fuel supply line to the engine can be pressurized. Because the fuel, when pressurized, has a higher boiling point, it is unlikely that vapor will form to interfere with fuel flow.

Most vehicles use the impeller or turbine pumps. See Figure 58–12. All electrical pumps are driven by a small electric motor, but the turbine pump turns at higher speeds and is quieter than the others.

Positive Displacement Pump A positive displacement pump is a design that forces everything that enters the pump to leave the pump.

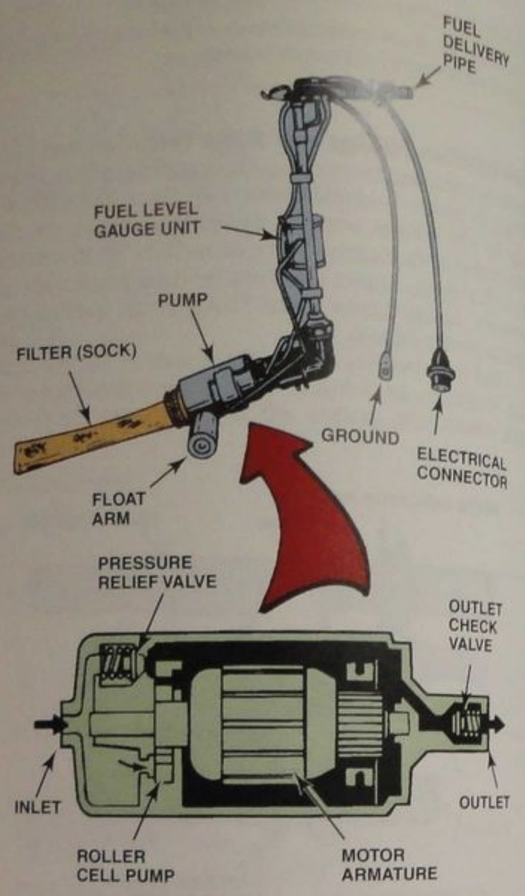


Figure 58–12 A roller cell-type electric fuel pump.

In the **roller cell** or vane pump, the impeller draws fuel into the pump, and then pushes it out through the fuel line to the injection system. All designs of pumps use a variable-sized chamber to draw in fuel. When the maximum volume has been reached, the supply port closes and the discharge opens. Fuel is then forced out the discharge as this volume decreases. The chambers are formed by rollers or gears in a rotor plate. Since this type of pump uses no valves to move the fuel, the fuel flows steadily through the pump housing. Since fuel flows steadily through the entire pump, including the electrical portion, the pump stays cool. Usually, only when a vehicle runs out of fuel is there a risk of pump damage.

Most electric fuel pumps are equipped with a fuel outlet check valve that closes to maintain fuel pressure when the pump shuts off. **Residual or rest pressure** prevents vapor lock and hot-start problems on these systems.

Figure 58–13 shows the pumping action of a **rotary vane pump.** The pump consists of a central impeller disk, several rollers or vanes that ride in notches in the impeller, and a pump housing that is offset from the impeller centerline. The impeller is mounted on the end of the motor armature and spins whenever the motor is running. The rollers are free to slide in and out within the notches in the impeller to maintain sealing contact. Unpressurized fuel enters the pump, fills the spaces between the rollers, and is trapped

between the impeller, the housing, and two rollers. An internal gear pump, called a **gerotor,** is another type of positive displacement pump that is often used in engine oil pumps. It uses the meshing of internal and external gear teeth to pressurize the fuel. See Figure 58–14 for an example of a gerotor-type fuel pump that uses an impeller as the first stage and is used to move the fuel gerotor section where it is pressurized.

Hydrokinetic Flow Pump Design The word *hydro* means liquid and the term *kinetic* refers to motion, so the term **hydrokinetic pump** means that this design of pump rapidly moves the fuel to create pressure. This design of pump is a nonpositive displacement pump design.

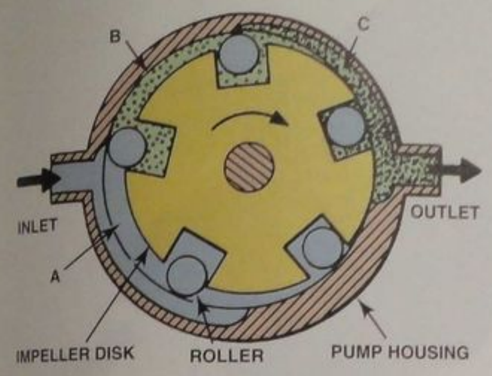


Figure 58–13 The pumping action of an impeller or rotary vane pump.

A **turbine pump** is the most common because it tends to be less noisy. Sometimes called **turbine, peripheral,** and **side-channel,** these units use an impeller that accelerates the fuel particles before actually discharging them into a tract where they generate pressure via pulse exchange. Actual pump volume is controlled by using a different number of impeller blades, and in some cases a higher number of impellers, or different shapes along the side discharge channels. These units are fitted more toward lower operating pressures of less than 60 PSI. See Figure 58–15 for an example of a two-stage turbine pump. The turbine impeller has a staggered blade design to minimize pump harmonic noise and to separate vapor from the liquid fuel. The end cap assembly contains a pressure relief valve and a radio-frequency interference (RFI) suppression module. The check valve is usually located in the upper fuel pipe connector assembly.

After it passes through the strainer, fuel is drawn into the lower housing inlet port by the impellers. It is pressurized and delivered to the convoluted fuel tube for transfer through a check valve into the fuel feed pipe. A typical electric fuel pump used on a fuel-injection system delivers about 40 to 50 gallons per hour or 0.6 to 0.8 gallons per minute at a pressure of 70 to 90 PSI.

Modular Fuel Sender Assembly The modular fuel sender consists of a replaceable fuel level sensor, a turbine pump, and a jet

Figure 58–14 An exploded view of a gerotor electric fuel pump.

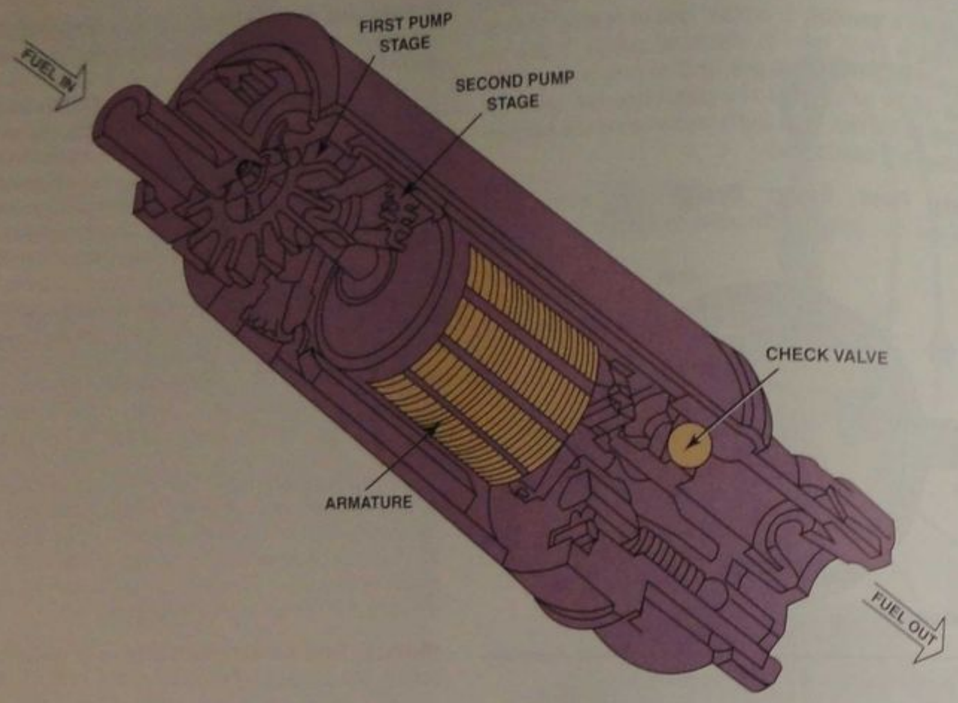


Figure 58–15 A cutaway view of a typical two-stage turbine electric fuel pump.

pump. The reservoir housing is attached to the cover containing fuel pipes and the electrical connector. Fuel is transferred from the pump to the fuel pipe through a convoluted (flexible) fuel pipe. The convoluted fuel pipe eliminates the need for rubber hoses, nylon pipes, and clamps. The reservoir dampens fuel slosh to maintain a constant fuel level available to the roller vane pump; it also reduces noise.

Some of the flow, however, is returned to the jet pump for recirculation. Excess fuel is returned to the reservoir through one of the three hollow support pipes. The hot fuel quickly mixes with the cooler fuel in the reservoir; this minimizes the possibility of vapor lock. In these modules, the reservoir is filled by the jet pump. Some of the fuel from the pump is sent through the jet pump to lift fuel from the tank into the reservoir.

FREQUENTLY ASKED QUESTION ???

Why Are Many Fuel-Pump Modules Spring-Loaded?

Fuel modules that contain the fuel pickup sock, fuel pump, and fuel level sensor are often spring-loaded when fitted to a plastic fuel tank. The plastic material shrinks when cold and expands when hot, so having the fuel module spring-loaded ensures that the fuel pickup sock will always be the same distance from the bottom of the tank. See Figure 58–16.



Figure 58–16 A typical fuel-pump module assembly, which includes the pickup strainer and fuel pump, as well as the fuel-pressure sensor and fuel level sensing unit.

Electric Pump Control Circuits Fuel-pump circuits are controlled by the fuel-pump relay. Fuel-pump relays are activated initially by turning the ignition key to on, which allows the pump to pressurize the fuel system. As a safety precaution, the relay de-energizes after a few seconds until the key is moved to the crank position. On some systems, once an ignition coil signal, or "tach" signal, is received by the engine control computer, indicating the engine is rotating, the relay remains energized even with the key released to the run position.

Chrysler On Chrysler vehicles, the PCM must receive an engine speed (RPM) signal during cranking before it can energize a circuit driver inside the power module to activate an automatic shutdown (ASD) relay to power the fuel pump, ignition coil, and injectors. As a safety precaution, if the RPM signal to the logic module is interrupted, the logic module signals the power module to deactivate the ASD, turning off the pump, coil, and injectors. In some vehicles, the oil pressure switch circuit may be used as a safety circuit to activate the pump in the ignition switch run position.

General Motors General Motors systems energize the pump with the ignition switch to initially pressurize the fuel lines, but then deactivate the pump if an RPM signal is not received within one or two seconds. The pump is reactivated as soon as engine cranking is detected. The oil pressure sending unit serves as a backup to the fuel-pump relay on some vehicles. In case of pump relay failure, the oil pressure switch will operate the fuel pump once oil pressure reaches about 4 PSI (28 kPa).

Ford Most Ford vehicles with fuel injection have an inertia switch in the trunk between the fuel-pump relay and fuel pump. When the ignition switch is turned to the On position, the electronic engine control (EEC) power relay energizes, providing current to the fuel-pump relay and a timing circuit in the EEC module. If the ignition key is not turned to the Start position within about one second, the timing circuit opens the ground circuit to de-energize the fuel-pump relay and shut down the pump. This circuit is designed to prepressurize the system. Once the key is turned to the start position, power to the pump is sent through the relay and inertia switch.

The inertia switch opens under a specified impact, such as a collision. When the switch opens, current to the pump shuts off because the fuel-pump relay will not energize. The switch must be reset manually by opening the trunk and depressing the reset button before current flow to the pump can be restored. See Figure 58–17 for a schematic of a typical fuel system that uses an injector switch in the power feed circuit to the electric fuel pump.

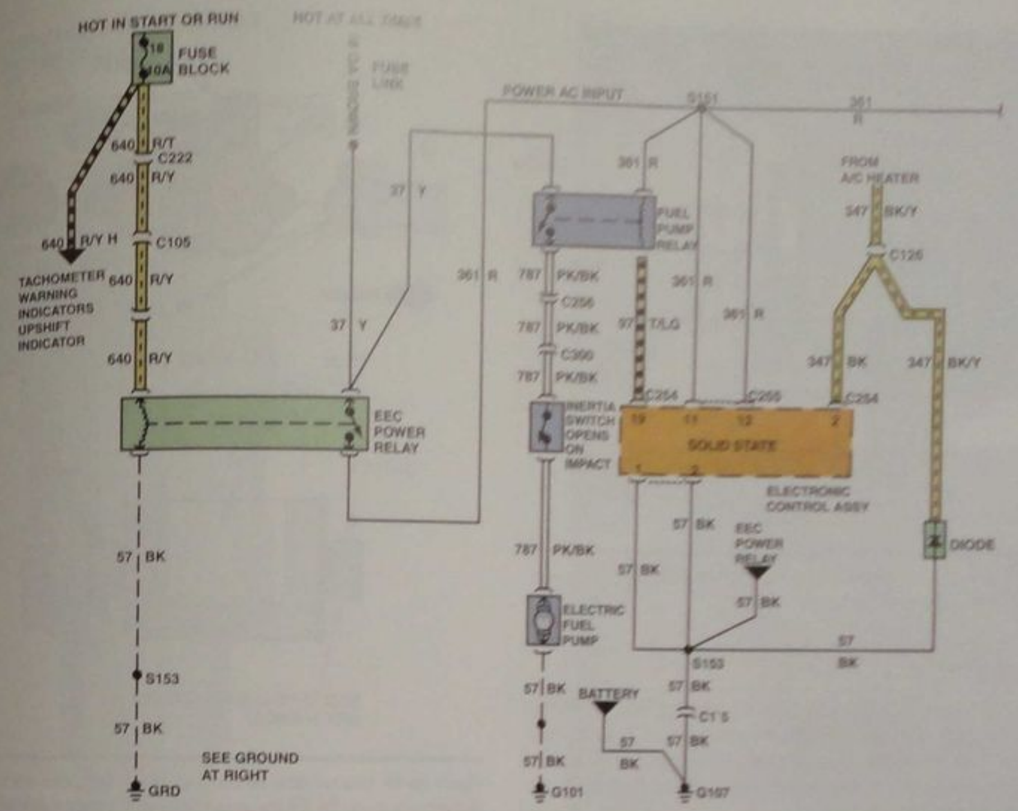


Figure 58–17 A schematic showing that an inertia switch is connected in series between the fuel-pump relay and the fuel pump.

Pump Pulsation Dampening Some manufacturers use an **accumulator** in the system to reduce pressure pulses and noise. Others use a pulsator located at the outlet of the fuel pump to absorb pressure pulsations that are created by the pump. These pulsators are usually used on roller vane pumps and are a source of many internal fuel leaks. See Figure 58–18.

NOTE: Some experts suggest that the pulsator be removed and replaced with a standard section of fuel line to prevent the loss of fuel pressure that results when the connections on the pulsator loosen and leak fuel back into the tank.

Variable Speed Pumps Another way to help reduce noise, current draw, and pump wear is to reduce the speed of the pump when less than maximum output is required. Pump speed and pressure can be regulated by controlling the voltage supplied to the pump with a resistor switched into the circuit, or by letting the engine-control computer pulse-width modulate (PWM) the voltage supply to the pump, through a separate fuel pump driver electronic module. With slower pump speed and pressure, less noise is produced.

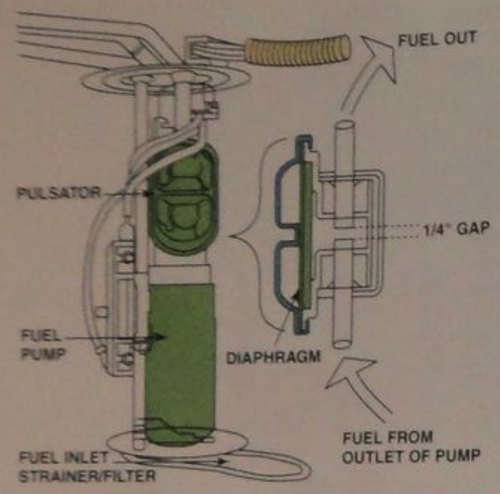


Figure 58–18 A typical fuel pulsator used mostly with roller vane-type pumps to help even out the pulsation in pressure that can cause noise.

FUEL FILTERS

Despite the care generally taken in refining, storing, and delivering gasoline, some impurities get into the automotive fuel system. Fuel filters remove dirt, rust, water, and other contamination from the gasoline before it can reach the fuel injectors. Most fuel filters are designed to filter particles that are 10 to 20 microns or larger in size.

The useful life of all filters is limited, although Ford specifies that its filters, when used with some fuel-injection systems, should last the life of the vehicle. If fuel filters are not cleaned or replaced according to the manufacturer's recommendations, they can become clogged and restrict fuel flow.

In addition to using several different types of fuel filters, a single fuel system may contain two or more filters. The inline filter is located in the line between the fuel pump and the throttle body or fuel rail. See Figure 58–19. This filter protects the system from contamination, but does not protect the fuel pump. The inline filter usually is a metal or plastic container with a pleated paper element sealed inside.

Fuel filters may be mounted on a bracket on the fender panel, a shock tower, or another convenient place in the engine compartment. They may also be installed under the vehicle near the fuel tank. Fuel filters should be replaced according to the vehicle manufacturer's recommendations, which range from every 30,000 miles (48,000 km) to 100,000 miles (160,000 km) or longer. Fuel filters that are part of the fuel-pump module assemblies usually do not have any specified service interval.

TECH TIP ✔ **Be Sure That the Fuel Filter Is Installed Correctly**

The fuel filter has flow direction and if it is installed backwards, the vehicle will most likely have a restricted exhaust (low power at higher engine speeds and loads).

All injectors, throttle body or port, are fitted with one or more filter screens or strainers to remove any particles (generally 10 microns or 0.00039 in.) that might have passed through the other filters. These screens, which surround the fuel inlet, are on the side of throttle-body injectors and are inserted in the top of port injectors. See Figure 58–20.

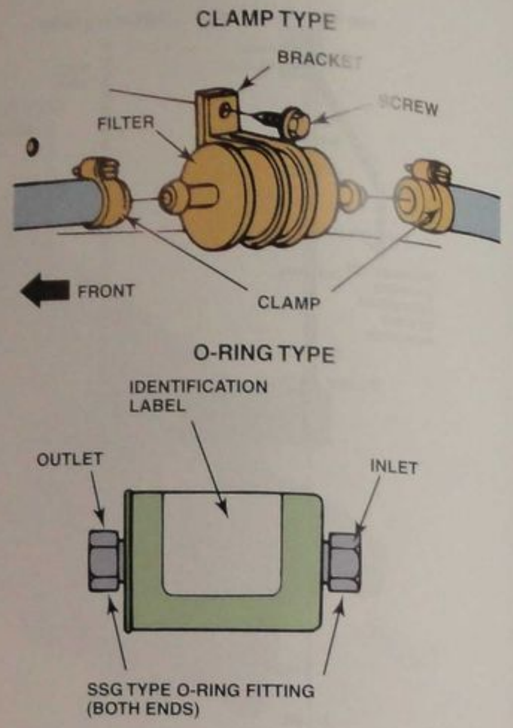


Figure 58–19 Inline fuel filters are usually attached to the fuel line with screw clamps or threaded connections. The fuel filter must be installed in the proper direction or a restricted fuel flow can result.

FUEL-PUMP TESTING

Fuel-pump testing includes many different tests and procedures. Even though a fuel pump can pass one test, it does not mean that there is not a fuel-pump problem. For example, if the pump motor is rotating slower than normal, it may be able to produce the specified pressure, but not enough volume to meet the needs of the engine while operating under a heavy load.

TECH TIP ✔ **The Ear Test**

No, this is not a test of your hearing, but rather using your ear to check that the electric fuel pump is operating. The electric fuel pump inside the fuel tank is often difficult to hear running, especially in a noisy shop environment. A commonly used trick to better hear the pump is to use a funnel in the fuel filler neck. See Figure 58–21.

Testing Fuel-Pump Pressure Fuel-pump-regulated pressure has become more important than ever with a more exact fuel control. Although an increase in fuel pressure does increase fuel volume to the engine, this is *not* the preferred method to add additional fuel as some units will not open correctly at the increased fuel pressure. On the other side of the discussion, many newer engines will not start when fuel pressure is just a few PSI low. Correct fuel pressure is very important for proper engine operation. Most fuel-injection systems operate at either a low pressure of about 10 PSI or a high pressure of between 35 and 45 PSI.

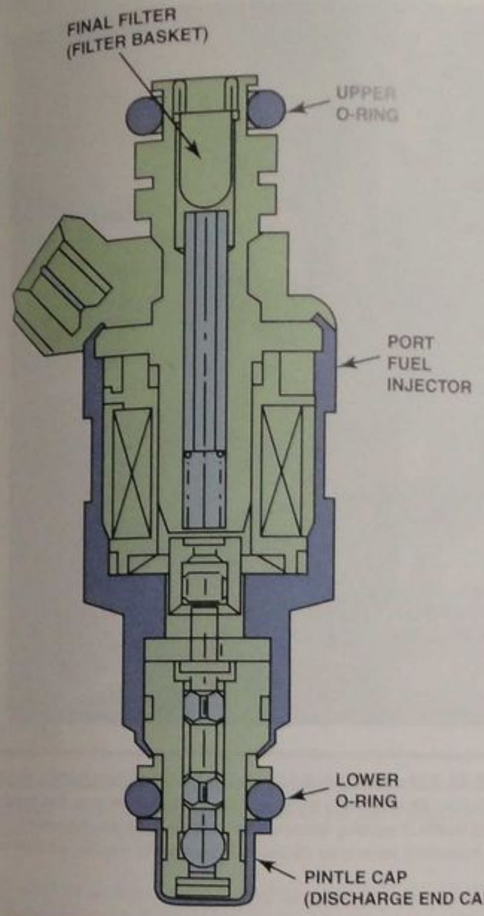


Figure 58–20 The final filter, also called a **filter basket,** is the last filter in the fuel system.

Normal Operating Pressure	(PSI)	Maximum Pump Pressure (PSI)
Low-pressure TBI units	9–13	18–20
High-pressure TBI units	25–35	50–70
Port fuel-injection systems	35–45	70–90
Central port fuel injection (GM)	55–64	90–110

In both types of systems, maximum fuel-pump pressure is about double the normal operating pressure to ensure that a continuous flow of cool fuel is being supplied to the injector(s) to help prevent vapor from forming in the fuel system. Although vapor or foaming in a fuel system can greatly affect engine operation, the cooling and lubricating flow of the fuel must be maintained to ensure the durability of injector nozzles.

To measure fuel-pump pressure, locate the Schrader valve and attach a fuel-pressure gauge. See Figure 58–22.

NOTE: Some vehicles, such as those with General Motors TBI fuel-injection systems, require a specific fuel-pressure gauge that connects to the fuel system. Always follow the manufacturers' recommendations and procedures.



(a)

(b)

Figure 58–21 (a) A funnel helps in hearing if the electric fuel pump inside the gas tank is working. (b) If the pump is not running, check the wiring and current flow before going through the process of dropping the fuel tank to remove the pump.



Figure 58–22 The Schrader valve on this General Motors 3800 V-6 is located next to the fuel-pressure regulator.

TECH TIP ✔ **The Rubber Mallet Trick**

Often a no-start condition is due to an inoperative electric fuel pump. A common trick is to tap on the bottom of the fuel tank with a rubber mallet in an attempt to jar the pump motor enough to work. Instead of pushing a vehicle into the shop, simply tap on the fuel tank and attempt to start the engine. This is not a repair, but rather a confirmation that the fuel pump does indeed require replacement.

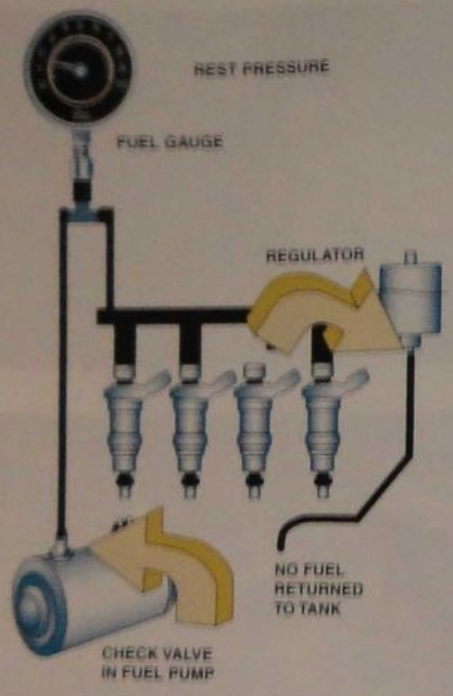


Figure 58–23 The fuel system should hold pressure if the system is leak free.

Rest Pressure Test If the fuel pressure is acceptable, then check the system for leakdown. Observe the pressure gauge after five minutes. See Figure 58–23. The pressure should be the same as the initial reading. If not, then the pressure regulator, fuel-pump check valve, or the injectors are leaking.

Dynamic Pressure Test To test the pressure dynamically, start the engine. If the pressure is vacuum referenced, then the pressure should change when the throttle is cycled. If it does not, then check the vacuum supply circuit. Remove the vacuum line from the regulator and inspect for any presence of fuel. See Figure 58–24. There should never be any fuel present on the vacuum side of the regulator diaphragm. When the engine speed is increased, the pressure reading should remain within the specifications.

Some engines do not use a vacuum-referenced regulator. The running pressure remains constant, which is typical for a mechanical returnless-type fuel system. On these systems, the pressure is higher than on return-type systems to help reduce the formation of fuel vapors in the system.

TECH TIP ✓ **The Fuel-Pressure Stethoscope Test**

When the fuel pump is energized and the engine is not running, fuel should be heard flowing back to the fuel tank at the outlet of the fuel-pressure regulator. See Figure 58–25. If fuel is heard flowing through the return line, the fuel-pump pressure is higher than the regulator pressure. If no sound of fuel is heard, either the fuel pump or the fuel-pressure regulator is at fault.

Testing Fuel-Pump Volume Fuel pressure alone is not enough for proper engine operation. See Figure 58–26. Sufficient fuel capacity (flow) should be at least 2 pints (1 liter) every 30 seconds or 1 pint in 15 seconds. Fuel flow specifications are usually expressed in gallons per minute. A typical specification would be 0.5 gallons per minute or more. Volume testing is shown in Figure 58–27.

All fuel must be filtered to prevent dirt and impurities from damaging the fuel system components and/or engine. The first filter is inside the gas tank and is usually not replaceable separately

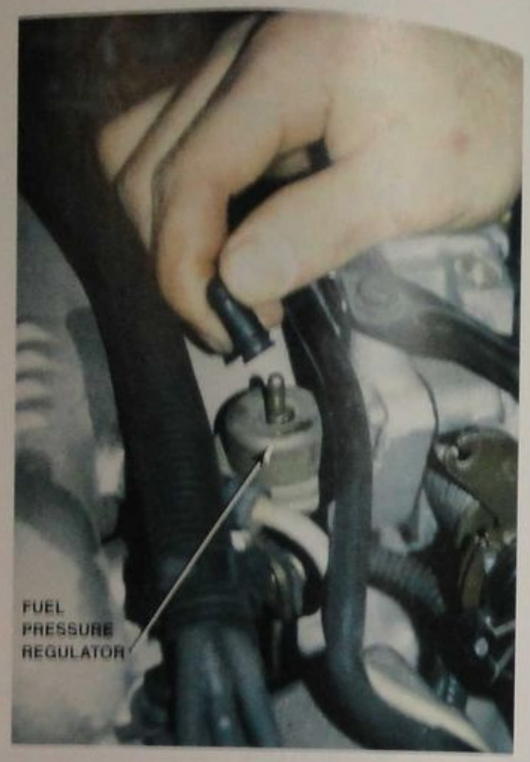


Figure 58–24 If the vacuum hose is removed from the fuel-pressure regulator when the engine is running, the fuel pressure should increase. If it does not increase, then the fuel pump is not capable of supplying adequate pressure or the fuel-pressure regulator is defective. If gasoline is visible in the vacuum hose, the regulator is leaking and should be replaced.



Figure 58–25 Fuel should be heard returning to the fuel tank at the fuel return line if the fuel pump and fuel-pressure regulator are functioning correctly.

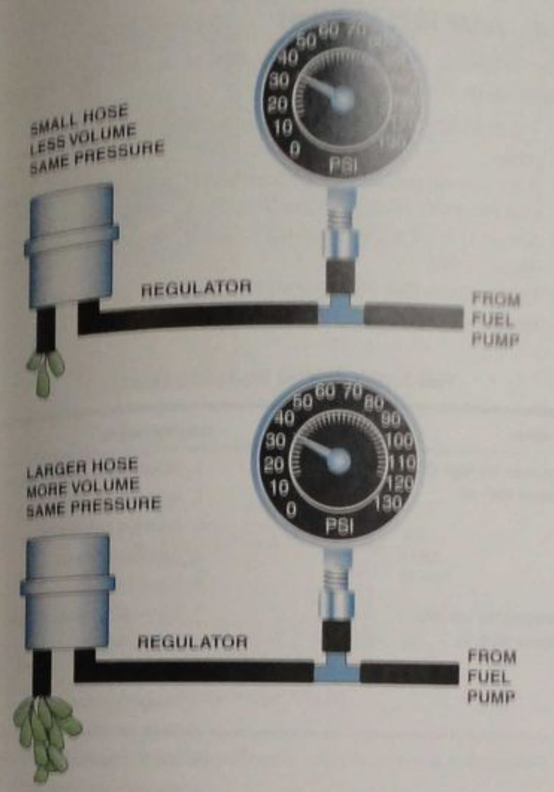


Figure 58–26 A fuel-pressure reading does not confirm that there is enough fuel volume for the engine to operate correctly.

but is attached to the fuel pump (if the pump is electric) and/or fuel gauge sending unit. The replaceable fuel filter is usually located between the fuel tank and the fuel rail or inlet to the fuel-injection system. For long engine and fuel-system life and optimum performance, the fuel filter should be replaced every year or every 15,000 miles or 24,000 kilometers (km). (Check the vehicle manufacturers' recommendations for exact time and mileage intervals.)

If the fuel filter becomes partially clogged, the following are likely to occur:

1. There will be low power at higher engine speeds. The vehicle usually will not go faster than a certain speed (engine acts as if it has a built-in speed governor).
2. The engine will cut out or miss on acceleration, especially when climbing hills or during heavy-load acceleration.

A weak or defective fuel pump can also be the cause of the symptoms just listed. If an electric fuel pump for a fuel-injected engine becomes weak, additional problems include the following:

1. The engine may be hard to start.
2. There may be a rough idle and stalling.
3. There may be erratic shifting of the automatic transmission as a result of engine missing due to lack of fuel-pump pressure and/or volume.

CAUTION: Be certain to consult the vehicle manufacturers' recommended service and testing procedures before attempting to test or replace any component of a high-pressure electronic fuel-injection system.



Figure 58–27 A fuel system tester connected in series in the fuel system so all of the fuel used flows through the meter which displays the rate of flow and the fuel pressure.

TECH TIP ✓ **Quick and Easy Fuel Volume Test**

Testing for pump volume involves using a specialized tester or a fuel-pressure gauge equipped with a hose to allow the fuel to be drawn from the system into a container with volume markings to allow for a volume measurement. This test can be hazardous because of expanding gasoline. An alternative test involves connecting a fuel-pressure gauge to the system with the following steps:

Step #1 Start the engine and observe the fuel-pressure gauge. The reading should be within factory specifications (typically between 35 PSI and 45 PSI).

Step #2 Remove the hose from the fuel-pressure regulator. The pressure should increase if the system uses a demand-type regulator.

Step #3 Rapidly accelerate the engine while watching the fuel-pressure gauge. If the fuel volume is okay, the fuel pressure should not drop more than 2 PSI. If the fuel pressure drops more than 2 PSI, replace the fuel filter and retest.

Step #4 After replacing the fuel filter, accelerate the engine and observe the pressure gauge. If the pressure drops more than 2 PSI, replace the fuel pump.

NOTE: The fuel pump could still be delivering less than the specified volume of fuel, but as long as the volume needed by the engine is met, the pressure will not drop. If, however, the vehicle is pulling a heavy load, the demand for fuel volume may exceed the capacity of the pump.

TECH TIP ✓ **Remove the Bed to Save Time?**

The electric fuel pump is easier to replace on many General Motors pickup trucks if the bed is removed. Access to the top of the fuel tank, where the access hole is located, for the removal of the fuel tank sender unit and pump is restricted by the bottom of the pickup truck bed. Rather than drop the tank, it is often much easier to use an engine hoist or a couple of other technicians to lift the bed from the frame after removing only a few fasteners. See Figure 58–28.

CAUTION: Be sure to clean around the fuel pump opening so that dirt or debris does not enter the tank when the fuel pump is removed.

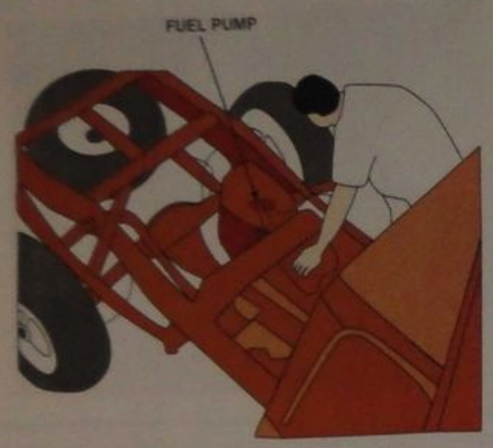


Figure 58–28 Removing the bed from a pickup truck makes gaining access to the fuel pump a lot easier.

FUEL-PUMP CURRENT DRAW TEST

Another test that can and should be performed on a fuel pump is to measure the current draw in amperes. This test is most often performed by connecting a digital multimeter set to read DC amperes and test the current draw. See Figure 58–29 for the hookup for vehicles equipped with a fuel-pump relay. Compare the reading to factory specifications. See the chart for an example of typical fuel-pump current draw readings.

Fuel-Pump Current Draw Table

Amperage Reading	Expected Value	Amperage Too High	Amperage Too Low
Throttle-Body Fuel-Injection Engines	2 to 5 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.
Port Fuel-Injection Engines	4 to 8 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.
Turbo Engines	6 to 10 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.
GM CPI Truck Engines	8 to 12 amps	• Check the fuel filter. • Check for restrictions in other fuel line areas. • Replace the fuel pump.	• Check for a high-resistance connection. • Check for a high-resistance ground fault. • Replace the fuel pump.

NOTE: Testing the current draw of an electric fuel pump may not indicate whether the pump is good. A pump that is not rotating may draw normal current.

FUEL-PUMP REPLACEMENT

The following recommendations should be followed whenever replacing an electric fuel pump:

- The fuel-pump strainer (sock) should be replaced with the new pump.
- If the original pump had a defector shield, it should always be used to prevent fuel return bubbles from blocking the inlet to the pump.
- Always check the interior of the fuel tank for evidence of contamination or dirt.
- Double-check that the replacement pump is correct for the application.

Fuel Supply-Related Diagnostic Chart

Problem	Possible Causes
Pressure too high after engine start-up.	1. Defective fuel-pressure regulator 2. Restricted fuel return line 3. Excessive system voltage 4. Restricted return line 5. Wrong fuel pump
Pressure too low after engine start-up.	1. Stuck-open pressure regulator 2. Low voltage 3. Poor ground 4. Plugged fuel filter 5. Faulty inline fuel pump 6. Faulty in-tank fuel pump 7. Partially clogged filter sock 8. Faulty hose coupling 9. Leaking fuel line 10. Wrong fuel pump 11. Leaking pulsator 12. Restricted accumulator 13. Faulty pump check valves 14. Faulty pump installation
Pressure drops off with key on/engine off.	1. Leaky pulsator 2. Leaking fuel-pump coupling hose 3. Faulty fuel pump (check valves) 4. Faulty pressure regulator 5. Leaking fuel injector 6. Leaking cold-start fuel injector
With key off, the pressure does not hold.	7. Faulty installation 8. Lines leaking

SUMMARY

1. The fuel delivery system includes the following items:
   - Fuel tank
   - Fuel pump
   - Fuel filter(s)
   - Fuel lines
2. A fuel tank is either constructed of steel with a tin plating for corrosion resistance or polyethylene plastic.
3. Fuel tank filler tubes contain an anti-siphoning device.
4. Accident and rollover protection devices include check valves and inertia switches.
5. Most fuel lines are made of nylon plastic.
6. Electric fuel-pump types include: roller cell, gerotor, and turbine.
7. Fuel filters remove particles that are 10 to 20 microns or larger in size and should be replaced regularly.

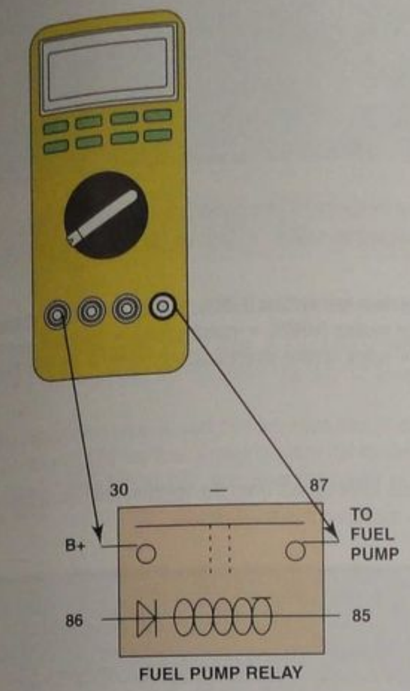


Figure 58–29 Hookup for testing fuel-pump current draw on any vehicle equipped with a fuel-pump relay.

8. Fuel pumps can be tested by checking:
   - Pressure
   - Volume
   - Specified current draw

REVIEW QUESTIONS

1. What are the two materials used to construct fuel tanks?
2. What are the three most commonly used pump designs?
3. What is the proper way to disconnect and connect plastic fuel line connections?
4. Where are the fuel filters located in the fuel system?
5. What accident and rollover devices are installed in a fuel delivery system?
6. What three methods can be used to test a fuel pump?

CHAPTER QUIZ

1. The first fuel filter in the sock inside the fuel tank normally filters particles larger than _____.
   a. 0.001 to 0.003 in.
   b. 0.010 to 0.030 in.
   c. 10 to 20 microns
   d. 70 to 100 microns

2. If it is tripped, which type of safety device will keep the electric fuel pump from operating?
   a. Rollover valve
   b. Inertia switch
   c. Anti-siphoning valve
   d. Check valve
3. Fuel lines are constructed from _____.
   a. Seamless steel tubing
   b. Nylon plastic
   c. Copper and/or aluminum tubing
   d. Both a and b are used
4. Which is not a commonly used type of fuel-pump design?
   a. Gerotor
   b. Pulsating
   c. Roller cell
   d. Turbine
5. A good fuel pump should be able to supply how much fuel per minute?
   a. ¼ pint
   b. ½ pint
   c. 1 pint
   d. 0.6 to 0.8 gallons
6. Technician A says that fuel pump modules are spring-loaded so that they can be compressed to fit into the opening. Technician B says that they are spring-loaded to allow for expansion and contraction of plastic fuel tanks. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Most fuel filters are designed to remove particles larger than _____.
   a. 10 microns
   b. 20 microns
   c. 70 microns
   d. 100 microns
8. The amperage draw of an electric fuel pump is higher than specified. All of the following are possible causes *except*:
   a. Corroded electrical connections at the pump motor
   b. Clogged fuel filter
   c. Restriction in the fuel line
   d. Defective fuel pump
9. A fuel pump is being replaced for the third time. Technician A says that the gasoline could be contaminated. Technician B says that wiring to the pump could be corroded. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A fuel filter has been accidentally installed backwards. What is the most likely result?
    a. Nothing will be noticed
    b. Reduced fuel economy
    c. Lower power at higher engine speeds and loads
    d. Fuel system pulsation noises may be heard

CHAPTER 59

Fuel-Injection Components and Operation

OBJECTIVES: After studying Chapter 59, the reader will be able to: Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Describe how a port fuel-injection system works. • Discuss the purpose and function of the fuel-pressure regulator. • List the types of fuel-injection systems.

KEY TERMS: demand delivery system (DDS) • electronic air control (EAC) • electronic returnless fuel system (ERFS) • flare • fuel rail • gang fired • gasoline direct injection (GDI) • idle speed control (ISC) motor • mechanical returnless fuel system (MRFS) • nonchecking • port fuel-injection • pressure control valve (PCV) • pressure vent valve (PVV) • sequential fuel injection (SFI) • spark ignition direct injection (SIDI) • throttle-body injection (TBI)

ELECTRONIC FUEL-INJECTION OPERATION

Electronic fuel-injection systems use the computer to control the operation of fuel injectors and other functions based on information sent to the computer from the various sensors. Most electronic fuel-injection systems share the following:

1. Electric fuel pump (usually located inside the fuel tank)
2. Fuel-pump relay (usually controlled by the computer)
3. Fuel-pressure regulator (mechanically operated spring-loaded rubber diaphragm maintains proper fuel pressure)
4. Fuel-injector nozzle or nozzles

See Figure 59–1. Most electronic fuel-injection systems use the computer to control these aspects of their operation:

1. **Pulsing the fuel injectors on and off.** The longer the injectors are held open, the greater the amount of fuel injected into the cylinder.
2. **Operating the fuel pump relay circuit.** The computer usually controls the operation of the electric fuel pump located inside (or near) the fuel tank. The computer uses signals from the ignition switch and RPM signals from the ignition module or system to energize the fuel-pump relay circuit.

NOTE: This is a safety feature, because if the engine stalls and the tachometer (engine speed) signal is lost, the computer will shut off (de-energize) the fuel-pump relay and stop the fuel pump.

Computer-controlled fuel-injection systems are normally reliable systems if the proper service procedures are followed. Fuel-injection systems use the gasoline flowing through the injectors to lubricate and cool the injector electrical windings and pintle valves.

NOTE: The fuel does not actually make contact with the electrical windings because the injectors have O-rings at the top and bottom of the winding spool to keep fuel out.

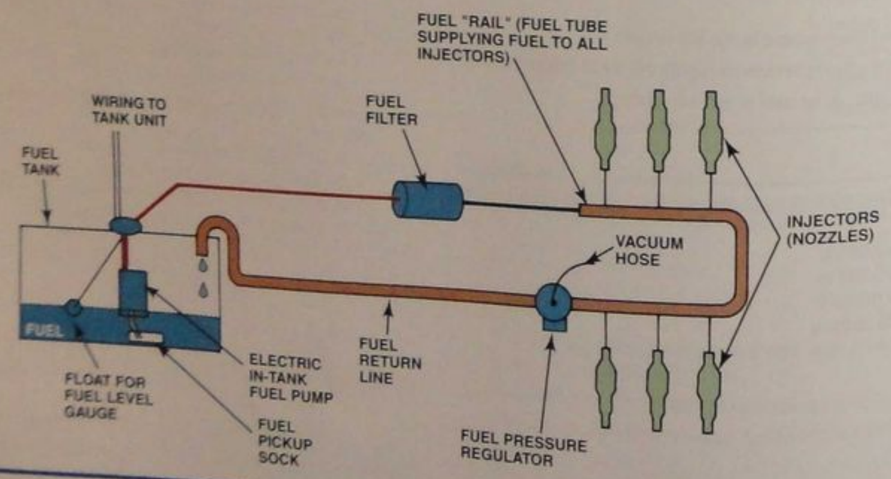


Figure 59–1 Typical port fuel-injection system, indicating the location of various components. Notice that the fuel-pressure regulator is located on the fuel return side of the system. The computer does not control fuel pressure. But does control the operation of the electric fuel pump (on most systems) and the pulsing on and off of the injectors.

TECH TIP ✓ **"Two Must-Do's"**

For long service life of the fuel system always do the following:

1. Avoid operating the vehicle on a near-empty tank of fuel. The water or alcohol becomes more concentrated when the fuel level is low. Dirt that settles near the bottom of the fuel tank can be drawn through the fuel system and cause damage to the pump and injector nozzles.
2. Replace the fuel filter at regular service intervals.

There are two types of electronic fuel-injection systems:

- **Throttle-body-injection (TBI)** type. A TBI system delivers fuel from a nozzle(s) into the air above the throttle plate. See Figure 59–2.
- **Port fuel-injection**-type. A port fuel-injection design uses a nozzle for each cylinder and the fuel is squirted into the intake manifold about 2 to 3 inches (70 to 100 mm) from the intake valve. See Figure 59–3.

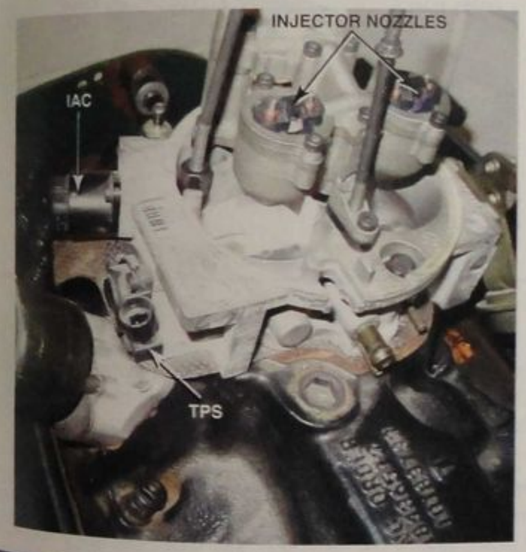


Figure 59–2 A dual-nozzle TBI unit on a Chevrolet 4.3-L V-6 engine.

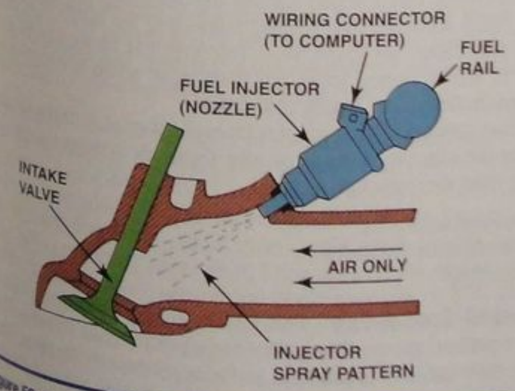


Figure 59–3 A typical port fuel-injection system squirts fuel into the low pressure (vacuum) of the intake manifold, about 3 in. (70 to 100 mm) from the intake valve.

SPEED-DENSITY FUEL-INJECTION SYSTEMS

Fuel-injection computer systems require a method for measuring the amount of air the engine is breathing in, in order to match the correct fuel delivery. There are two basic methods used:

1. Speed density
2. Mass airflow

The speed-density method does not require an air quantity sensor, but rather calculates the amount of fuel required by the engine. The computer uses information from sensors such as the MAP and TP to calculate the needed amount of fuel.

- **MAP sensor.** The value of the intake (inlet) manifold pressure (vacuum) is a direct indication of engine load.
- **TP sensor.** The position of the throttle plate and its rate of change are used as part of the equation to calculate the proper amount of fuel to inject.
- **Temperature sensors.** Both engine coolant temperature (ECT) and intake air temperature (IAT) are used to calculate the density of the air and the need of the engine for fuel. A cold engine (low-coolant temperature) requires a richer air–fuel mixture than a warm engine.

On speed-density systems, the computer calculates the amount of air in each cylinder by using manifold pressure and engine rpm. The amount of air in each cylinder is the major factor in determining the amount of fuel needed. Other sensors provide information to modify the fuel requirements. The formula used to determine the injector pulse width (PW) in milliseconds (ms) is:

Injector pulse width = MAP/BARO × RPM/maximum rpm

The formula is modified by values from other sensors, including:

- Throttle position (TP)
- Engine coolant temperature (ECT)
- Intake air temperature (IAT)
- Oxygen sensor voltage (O2S)
- Adaptive memory

A fuel injector delivers atomized fuel into the airstream where it is instantly vaporized. All throttle-body (TB) fuel-injection systems and many multipoint (port) injection systems use the speed-density method of fuel calculation.

MASS AIRFLOW FUEL-INJECTION SYSTEMS

The formula used by fuel-injection systems that use a mass airflow (MAF) sensor to calculate the injection base pulse width is:

Injector pulse width = airflow/rpm

The formula is modified by other sensor values such as:

- Throttle position
- Engine coolant temperature
- Barometric pressure
- Adaptive memory

NOTE: Many four-cylinder engines do not use a MAF sensor because, due to the time interval between intake events, some reverse airflow can occur in the intake manifold. The MAF sensor would "read" this flow of air as being additional air entering the engine, giving the PCM incorrect airflow information. Therefore, most four-cylinder engines use the speed-density method of fuel control.

FREQUENTLY ASKED QUESTION ???

How Do the Sensors Affect the Pulse Width?

The base pulse width of a fuel-injection system is primarily determined by the value of the MAF or MAP sensor and engine speed (RPM). However, the PCM relies on the input from many other sensors to modify the base pulse width as needed. For example,

- **TP Sensor.** This sensor causes the PCM to command up to 500% (5 times) the base pulse width if the accelerator pedal is depressed rapidly to the floor. It can also reduce the pulse width by about 70% if the throttle is rapidly closed.
- **ECT.** The value of this sensor determines the temperature of the engine coolant, helps determine the base pulse width, and can account for up to 60% of the determining factors.
- **BARO.** The BARO sensor compensates for altitude and adds up to about 10% under high-pressure conditions and subtracts as much as 50% from the base pulse width at high altitudes.
- **IAT.** The intake air temperature is used to modify the base pulse width based on the temperature of the air entering the engine. It is usually capable of adding as much as 20% if very cold air is entering the engine or reduce the pulse width by up to 20% if very hot air is entering the engine.
- **O2S.** This is one of the main modifiers to the base pulse width and can add or subtract up to about 20% to 25% or more, depending on the oxygen sensor activity.

THROTTLE-BODY INJECTION

The computer controls injector pulses in one of two ways:

- Synchronized
- Nonsynchronized

If the system uses a synchronized mode, the injector pulses once for each distributor reference pulse. In some vehicles, when dual injectors are used in a synchronized system, the injectors pulse alternately. In a nonsynchronized system, the injectors are pulsed once during a given period (which varies according to calibration) completely independent of distributor reference pulses.

The injector always opens the same distance, and the fuel pressure is maintained at a controlled value by the pressure regulator. The regulators used on throttle-body injection systems are not connected to a vacuum like many port fuel-injection systems. The strength of the spring inside the regulator determines at what pressure the valve is unseated, sending the fuel back to the tank and lowering the pressure. See Figure 59–4. The amount of fuel delivered by the injector depends on the amount of time (on-time) that the nozzle is open. This is the injector pulse width—the on-time in milliseconds that the nozzle is open.

The PCM commands a variety of pulse widths to supply the amount of fuel that an engine needs at any specific moment.

- A long pulse width delivers more fuel.
- A short pulse width delivers less fuel.

PORT FUEL INJECTION

The advantages of port fuel-injection design also are related to characteristics of intake manifolds:

- Fuel distribution is equal to all cylinders because each cylinder has its own injector. See Figure 59–5.
- The fuel is injected almost directly into the combustion chamber, so there is no chance for it to condense on the walls of a cold intake manifold.

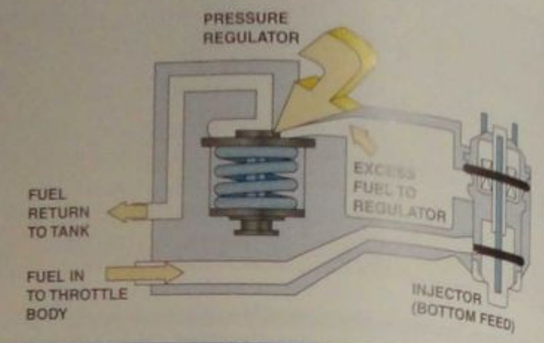


Figure 59–4 The tension of the spring in the fuel-pressure regulator determines the operating pressure on a throttle-body fuel-injection unit.

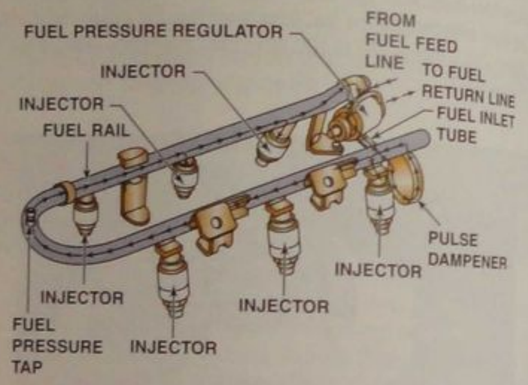


Figure 59–5 The injectors receive fuel and are supported by the fuel rail.

- Because the manifold does not have to carry fuel to properly position a TBI unit, it can be shaped and sized to tune the intake air flow to achieve specific engine performance characteristics.

An EFI injector is simply a specialized solenoid. See Figure 59–6. It has an armature winding to create a magnetic field, and a needle (pintle), a disc, or a ball valve. A spring holds the needle, disc, or ball closed against the valve seat, and when energized, the armature winding pulls open the valve when it receives a current pulse from the power train control module (PCM). When the solenoid is energized, it unseats the valve to inject fuel.

Electronic fuel-injection systems use a solenoid-operated injector to spray atomized fuel in timed pulses into the manifold or near the intake valve. See Figure 59–7. Injectors may be sequenced and fired in one of several ways, but their pulse width is determined and controlled by the engine computer.

Port systems have an injector for each cylinder, but they do not all fire the injectors in the same way. Domestic systems use one of three ways to trigger the injectors:

- Grouped double-fire
- Simultaneous double-fire
- Sequential

Grouped Double-Fire This system divides the injectors into two equalized groups. The groups fire alternately; each group fires once each crankshaft revolution, or twice per four-stroke cycle. The fuel injected remains near the intake valve and enters the engine when the valve opens. This method of pulsing injectors in groups is sometimes called **gang fired.**

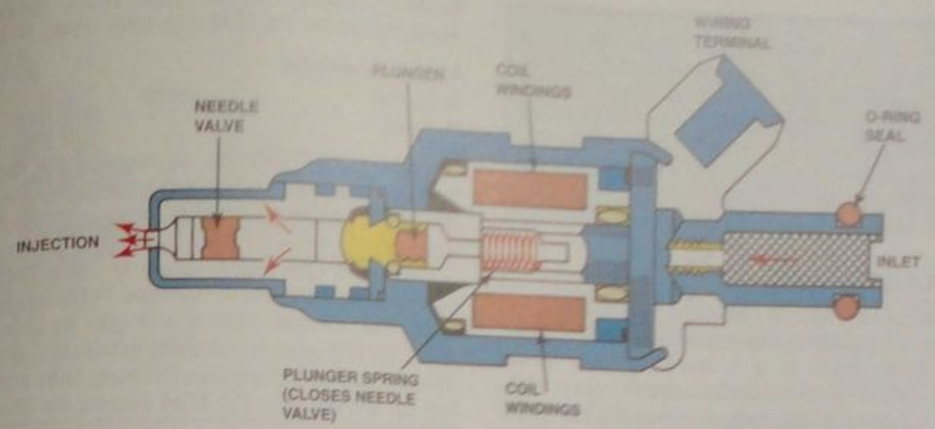


Figure 59–6 Cross-section of a typical port fuel-injection nozzle assembly. These injectors are serviced as an assembly only; no part replacement or service is possible except for replacement of external O-ring seals.

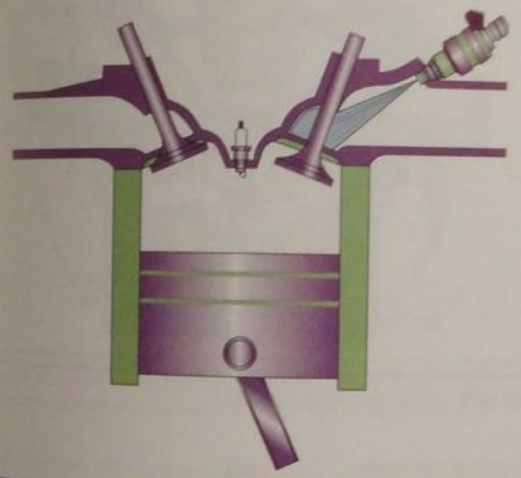


Figure 59–7 Port fuel injectors spray atomized fuel into the intake manifold about 3 inches (75 mm) from the intake valve.

Simultaneous Double-Fire This design fires all of the injectors at the same time once every engine revolution: two pulses per four-stroke cycle. Many port fuel-injection systems on four-cylinder engines use this pattern of injector firing. It is easier for engineers to program this system and it can make relatively quick adjustments in the air–fuel ratio, but it still requires the intake charge to wait in the manifold for varying lengths of time.

Sequential Sequential firing of the injectors according to engine firing order is the most accurate and desirable method of regulating port fuel injection. However, it is also the most complex and expensive to design and manufacture. In this system, the injectors are timed and pulsed individually, much like the spark plugs are sequentially operated in firing order of the engine. This system is often called **sequential fuel injection** or **SFI.** Each cylinder receives one charge every two crankshaft revolutions, just before the intake valve opens. This means that the mixture is never static in the intake manifold and mixture adjustments can be made almost instantaneously between the firing of one injector and the next. A camshaft position sensor (CMP) signal or a special distributor reference pulse informs the PCM when the



Figure 59–8 A port fuel-injected engine that is equipped with long, tuned intake manifold runners.

No. 1 cylinder is on its compression stroke. If the sensor fails or the reference pulse is interrupted, some injection systems shut down, while others revert to pulsing the injectors simultaneously.

FREQUENTLY ASKED QUESTION ???

How Can It Be Determined If the Injection System Is Sequential?

Look at the color of the wires at the injectors. If a sequentially fired injector is used, then one wire color (the pulse wire) will be a different color for each injector. The other wire is usually the same color because all injectors receive voltage from some source. If a group- or batch-fired injection system is being used, then the wire colors will be the same for the injectors that are group fired. For example, a V-6 group-fired engine will have three injectors with a pink and blue wire (power and pulse) and the other three will have pink and green wires.

The major advantage of using port injection instead of the simpler throttle-body injection is that the intake manifolds on port fuel-injected engines only contain air, not a mixture of air and fuel. This allows the engine design engineer the opportunity to design long, "tuned" intake- manifold runners that help the engine produce increased torque at low engine speeds. See Figure 59–8.

NOTE: Some port fuel-injection systems used on engines with four or more valves per cylinder may use two injectors per cylinder. One injector is used all the time, and the second injector is operated by the computer when high engine speed and high-load conditions are detected by the computer. Typically, the second injector injects fuel into the high-speed intake ports of the manifold. This system permits good low-speed power and throttle response as well as superior high-speed power.

DIRECT FUEL INJECTION

Several vehicle manufactures such as Mitsubishi, Toyota/Lexus, and General Motors are using **gasoline direct injection (GDI)** systems, which General Motors refers to as a **Spark Ignition Direct Injection (SIDI)** system. A direct-injection system sprays high-pressure fuel, up to 2,200 PSI, into the combustion chamber as the piston approaches the top of the compression stroke. With the combination of high-pressure swirl injectors and modified combustion chamber, almost instantaneous vaporization occurs. This combined with a higher compression ratio allows a direct-injected engine to operate using a leaner-than-normal air–fuel ratio, which results in improved fuel economy with higher power output and reduced exhaust emissions. See Figure 59–9.

Direct-Injection Fuel Delivery System The fuel pump in the fuel tank supplies fuel to the high-pressure fuel pump at a pressure of approximately 60 PSI. The engine control module (ECM) controls the output of the high-pressure pump, which has a range between 500 PSI (3,440 kPa) and 2,200 PSI (15,200 kPa) during engine operation. The high-pressure fuel pump mounts on the cylinder head and is driven by a camshaft. See Figure 59–10. The high-pressure fuel pump connects to the pump in the fuel tank through the low-pressure fuel line. The pump consists of a single-barrel piston pump which is driven by the engine camshaft. The pump plunger rides on a three-lobed cam on the camshaft. See Figure 59–11. An electric pressure-control valve is installed between the pump inlet and outlet valves. The fuel rail pressure sensor connects to the ECM with three wires:

- Five-volt reference
- Ground
- Signal

The sensor signal provides an analog signal to the ECM that varies in voltage as fuel rail pressure changes. Low pressure results in a low-voltage signal and high pressure results in a high-voltage signal.

The ECM uses internal drivers to control the power feed and ground for the pressure-control valve. When both ECM drivers are deactivated, the inlet valve is held open by spring pressure. This causes the high-pressure fuel pump to default to low-pressure mode. The fuel from the high-pressure fuel pump flows through a line to the fuel rail and injectors. The ECM controls the timing and duration

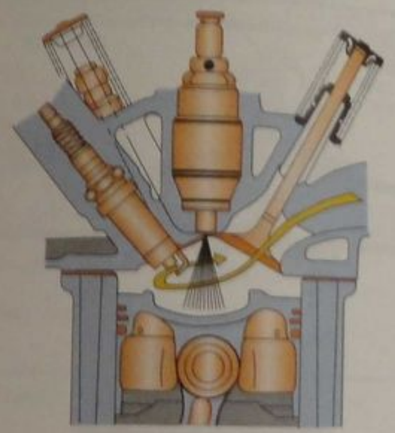


Figure 59–9 A gasoline direct-injection system.

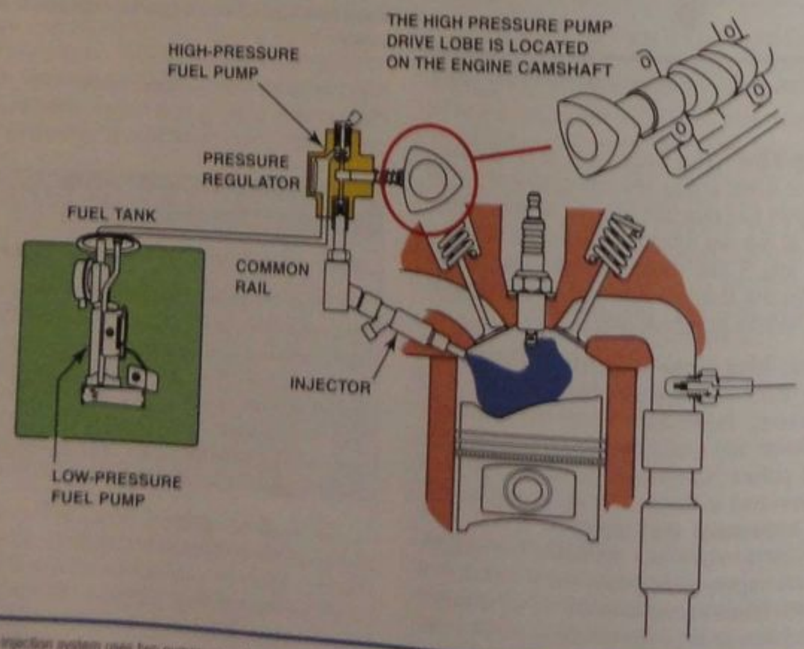


Figure 59–10 A typical direct-injection system uses two pumps—one low-pressure electric pump in the fuel tank and the other a high-pressure pump driven by the camshaft.

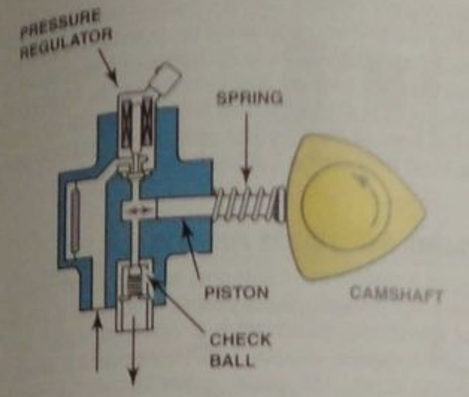


Figure 59–11 A typical camshaft-driven high-pressure pump used to increase fuel pressure to 2,000 PSI or higher.

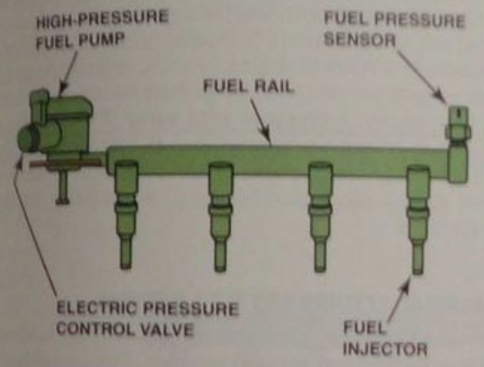


Figure 59–12 A gasoline direct-injection (GDI) assembly showing the high-pressure pump plus the fuel rail and injectors which inject fuel directly into the combustion chamber.

of fuel injection, which is introduced directly into the combustion chamber with either single or dual injection. As the piston approaches top dead center (TDC), the air–fuel mixture is ignited by the spark plug.

Direct-Injection Fuel Injectors Each high-pressure fuel injector assembly is an electrically magnetic injector mounted in the cylinder head. In the General Motors system, the ECM controls each fuel injector with 65 volts, which is created by a boost capacitor in the ECM. During the 65-volt boost phase, the capacitor is discharged through an injector, allowing for initial injector opening. The injector is then held open with 12 volts. The high-pressure fuel injector has six precision-machined holes that generate a cone-shaped oval spray pattern. The injector also has an extended tip to allow for cooling from a water jacket in the cylinder head. See Figure 59–12.

FUEL-PRESSURE REGULATOR

The pressure regulator and fuel pump work together to maintain the required pressure drop at the injector tips. The fuel-pressure regulator typically consists of a spring-loaded, diaphragm-operated valve in a metal housing.

Fuel-pressure regulators on fuel-return-type fuel-injection systems are installed on the return (downstream) side of the injectors at the end of the fuel rail, or are built into or mounted upon the throttle-body housing. Downstream regulation minimizes fuel-pressure

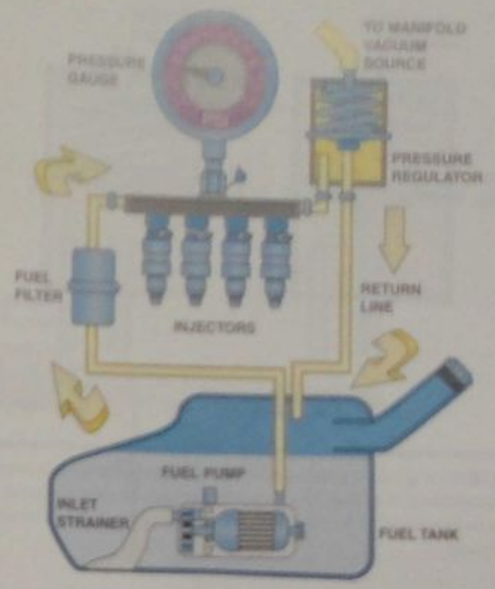


Figure 59–13 A typical port fuel-injected system showing a vacuum-controlled fuel-pressure regulator.

pulsations caused by pressure drop across the injectors as the nozzles open. It also ensures positive fuel pressure at the injectors at all times and holds residual pressure in the lines when the engine is off. On mechanical returnless systems, the regulator is located back at the tank with the fuel filter.

In order for excess fuel (about 80% to 90% of the fuel delivered) to return to the tank, fuel pressure must overcome spring pressure on the spring-loaded diaphragm to uncover the return line to the tank. This happens when system pressure exceeds operating requirements. With TBI, the regulator is close to the injector tip, so the regulator senses essentially the same air pressure as the injector.

The pressure regulator used in a port fuel-injection system has an intake manifold vacuum line connection on the regulator vacuum chamber. This allows fuel pressure to be modulated by a combination of spring pressure and manifold vacuum acting on the diaphragm. See Figures 59–13 and 59–14.

In both TBI and port fuel-injection systems, the regulator shuts off the return line when the fuel pump is not running. This maintains pressure at the injectors for easy restarting after hot soak as well as reducing vapor lock.

NOTE: Some General Motors throttle-body units do not hold pressure and are called **nonchecking**.

Port fuel-injection systems generally operate with pressures at the injector of about 30 to 55 PSI (207 to 379 kPa), while TBI systems work with injector pressures of about 10 to 20 PSI (69 to 138 kPa). The difference in system pressures results from the difference in how the systems operate. Since injectors in a TBI system inject the fuel into the airflow at the manifold inlet (above the throttle), there is more time for atomization in the manifold before the air–fuel charge reaches the intake valve. This allows TBI injectors to work at lower pressures than injectors used in a port system.

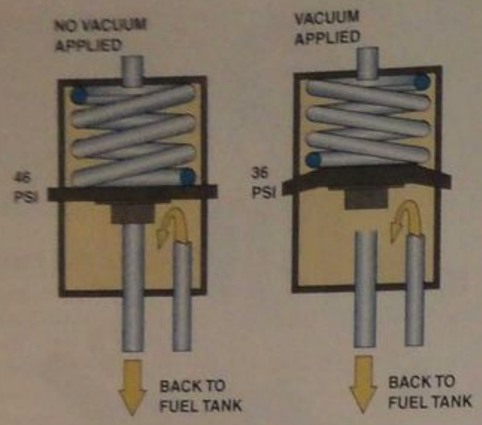


Figure 59–14 A typical fuel-pressure regulator that has a spring that exerts 46 pounds of force against the fuel. If 20 inches of vacuum are applied above the spring, the vacuum reduces the force exerted by the spring on the fuel, allowing the fuel to return to the tank at a lower pressure.

TECH TIP ✓ **Don't Forget the Regulator**

Some fuel-pressure regulators contain a 10-micron filter. If this filter becomes clogged, a lack of fuel flow would result. See Figure 59–15.



Figure 59–15 A lack of fuel flow could be due to a restricted fuel-pressure regulator. Notice the fine screen filter. If this filter were to become clogged, higher than normal fuel pressure would occur.

VACUUM-BIASED FUEL-PRESSURE REGULATOR

The primary reason why many port fuel-injected systems use a vacuum-controlled fuel-pressure regulator is to ensure that there is a constant pressure drop across the injectors. In a throttle-body fuel-injection system, the injector squirts into the atmospheric pressure regardless of the load on the engine. In a port fuel-injected engine, however, the pressure inside the intake manifold changes as the load on the engine increases.

Engine Operating Condition	Intake Manifold Vacuum	Fuel Pressure
Idle or cruise	High	Lower
Heavy load	Low	Higher

The computer can best calculate injector pulse width based on all sensors if the pressure drop across the injector is the same under all operating conditions. A vacuum-controlled fuel-pressure regulator allows the equal pressure drop by reducing the force exerted by the regulator spring at high vacuum (low-load condition), yet allowing the full force of the regulator spring to be exerted when the vacuum is low (high-engine-load condition).

ELECTRONIC RETURNLESS FUEL SYSTEM

This system is unique because it does not use a mechanical valve to regulate rail pressure. Fuel pressure at the rail is sensed by a pressure transducer, which sends a low-level signal to a controller. The controller contains logic to calculate a signal to the pump power driver. The power driver contains a high-current transistor that controls the pump speed using pulse width modulation (PWM). This system is called the **electronic returnless fuel system (ERFS).** See Figure 59–16. This transducer can be differentially referenced to manifold pressure for closed-loop feedback, correcting and maintaining the output of the pump to a desired rail setting. This system is capable of continuously varying rail pressure as a result of engine vacuum, engine fuel demand, and fuel temperature (as sensed by an external temperature transducer, if necessary). A **pressure vent valve (PVV)** is employed at the tank to relieve overpressure due to thermal expansion of fuel. In addition, a supply-side bleed, by means of an in-tank reservoir using a supply-side jet pump, is necessary for proper pump operation.

MECHANICAL RETURNLESS FUEL SYSTEM

The first production returnless systems employed the **mechanical returnless fuel system (MRFS)** approach. This system has a bypass regulator to control rail pressure that is located in close proximity to the fuel tank. Fuel is sent by the in-tank pump to a chassis-mounted inline filter with excess fuel returning to the tank through a short return line. See Figure 59–17. The inline filter may be mounted directly to the tank, thereby eliminating the shortened return line. Supply pressure is regulated on the downstream side of the inline filter to accommodate changing restrictions throughout the filter's service life. This system is limited to constant rail pressure (*CRP) system calibrations, whereas with ERFS, the pressure transducer can be referenced to atmospheric pressure for CRP systems or differentially referenced to intake manifold pressure for constant differential injector pressure (**CIP) systems.

NOTE: *CRP is referenced to atmospheric pressure, has lower operating pressure, and is desirable for calibrations using speed/air density sensing. **CIP is referenced to manifold pressure, varies rail pressure, and is desirable in engines that use mass airflow sensing.

DEMAND DELIVERY SYSTEM (DDS)

Given the experience with both ERFS and MRFS, a need was recognized to develop new returnless technologies that could combine the speed control and constant injector pressure attributes of ERFS together with the cost savings, simplicity, and reliability of MRFS. This new technology also needed to address pulsation dampening/hammering and fuel transient response. Therefore, the **demand delivery system (DDS)** technology was developed. A different form of demand pressure regulator has been applied to

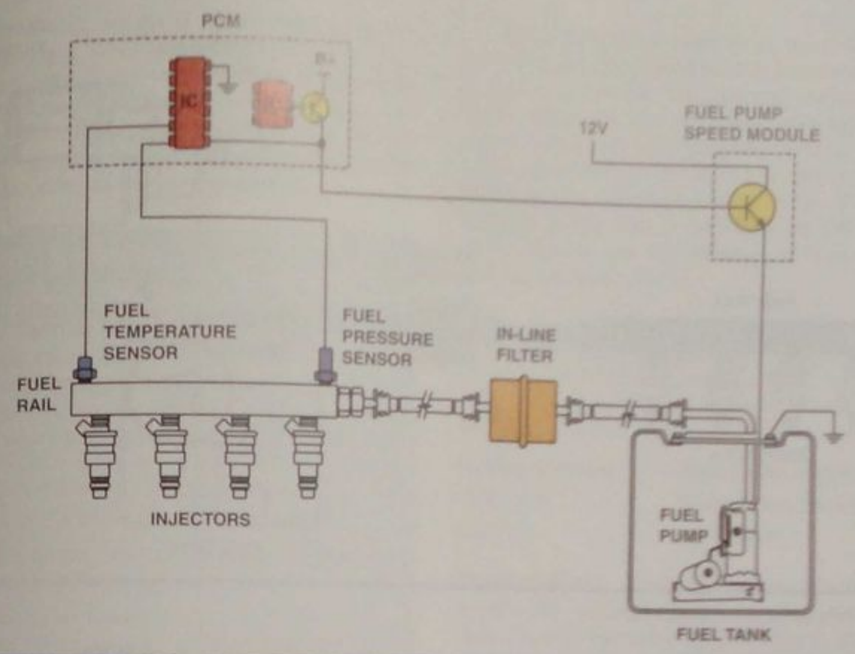


Figure 59–16 The fuel-pressure sensor and fuel-temperature sensor are often constructed together in one assembly to help give the PCM the needed data to control the fuel-pump speed.

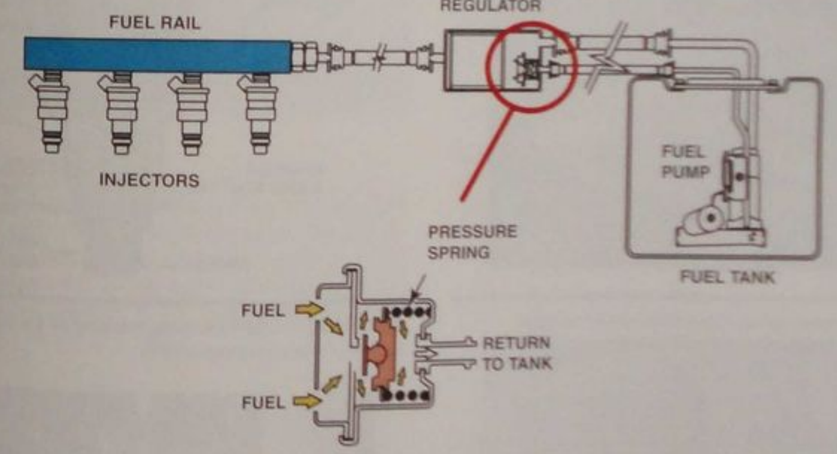


Figure 59–17 A mechanical returnless fuel system. The bypass regulator in the fuel tank controls fuel line pressure.

the fuel rail. It mounts at the head or port entry and regulates the pressure downstream at the injectors by admitting the precise quantity of fuel into the rail as consumed by the engine. Having demand regulation at the rail improves pressure response to flow transients and provides rail pulsation dampening. A fuel pump and a low-cost, high-performance bypass regulator are used within the appropriate fuel sender. See Figure 59–18. They supply a pressure somewhat higher than the required rail set pressure to accommodate dynamic line and filter pressure losses. Electronic pump speed control is accomplished using a smart regulator as an integral flow sensor. A **pressure control valve (PCV)** may also be used and can readily reconfigure an existing design fuel sender into a return-less sender.

FREQUENTLY ASKED QUESTION ???

Why Are Some Fuel Rails Rectangular Shaped?

A port fuel-injection system uses a pipe or tubes to deliver fuel from the fuel line to the intended fuel injectors. This pipe or tube is called the **fuel rail.** Some vehicle manufacturers construct the fuel rail in a rectangular cross-section. See Figure 59–19. The sides of the fuel rail are able to move in and out slightly, thereby acting as a fuel pulsator evening out the pressure pulses created by the opening and closing of the injectors to reduce underhood noise. A round cross-section fuel rail is not able to deform and, as a result, some manufacturers have had to use a separate dampener.

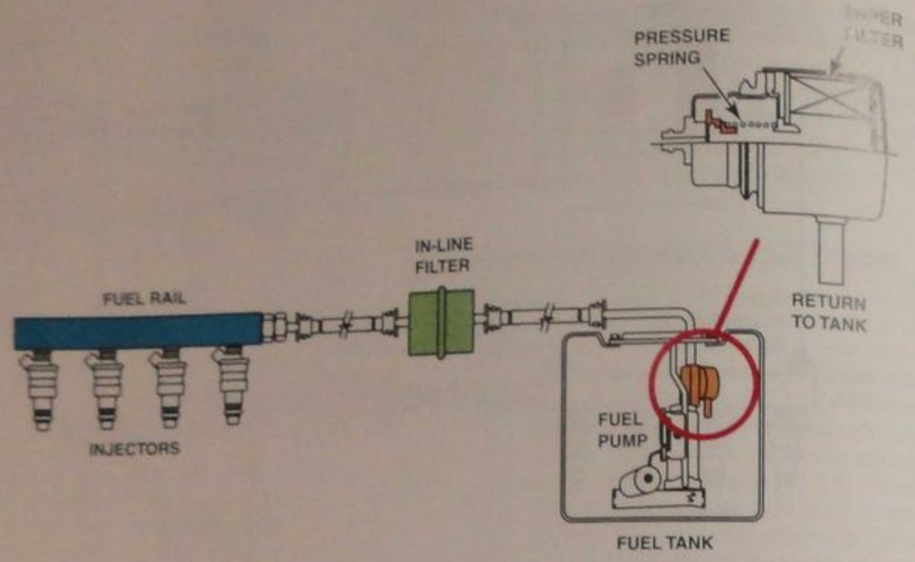


Figure 59–18 A demand delivery system uses an intake regulator.



Figure 59–19 A rectangular-shaped fuel rail is used to help dampen fuel system pulsations and noise caused by the injectors opening and closing.

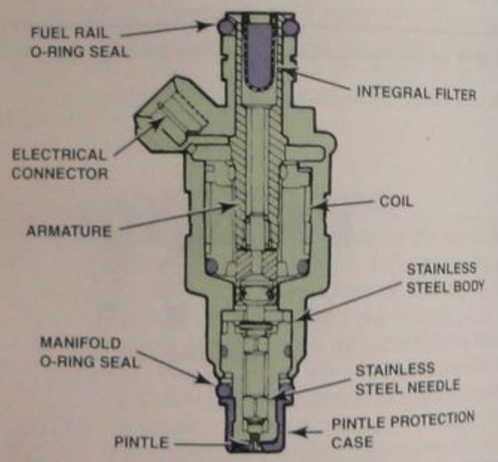


Figure 59–20 A multiport fuel injector. Notice that the fuel flows straight through and does not come in contact with the coil windings.

FUEL INJECTORS

EFI systems use solenoid-operated injectors. See Figure 59–20. This electromagnetic device contains an armature and a spring-loaded needle valve or ball valve assembly. When the computer energizes the solenoid, voltage is applied to the solenoid coil until the current reaches a specified level. This permits a quick pull-in of the armature during turn-on. The armature is pulled off of its seat against spring force, allowing fuel to flow through the inlet filter screen to the spray nozzle, where it is sprayed in a pattern that varies with application. See Figure 59–21. The injector opens the same amount each time it is energized, so the amount of fuel injected depends on the length of time the injector remains open. By angling the director hole plates, the injector sprays fuel more directly at the intake valves, which further atomizes and vaporizes the fuel before it enters the combustion chamber. PFI injectors typically are a top-feed design in which fuel enters the top of the injector and passes through its entire length to keep it cool before being injected.



Figure 59–21 Each of the eight injectors shown are producing a correct spray pattern for the applications. While all throttle-body injectors spray a conical pattern, most port fuel injections do not.

Ford introduced two basic designs of deposit-resistant injectors on some engines. The design, manufactured by Bosch, uses a four-hole director/metering plate similar to that used on the Rochester Multec injectors. The design manufactured by Nippondenso uses an internal upstream orifice in the adjusting tube. It also has a redesigned pintle/seat containing a wider tip opening that tolerates deposit buildup without affecting injector performance.

FREQUENTLY ASKED QUESTION ???

How Can the Proper Injection Size Be Determined?

Most people want to increase the output of fuel to increase engine performance. Injector sizing can sometimes be a challenge, especially if the size of injector is not known. In most cases, manufacturers publish the rating of injectors, in pounds of fuel per hour (lb/hr). The rate is figured with the injector held open at 3 bars (43.5 PSI). An important consideration is that larger flow injectors have a higher minimum flow rating. Here is a formula to calculate injector sizing when changing the mechanical characteristics of an engine.

Flow rate = hp × BSFC/# of cylinders × maximum duty cycle (% of on-time of the injectors)

- **hp** is the projected horsepower. Be realistic!
- **BSFC** is brake-specific fuel consumption in pounds per horsepower-hour. Calculated values are used for this, 0.4 to 0.8 lb. In most cases, start on the low side for naturally aspirated engines and the high side for engines with forced induction.
- **# of cylinders** is actually the number of injectors being used.
- **Maximum duty cycle** is considered at 0.8 (80%). Above this, the injector may overheat, lose consistency, or not work at all.

For example:

5.7 liter V-8 = 240 hp × 0.65/8 cylinders × 8 = 24.37 lb/hr injectors required

CENTRAL PORT INJECTION

A cross between port fuel injection and throttle-body injection, CPI was introduced in the early 1990s by General Motors. The CPI assembly consists of a single fuel injector, a pressure regulator, and six poppet nozzle assemblies with nozzle tubes. See Figure 59–22. The central sequential fuel injection (CSFI) system has six injectors in place of just one used on the CPI unit.

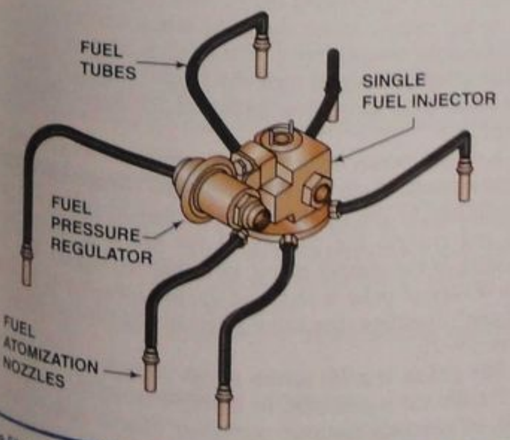


Figure 59–22 A central port fuel-injection system.

When the injector is energized, its armature lifts off of the six fuel tube seats and pressurized fuel flows through the nozzle tubes to each poppet nozzle. The increased pressure causes each poppet nozzle ball to also lift from its seat, allowing fuel to flow from the nozzle. This hybrid injection system combines the single injector of a TBI system with the equalized fuel distribution of a PFI system. It eliminates the individual fuel rail while allowing more efficient manifold tuning than is otherwise possible with a TBI system. Newer versions use six individual solenoids to fire one for each cylinder. See Figure 59–23.

FUEL-INJECTION MODES OF OPERATION

All fuel-injection systems are designed to supply the correct amount of fuel under a wide range of engine operating conditions. These modes of operation include:

Starting (cranking)	Acceleration enrichment
Clear flood	Deceleration enleanment
Idle (run)	Fuel shutoff

Starting Mode When the ignition is turned to the start (on) position, the engine cranks and the PCM energizes the fuel pump relay. The PCM also pulses the injectors on, basing the pulse width on engine speed and engine coolant temperature. The colder the engine is, the greater the pulse width. Cranking mode air–fuel ratio varies from about 1.5:1 at −40°F (−40°C) to 14.7:1 at 200°F (93°C).

Clear Flood Mode If the engine becomes flooded with too much fuel, the driver can depress the accelerator pedal to greater than 80% to enter the clear flood mode. When the PCM detects that the engine speed is low (usually below 600 RPM) and the throttle-position (TP) sensor voltage is high (WOT), the injector pulse width is greatly reduced or even shut off entirely, depending on the vehicle.

Open-Loop Mode Open-loop operation occurs during warm-up before the oxygen sensor can supply accurate information to the PCM. The PCM determines injector pulse width based on values from the MAF, MAP, TP, ECT, and IAT sensors.



Figure 59–23 A factory replacement unit for a CSFI unit that has individual injectors at the ends that go into the intake manifold instead of poppet valves.

Closed-Loop Mode Closed-loop operation is used to modify the base injector pulse width as determined by feedback from the oxygen sensor to achieve proper fuel control.

Acceleration Enrichment Mode During acceleration, the throttle-position (TP) voltage increases, indicating that a richer air–fuel mixture is required. The PCM then supplies a longer injector pulse width and may even supply extra pulses to supply the needed fuel for acceleration.

Deceleration Enleanment Mode When the engine decelerates, a leaner air–fuel mixture is required to help reduce emissions and to prevent deceleration backfire. If the deceleration is rapid, the injector may be shut off entirely for a short time and then pulsed on enough to keep the engine running.

Fuel Shutoff Mode Besides shutting off fuel entirely during periods of rapid deceleration, PCM also shuts off the injector when the ignition is turned off to prevent the engine from continuing to run.

FREQUENTLY ASKED QUESTION ???

What Is Battery Voltage Correction?

Battery voltage correction is a program built into the PCM that causes the injector pulse width to increase if there is a drop in electrical system voltage. Lower battery voltage would cause the fuel injectors to open slower than normal and the fuel pump to run slower. Both of these conditions can cause the engine to run leaner than normal if the battery voltage is low. Because a lean air–fuel mixture can cause the engine to overheat, the PCM compensates for the lower voltage by adding a percentage to the injector pulse width. This richer condition will help prevent serious engine damage. The idle speed is also increased to turn the generator (alternator) faster if low battery voltage is detected.

IDLE CONTROL

Port fuel-injection systems generally use an auxiliary air bypass. See Figure 59–24. This air bypass or regulator provides needed additional airflow, and thus more fuel. The engine needs more power when cold to maintain its normal idle speed to overcome the increased friction from cold lubricating oil. It does this by opening an intake air passage to let more air into the engine just as depressing the accelerator pedal would open the throttle valve, allowing more air into the engine. The system is calibrated to maintain engine idle speed at a specified value regardless of engine temperature.

Most PFI systems use an idle air control (IAC) motor to regulate idle bypass air. The IAC is computer-controlled, and is either a solenoid-operated valve or a stepper motor that regulates the airflow around the throttle. The idle air control valve is also called an **electronic air control (EAC)** valve.

When the engine stops, most IAC units will retract outward to get ready for the next engine start. When the engine starts, the engine speed is high to provide for proper operation when the engine is cold. Then, as the engine gets warmer, the computer reduces engine idle speed gradually by reducing the number of counts or steps commanded by the IAC.

When the engine is warm and restarted, the idle speed should momentarily increase, then decrease to normal idle speed. This increase and then decrease in engine speed is often called an engine

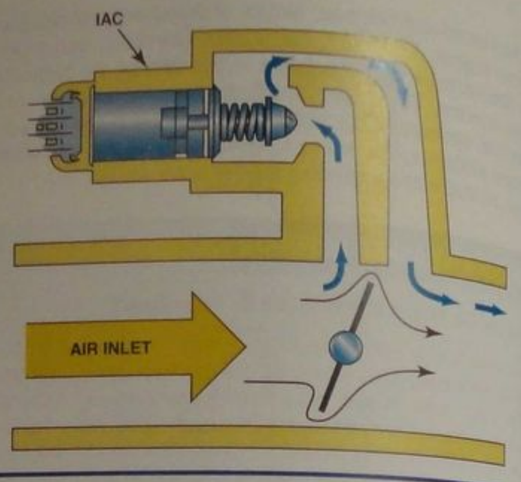


Figure 59–24 The small arrows indicate the air bypassing the throttle plate in the closed throttle position. This air is called minimum air. The air flowing through the IAC is the airflow that determines the idle speed.

flare. If the engine speed does not flare, then the IAC may not be working (it may be stuck in one position).

STEPPER MOTOR OPERATION

A digital output is used to control stepper motors. Stepper motors are direct-current motors that move in fixed steps or increments from de-energized (no voltage) to fully energized (full voltage). A stepper motor often has as many as 120 steps of motion.

A common use for stepper motors is as an idle air control (IAC) valve, which controls engine idle speeds and prevents stalls due to changes in engine load. When used as an IAC, the stepper motor is usually a reversible DC motor that moves in increments, or steps. The motor moves a shaft back and forth to operate a conical valve. When the conical valve is moved back, more air bypasses the throttle plates and enters the engine, increasing idle speed. As the conical valve moves inward, the idle speed decreases.

When using a stepper motor that is controlled by the PCM, it is very easy for the PCM to keep track of the position of the stepper motor. By counting the number of steps that have been sent to the stepper motor, the PCM can determine the relative position of the stepper motor. While the PCM does not actually receive a feedback signal from the stepper motor, it does know how many steps forward or backward the motor should have moved.

A typical stepper motor uses a permanent magnet and two electromagnets. Each of the two electromagnetic windings is controlled by the computer. The computer pulses the windings and changes the polarity of the windings to cause the armature of the stepper motor to rotate 90 degrees at a time. Each 90-degree pulse is recorded by the computer as a "count" or "step"; therefore, the name given to this type of motor. See Figure 59–25.

Idle airflow in a TBI system travels through a passage around the throttle and is controlled by a stepper motor. In some applications, an externally mounted permanent magnet motor called the **idle speed control (ISC) motor** mechanically advances the throttle linkage to advance the throttle opening.

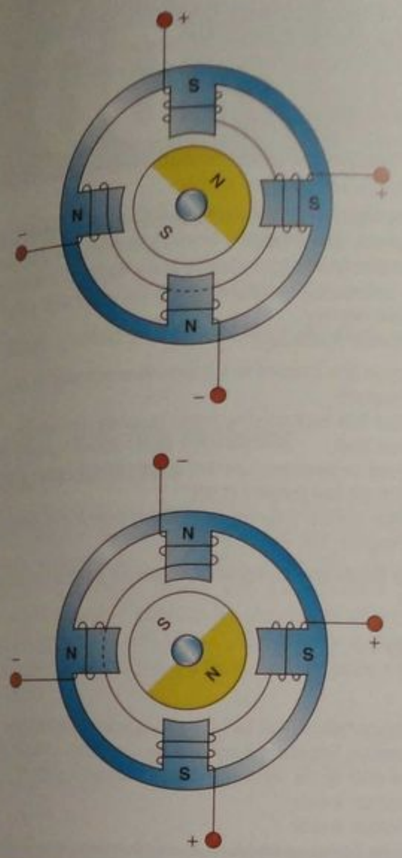


Figure 59–25 Most stepper motors use four wires, which are pulsed by the computer to rotate the armature in steps.

FREQUENTLY ASKED QUESTION ???

Why Does the Idle Air Control Valve Use Milliamperes?

Some Chrysler vehicles, such as the Dodge minivan, use linear solenoid idle air control valves (LSIAC). The PCM uses regulation current flow through the solenoid to control idle speed and the scan tool display is in milliamperes (mA).

Closed position = 180 to 200 mA
Idle = 300 to 450 mA
Light cruise = 500 to 700 mA
Fully open = 900 to 950 mA

ELECTRONIC THROTTLE CONTROL

Electronic throttle control (ETC) systems, used by some manufacturers, replace the idle air control and also serve as a cruise control servo. This system eliminates the mechanical linkage between the accelerator pedal and the throttle plates.

A typical electronic throttle control system includes the following components:

1. Accelerator pedal position(APP) sensor
2. Throttle valve actuator
3. Throttle position sensor
4. Throttle actuator module (or PCM)

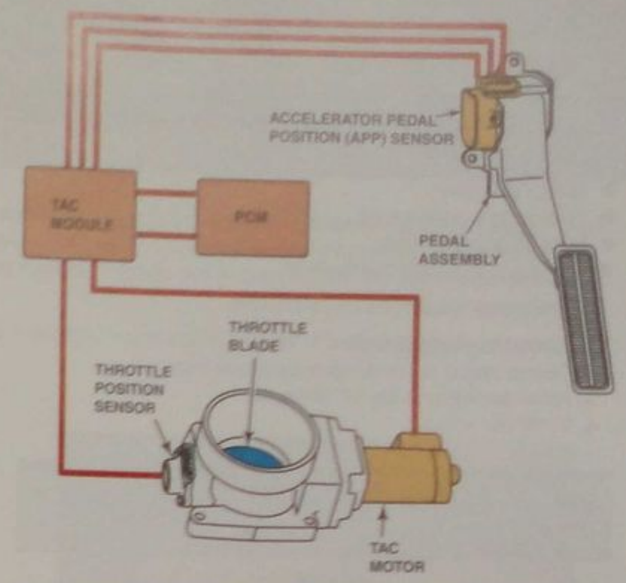


Figure 59–26 A GM electronic throttle control system showing the APP and TP sensors and the DC throttle actuator control (TAC) module and PCM. In many systems the motor control is located inside the PCM.

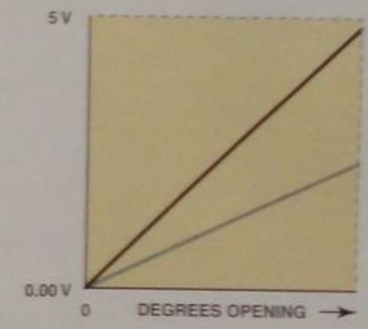


Figure 59–27 A typical accelerator pedal position (APP) sensor showing two different output voltage signals that are used by the PCM to determine accelerator pedal position. Two (or three in some applications) are used as a double check because this is a safety-related sensor.

See Figure 59–26. The throttle plates are controlled by an electric actuator motor and the PCM. Incorporated into the accelerator position sensor are two and sometimes three throttle position sensors that provide accelerator pedal position input to the PCM. See Figure 59–27.

Failure Mode The throttle blade is spring-loaded to a partially open position called the neutral position, which is about 16% to 20% open depending on the vehicle. The throttle blade is driven closed to idle and driven open by the DC actuator motor. Therefore the throttle is held closed by spring tension to a preset "limp home" position. The default position is usually a high idle that would allow the vehicle to be moved to the side of the road but not driven. The spring-loaded neutral position is about 1200 to 1500 RPM depending on the vehicle. If one of the sensors such as a TP or APP sensor were to fail, most systems will do the following:

1. Set a diagnostic trouble code (DTC)
2. Turn on the malfunction indicator lamp (MIL)

3. Limit engine speed and no speed although the vehicle will be driveable

If a throttle valve motor failure occurred, the throttle will be fixed at the neutral position and the engine speed fixed to a fast idle and a DTC will be set and the MIL will be on.

- Battery disconnect
- Throttle-body replacement
- ECM/PCM replacement
- Clearing of diagnostic trouble codes

The typical relearn procedure includes:

1. Turn off all electrical loads
2. Operate engine at normal operating temperature
3. Allow the engine to idle for 10 minutes
4. Verify idle quality

NOTE: Always follow the vehicle-specific procedures as found in service information.

SUMMARY

1. A fuel-injection system includes the electric fuel pump and fuel pump relay, fuel-pressure regulator, and fuel injectors (nozzles).
2. The two types of fuel-injection systems are the throttle-body design and the port fuel-injection design.
3. The two methods of fuel-injection control are the speed-density system, which uses the MAP to measure the load on the engine, and the mass airflow, which uses the MAF sensor to directly measure the amount of air entering the engine.
4. The amount of fuel supplied by fuel injectors is determined by how long they are kept open. This opening time is called the pulse width and is measured in milliseconds.
5. The fuel-pressure regulator is usually located on the fuel return on return-type fuel-injection systems.
6. TBI-type fuel-injection systems do not use a vacuum-controlled fuel-pressure regulator, whereas many port fuel-injection systems use a vacuum-controlled regulator to maintain equal pressure drop across the injectors.
7. Other fuel designs include the electronic returnless, the mechanical returnless, and the demand delivery systems.

REVIEW QUESTIONS

1. What are the various types of fuel-injection systems?
2. What is the purpose of the vacuum-controlled (biased) fuel-pressure regulator?
3. How many sensors are used to determine the base pulse width on a speed-density system?
4. How many sensors are used to determine the base pulse width on a mass airflow system?
5. Why should the fuel rail be inspected?

CHAPTER QUIZ

1. Technician A says that the fuel pump relay is usually controlled by the PCM. Technician B says that a TBI injector squirts fuel above the throttle plate at atmospheric pressure. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that an electronic throttle control uses a stepper motor. Technician B says that an electronic throttle control uses a throttle blade that is spring-loaded to about 16% to 20% throttle opening. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Which fuel-injection system uses the MAP sensor as the primary sensor to determine the base pulse width?
   a. Speed density
   b. Mass airflow
   c. Demand delivery
   d. Mechanical returnless
4. Why is a vacuum line attached to a fuel-pressure regulator on many port fuel-injected engines?
   a. To draw fuel back into the intake manifold through the vacuum hose
   b. To create an equal pressure drop across the injectors
   c. To raise the fuel pressure at idle
   d. To lower the fuel pressure under heavy engine load conditions to help improve fuel economy
5. Which sensor has the greatest influence on injector pulse width besides the MAF sensor?
   a. IAT
   b. BARO
   c. ECT
   d. TP
6. Technician A says that the port fuel-injection injectors operate using 5 volts from the computer. Technician B says that sequential fuel injectors all use a different wire color on the injectors. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Which type of port fuel-injection system uses a fuel temperature and/or fuel-pressure sensor?
   a. All port-fuel-injected engines
   b. TBI units only
   c. Electronic returnless systems
   d. Demand delivery systems
8. Dampeners are used on some fuel rails to _____.
   a. Increase the fuel pressure in the rail
   b. Reduce (decrease) the fuel pressure in the rail
   c. Reduce noise
   d. Trap dirt and keep it away from the injectors
9. Where is the fuel-pressure regulator located on a vacuum-biased port fuel injection system?
   a. In the tank
   b. At the inlet of the fuel rail
   c. At the outlet of the fuel rail
   d. Near or on the fuel filter
10. What type of device is used in a typical idle air control?
    a. DC motor
    b. Stepper motor
    c. Pulsator-type actuator
    d. Solenoid

CHAPTER 60

Fuel-Injection System Diagnosis and Service

OBJECTIVES: After studying Chapter 60, the reader will be able to: Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Describe how to check an electric fuel pump for proper pressure and volume delivery. • Explain how to check a fuel-pressure regulator. • Describe how to test fuel injectors. • Explain how to diagnose electronic fuel-injection problems. • Describe how to service the fuel injection system.

KEY TERMS: graphing multimeter (GMM) • IAC counts • idle air control (IAC) • noid light • peak-and-hold injector • pressure transducer • saturation

PORT FUEL-INJECTION PRESSURE REGULATOR DIAGNOSIS

Most port-fuel-injected engines use a vacuum hose connected to the fuel-pressure regulator. At idle, the pressure inside the intake manifold is low (high vacuum). Manifold vacuum is applied above the diaphragm inside the fuel-pressure regulator. This reduces the pressure exerted on the diaphragm and results in a lower, about 10 PSI (69 kPa), fuel pressure applied to the injectors. To test a vacuum-controlled fuel-pressure regulator, follow these steps:

1. Connect a fuel-pressure gauge to monitor the fuel pressure.
2. Locate the fuel-pressure regulator and disconnect the vacuum hose from the regulator.

NOTE: If gasoline drips out of the vacuum hose when removed from the fuel-pressure regulator, the regulator is defective and will require replacement.

3. With the engine running at idle speed, reconnect the vacuum hose to the fuel-pressure regulator while watching the fuel-pressure gauge. The fuel pressure should drop (about 10 PSI or 69 kPa) when the hose is reattached to the regulator.
4. Using a hand-operated vacuum pump, apply vacuum (20 in. Hg) to the regulator. The regulator should hold vacuum. If the vacuum drops, replace the fuel-pressure regulator. See Figure 60–1.

NOTE: Some vehicles do not use a vacuum-regulated fuel-pressure regulator. Many of these vehicles use a regulator located inside the fuel tank that supplies a constant fuel pressure to the fuel injectors.

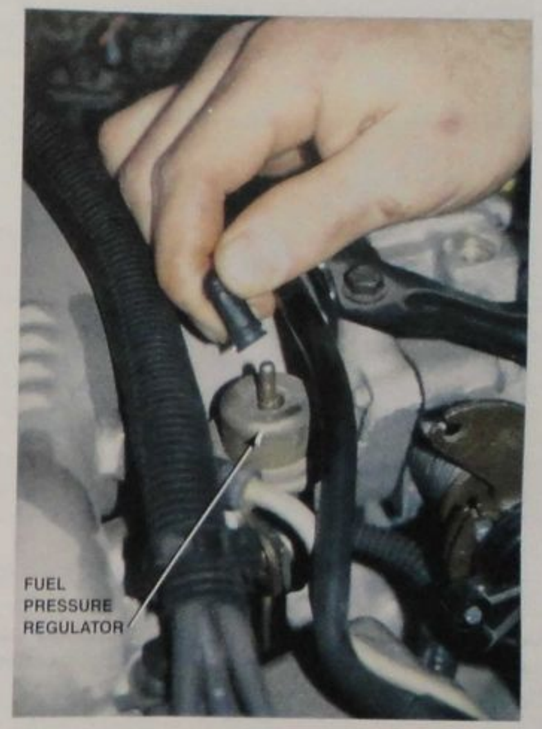


Figure 60–1 If the vacuum hose is removed from the fuel-pressure regulator when the engine is running, the fuel pressure should increase. If it does not increase, then the fuel pump is not capable of supplying adequate pressure or the fuel-pressure regulator is defective. If gasoline is visible in the vacuum hose, the regulator is leaking and should be replaced.

TECH TIP

Pressure Transducer Fuel Pressure Test

Using a **pressure transducer** and a **graphing multimeter (GMM)** or digital storage oscilloscope (DSO) allows the service technician to view the fuel pressure over time. See Figure 60–2(a). Note that the fuel pressure dropped from 10 PSI down to 6 PSI on a TBI-equipped vehicle after just one minute. A normal pressure holding capability is shown in Figure 60–2(b) when the pressure dropped only about 10% after 10 minutes.

DIAGNOSING ELECTRONIC FUEL-INJECTION PROBLEMS USING VISUAL INSPECTION

All fuel-injection systems require the proper amount of clean fuel delivered to the system at the proper pressure and the correct amount of filtered air. The following items should be carefully inspected before proceeding to more detailed tests.

- Check the air filter and replace as needed.
- Check the air induction system for obstructions.
- Check the conditions of all vacuum hoses. Replace any hose that is split, soft (mushy), or brittle.
- Check the positive crankcase ventilation (PCV) valve for proper operation or replacement as needed. See Figure 60–3.

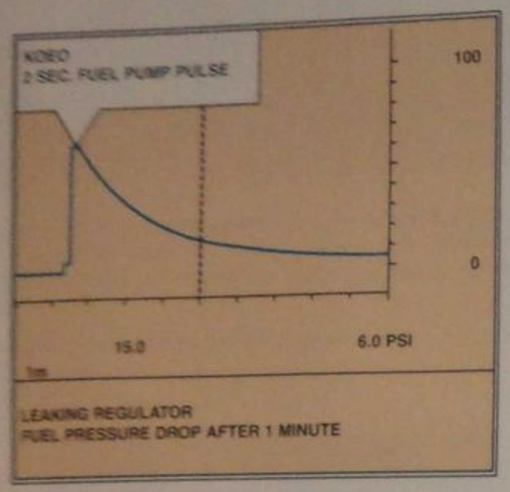


Figure 60–2 (a) A fuel-pressure graph after key on, engine off (KOEO). (b) Pressure drop after 10 minutes on a normal port fuel-injection system.



Figure 60–3 A clogged PCV system caused the engine oil fumes to be drawn into the air cleaner assembly. This is what the technician discovered during a visual inspection.

NOTE: The use of an incorrect PCV valve can cause a rough idle or stalling.

- Check all fuel-injection electrical connections for corrosion or damage.
- Check for gasoline at the vacuum port of the fuel-pressure regulator if the vehicle is so equipped. Gasoline in the vacuum hose at the fuel-pressure regulator indicates that the regulator is defective and requires replacement.

TECH TIP ✔ **Stethoscope Fuel-Injection Test**

A commonly used test for injector operation is to listen to the injector using a stethoscope with the engine operating at idle speed. See Figure 60–4. All injectors should produce the same clicking sound. If any injector makes a clunking or rattling sound, it should be tested further or replaced. With the engine still running, place the end of the stethoscope probe to the return line from the fuel-pressure regulator. See Figure 60–5. Fuel should be heard flowing back to the fuel tank if the fuel-pump pressure is higher than the fuel-regulator pressure. If no sound of fuel is heard, then either the fuel pump or the fuel-pressure regulator is at fault.

TECH TIP ✔ **Quick and Easy Leaking Injector Test**

Leaking injectors may be found by disabling the ignition, unhooking all injectors, and checking exhaust for hydrocarbons (HC) using a gas analyzer while cranking the engine (maximum HC = 300 ppm).

SCAN TOOL VACUUM LEAK DIAGNOSIS

If a vacuum (air) leak occurs on an engine equipped with a speed density-type of fuel injection, the extra air would cause the following to occur:

- The idle speed increases due to the extra air just as if the throttle pedal was depressed.
- The MAP sensor reacts to the increased air from the vacuum leak as an additional load on the engine.



Figure 60–4 All fuel injectors should make the same sound with the engine running at idle speed. A lack of sound indicates a possible electrically open injector or a break in the wiring. A defective computer could also be the cause of a lack of clicking (pulsing) of the injectors.



Figure 60–5 Fuel should be heard returning to the fuel tank at the fuel return line if the fuel-pump and fuel-pressure regulator are functioning correctly.



Figure 60–7 Checking the fuel pressure using a fuel pressure gauge connected to the Schrader valve.



Figure 60–6 Using a scan tool to check for IAC counts or percentage as part of a diagnostic routine.

- The computer increases the injector pulse width slightly longer due to the signal from the MAP sensor.
- The air–fuel mixture remains unchanged.
- The idle air control (IAC) counts will decrease, thereby attempting to reduce the engine speed to the target idle speed stored in the computer memory. See Figure 60–6.

Therefore, one of the best indicators of a vacuum leak on a speed-density fuel-injection system is to look at the IAC counts or percentage. Normal **IAC counts** or percentage is usually 15 to 25. A reading of less than 5 indicates a vacuum leak.

If a vacuum leak occurs on an engine equipped with a mass airflow-type fuel-injection system, the extra air causes the following to occur:

- The engine will operate leaner-than-normal because the extra air has not been measured by the MAF sensor.
- The idle speed will likely be lower due to the leaner-than-normal air–fuel mixture.
- The idle air control (IAC) counts or percentage will often increase in an attempt to return the engine speed to the target speed stored in the computer.

TECH TIP ✔ **No Spark, No Squirt**

Most electronic fuel-injection computer systems use the ignition primary (pickup coil or crank sensor) pulse as the trigger for when to inject (squirt) fuel from the injectors (nozzles). If this signal were not present, no fuel would be injected. Because this pulse is also necessary to trigger the module to create a spark from the coil, it can be said that "no spark" could also mean "no squirt." Therefore, if the cause of a no-start condition is observed to be a lack of fuel injection, do not start testing or replacing fuel-system components until the ignition system is checked for proper operation.

PORT FUEL-INJECTION SYSTEM DIAGNOSIS

To determine if a port fuel-injection system—including the fuel pump, injectors, and fuel-pressure regulator—is operating correctly, take the following steps.

1. Attach a fuel-pressure gauge to the Schrader valve on the fuel rail. See Figure 60–7.
2. Turn the ignition key on or start the engine to build up the fuel-pump pressure (to about 35 to 45 PSI).
3. Wait 20 minutes and observe the fuel pressure retained in the fuel rail and note the PSI reading. The fuel pressure should not drop more than 20 PSI (140 kPa) in 20 minutes. If the drop is less than 20 PSI in 20 minutes, everything is okay; if the drop is *greater*, then there is a possible problem with:
   - The check valve in the fuel pump
   - Leaking injectors, lines, or fittings
   - A defective (leaking) fuel-pressure regulator

To determine which unit is defective, perform the following:

- Reenergize the electric fuel pump.
- Clamp the fuel *supply* line, and wait 10 minutes (see Caution box). If the pressure drop does not occur, replace the fuel pump. If the pressure drop still occurs, continue with the next step.
- Repeat the pressure buildup of the electric pump and clamp the fuel return line. If the pressure drop time is now okay, replace the fuel-pressure regulator.

- If the pressure drop still occurs, one or more of the injectors is leaking. Remove the injectors with the fuel rail and hold over paper. Replace those injectors that drip one or more drops after 10 minutes with pressurized fuel.

CAUTION: Do not clamp plastic fuel lines. Connect shutoff valves to the fuel system to shut off supply and return lines. See Figure 60–8.

TESTING FOR AN INJECTOR PULSE

One of the first checks that should be performed when diagnosing a no-start condition is whether the fuel injectors are being pulsed by the computer. Checking for proper pulsing of the injector is also important in diagnosing a weak or dead cylinder.

A **noid light** is designed to electrically replace the injector in the circuit and to flash if the injector circuit is working correctly. See Figure 60–9. To use a noid light, disconnect the electrical connector at the fuel injector and plug the noid light into the injector harness connectors. Crank or start the engine. The noid light should flash regularly.

NOTE: The term noid is simply an abbreviation of the word solenoid. Injectors use a moveable iron core and are therefore solenoids. Therefore, a noid light is a replacement for the solenoid (injector).

Possible noid light problems and causes include the following:

1. **The light is off and does not flash.** The problem is an open in either the power side or ground side (or both) of the injector circuit.
2. **The noid light flashes dimly.** A dim noid light indicates excessive resistance or low voltage available to the injector. Both the power and ground side must be checked.
3. **The noid light is on and does not flash.** If the noid light is on, then both a power and a ground are present. Because the light does not flash (blink) when the engine is being cranked or started, then a short-to-ground fault exists either in the computer itself or in the wiring between the injector and the computer.

CAUTION: A noid lamp must be used with caution. The computer may show a good noid light operation and have low supply voltage. See Figure 60–10.



Figure 60–8 Shutoff valves must be used on vehicles equipped with plastic fuel lines to isolate the cause of a pressure drop in the fuel system.



(a)



(b)

Figure 60–9 (a) Noid lights are usually purchased as an assortment so that one is available for any type or size of injector wiring connector. (b) The connector is unplugged from the injector and a noid light is plugged into the injector connector. The noid light should flash when the engine is being cranked if the power circuit and the pulsing to ground by the computer are functioning okay.

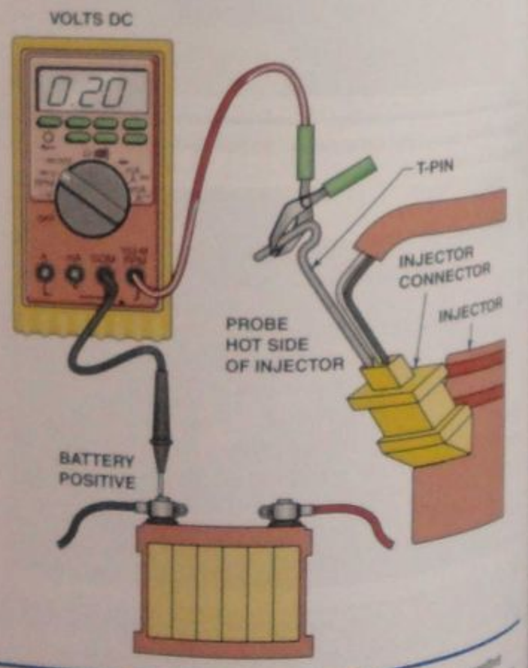


Figure 60–10 Use a DMM set to read DC volts to check the voltage drop of the positive circuit to the fuel injector. A reading of 0.5 volt or less is generally considered to be acceptable.

CHECKING FUEL-INJECTOR RESISTANCE

Each port fuel injector must deliver an equal amount of fuel or the engine will idle roughly or perform poorly.

The electrical balance test involves measuring the injector coil winding resistance. For best engine operation, all injectors should have the same electrical resistance. To measure the resistance, carefully release the locking feature of the connector and remove the connector from the injector.

Injector Resistance Table

Manufacturer	Injector Application	Resistance Values
General Motors		
	Quad 4	1.95–2.15 Ω
	CPI Vortec 4.3L	1.48–1.52 Ω
	MFI Bosch Style Injector (1985–1989) 2.8L	15.95–16.35 Ω
	MFI Black Multec Injector 2.8L, 3.1L, 3.3L, 3.4L	11.8–12.6 Ω
	MFI 3800	14.3–14.7 Ω
	MFI 3.8L, 5.0L, 5.7L	15.8–16.6 Ω
	MFI 5.7 LT5-ZR1	11.8–12.6 Ω
	TBI 220 Series 2.8L, 3.1L, 4.3L, 5.0L, 5.7L, 7.4L	1.16–1.36 Ω
	TBI 295 Series 4.3L, 6.0L, 7.0L	1.42–1.62 Ω
	TBI 700 Series 2.0L, 2.2L, 2.5L	1.42–1.62 Ω
Chrysler Brand		
	MFI Early Years through 1992 (majority of)	2.4 Ω
	MFI Later Years after 1992 (majority of)	14.5 Ω
	TBI Low-Pressure Systems (majority of)	1.3 Ω
	TBI High-Pressure Systems (majority of)	0.7 Ω
Ford		
	MFI (majority of)	15.0–18.0 Ω
	TBI Low-Pressure 1.9L (1987–1990)	1.0–2.0 Ω
	TBI Low-Pressure 2.3L (1985–1987)	1.0–2.0 Ω
	TBI Low-Pressure 2.5L (1986–1990)	1.0–2.0 Ω
	TBI High-Pressure 3.8L (1984–1987)	1.5–2.5 Ω
	TBI High-Pressure 5.0L (1981–1985)	1.5–3.5 Ω

NOTE: Some engines require specific procedures to gain access to the injectors. Always follow the manufacturers' recommended procedures.

With an ohmmeter, measure the resistance across the injector terminals. Be sure to use the low-ohms feature of the digital ohmmeter to read in tenths (0.1) of an ohm. See Figures 60–11 and 60–12. Check service information for the resistance specification of the injectors. Measure the resistance of all of the injectors. Replace any injector that does not fall within the resistance range of the specification. The resistance of the injectors should be measured twice—once when the engine (and injectors) are cold and once after the engine has reached normal operating temperature. If any injector measures close to specification, make certain that the terminals of the injector are electrically sound, and perform other tests to confirm an injector problem before replacement.

MEASURING RESISTANCE OF GROUPED INJECTORS

Many vehicles are equipped with a port fuel-injection system that "fires" two or more injectors at a time. For example, a V-6 may group all three injectors on one bank to pulse on at the same time. Then the other three injectors will be pulsed on. This sequence alternates. To measure the resistance of these injectors, it is often easiest to measure each group of three that is wired in parallel. The resistance of three injectors wired in parallel is one-third of the resistance of each individual injector. For example,

Injector resistance = 12 ohms (Ω)

Three injectors in parallel = 4 ohms (Ω)

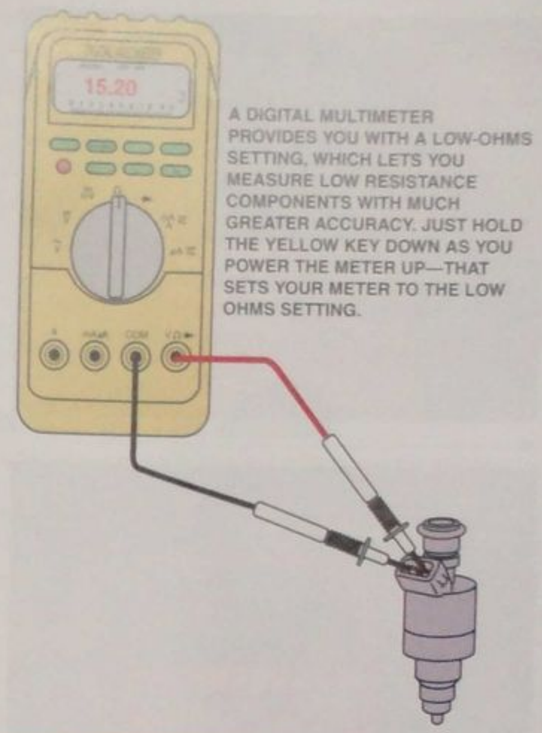


Figure 60–11 Connections and settings necessary to measure fuel-injector resistance.



Figure 60–12 To measure fuel-injector resistance, a technician constructed a short wiring harness with a double banana plug that fits into the V and COM terminals of the meter and an injector connector at the other end. This setup makes checking resistance of fuel injectors quick and easy.



(a)

(b)

Figure 60–13 (a) The meter is connected to read one group of three 12-ohm injectors. The result should be 4 ohms and this reading is a little low indicating that at least one injector is shorted (low resistance). (b) This meter is connected to the other group of 3 injectors and indicates that most, if not all three, injectors are shorted. The technician replaced all six injectors and the engine ran great.

A V-6 has two groups of three injectors. Therefore, both groups should measure the same resistance. If both groups measure 4 ohms, then it is likely that all six injectors are okay. However, if one group measures only 2.9 ohms and the other group measures 4 ohms, then it is likely that one or more fuel injectors are defective (shorted). This means that the technician now has reasonable cause to remove the intake manifold to get access to each injector for further testing. See Figure 60–13.

MEASURING RESISTANCE OF INDIVIDUAL INJECTORS

While there are many ways to check injectors, the first test is to measure the resistance of the coil inside and compare it to factory specifications. See Figure 60–14. If the injectors are not accessible, check service information for the location of the electrical connector for the injectors. Unplug the connector and measure the resistance of each injector at the injector side of the connector. Use service information to determine the wire colors for the power side and the pulse side of each injector.



Figure 60–14 Measuring injector resistance using a DMM and an injector connector. This setup was made by the technician and makes measuring injector resistance fast and easy.

TECH TIP ✓ **Equal Resistance Test**

All fuel injectors should measure the specified resistance. However the specification often indicates the temperature of the injectors be at room temperature and of course will vary according to the temperature. Rather than waiting for all of the injectors to achieve room temperature, measure the resistance and check that they are all within 0.4 ohm of each other. To determine the difference, record the resistance of each injector and then subtract the lowest resistance reading from the highest resistance reading to get the difference. If more than 0.4 ohm then further testing will be needed to verify defective injector(s).

PRESSURE-DROP BALANCE TEST

The pressure balance test involves using an electrical timing device to pulse the fuel injectors on for a given amount of time, usually 500 ms or 0.5 second, and observing the drop in pressure that accompanies the pulse. If the *fuel flow* through each injector is equal, the drop in pressure in the system will be equal. Most manufacturers recommend that the pressures be within about 1.5 PSI (10 kPa) of each other for satisfactory engine performance. This test method not only tests the electrical functioning of the injector (for definite time and current pulse), but also tests for mechanical defects that could affect fuel flow amounts.

The purpose of running this injector balance test is to determine which injector is restricted, inoperative, or delivering fuel differently than the other injectors. Replacing a complete set of injectors can be expensive. The basic tools needed are:

- Accurate pressure gauge with pressure relief
- Injector pulser with time control
- Necessary injector connection adapters
- Safe receptacle for catching and disposing of any fuel released

Step #1 Attach the pressure gauge to the fuel delivery rail on the supply side. Make sure the connections are safe and leakproof.

Step #2 Attach the injector pulser to the first injector to be tested.

Step #3 Turn the ignition key to the on position to prime the fuel rail. Note the static fuel pressure reading. See Figure 60–15.

Step #4 Activate the pulser for the timed firing pulses.

Step #5 Note and record the new static rail pressure after the injector has been pulsed.



Figure 60–15 Connect a fuel pressure gauge to the fuel rail at the Schrader valve.

Step #6 Reenergize the fuel pump and repeat this procedure for all of the engine injectors.

Step #7 Compare the two pressure readings and compute the pressure drop for each injector. Compare the pressure drops of the injectors to each other. Any variation in pressure drops will indicate an uneven fuel delivery rate between the injectors.

For example:

Injector	1	2	3	4	5	6
Initial Pressure	40	40	40	40	40	40
Second Pressure	30	30	35	30	20	30
Pressure Drop	10	10	5	10	20	10
Possible Problem	OK	OK	Restriction	OK	Leak	OK

INJECTOR VOLTAGE-DROP TESTS

Another test of injectors involves pulsing the injector and measuring the voltage drop across the windings as current is flowing. A typical voltage-drop tester is shown in Figure 60–16. The tester, which is recommended for use by General Motors Corporation, pulses the injector while a digital multimeter is connected to the unit, which will display the voltage drop as the current flows through the winding.



Figure 60–16 An injector tester being used to check the voltage drop through the injector while the tester is sending current through the injectors. This test is used to check the coil inside the injector. This same tester can be used to check for equal pressure drop of each injector by pulsing the injector on for 500 ms.

CAUTION: Do not use an injector using a pulse-type tester more than one time without starting the engine to help avoid a hydrostatic lock caused by the flow of fuel into the cylinder during the pulse test.

Record the highest voltage drop observed on the meter display during the test. Repeat the voltage-drop test for all of the injectors. The voltage drop across each injector should be within 0.1 volt of each other. If an injector has a higher-than-normal voltage drop, the injector windings have higher-than-normal resistance.

SCOPE-TESTING FUEL INJECTORS

A scope (analog or digital storage) can be connected into each injector circuit. There are three types of injector drive circuits and each type of circuit has its own characteristic pattern. See Figure 60–17 for an example of how to connect a scope to read a fuel-injector waveform.

Saturated Switch Type In a saturated switch-type injector driven circuit, voltage (usually a full 12 volts) is applied to the injector. The ground for the injector is provided by the vehicle computer. When the ground connection is completed, current flows through the injector windings. Due to the resistance and inductive reactance of the coil itself, it requires a fraction of a second (about 3 milliseconds or 0.003 seconds) for the coil to reach **saturation** or maximum current flow. Most saturated switch-type fuel injectors have 12 to 16 ohms of resistance. This resistance, as well as the computer switching circuit, control and limit the current flow through the injector. A voltage spike occurs when the computer shuts off (opens the injector ground-side circuit) the injectors. See Figure 60–18.

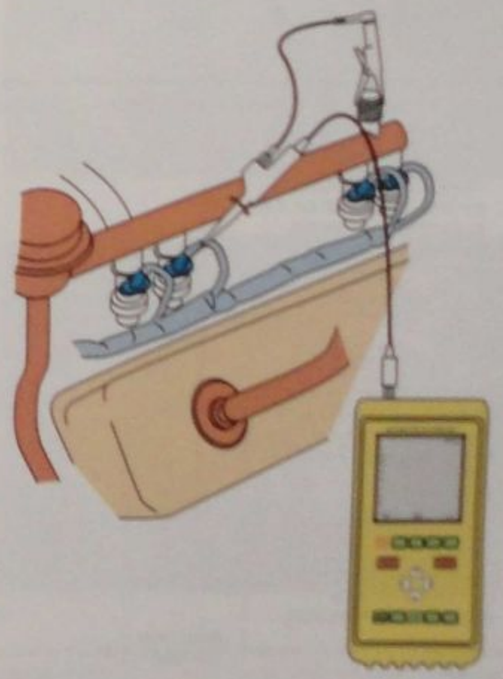


Figure 60–17 A digital storage oscilloscope can be easily connected to an injector by carefully back probing the electrical connector.

Peak-and-Hold Type A **peak-and-hold** type is typically used for TBI and some port low-resistance injectors. Full battery voltage is applied to the injector and the ground side is controlled through the computer. The computer provides a high initial current flow (about 4 amperes) to flow through the injector windings to open the injector core. Then the computer reduces the current to a lower level (about 1 ampere). The hold current is enough to keep the injector open, yet conserves energy and reduces the heat buildup that would occur if the full current flow remains on as long as the injector is commanded on. Typical peak-and-hold-type injector resistance ranges from 2 to 4 ohms.

The scope pattern of a typical peak-and-hold-type injector shows the initial closing of the ground circuit, then a voltage spike as the current flow is reduced. Another voltage spike occurs when the lower level current is turned off (opened) by the computer. See Figure 60–19.

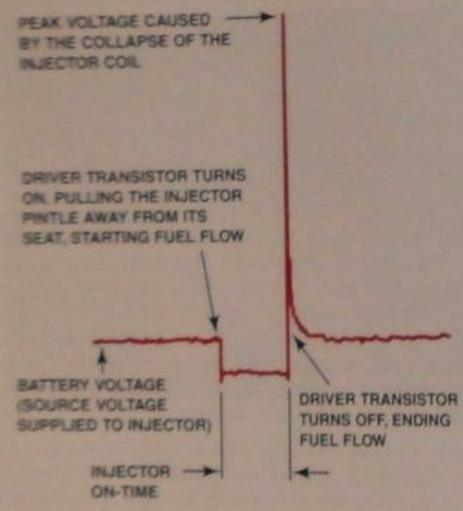


Figure 60–18 The injector on-time is called the pulse width. *(Courtesy of Fluke Corporation)*

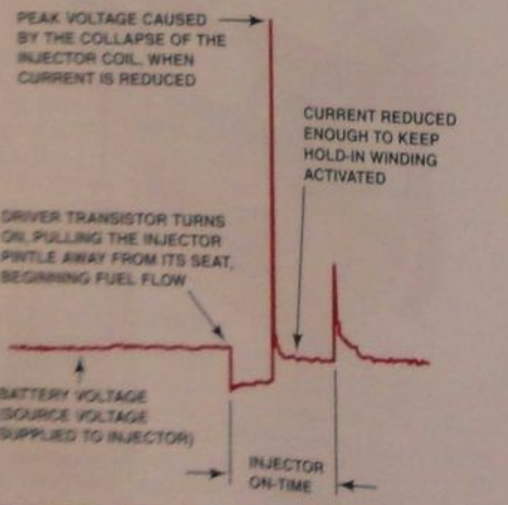


Figure 60–19 A typical peak-and-hold fuel injector waveform. Most fuel injectors that measure less than 5 ohms will usually display a similar waveform.

Pulse-Width Modulated Type A pulse-width modulated type of injector drive circuit uses lower-resistance coil injectors. Battery voltage is available at the positive terminal of the injector and the computer provides a variable-duration connection to ground on the negative side of the injector. The computer can vary the time intervals that the injector is grounded for very precise fuel control.

Each time the injector circuit is turned off (ground circuit opened), a small voltage spike occurs. It is normal to see multiple voltage spikes on a scope connected to a pulse-width modulated type of fuel injector.

FREQUENTLY ASKED QUESTION ???

If Three of Six Injectors Are Defective, Should I Also Replace the Other Three?

This is a good question. Many service technicians "recommend" that the three good injectors also be replaced along with the other three that tested as being defective. The reasons given by these technicians include:

- All six injectors have been operating under the same fuel, engine, and weather conditions.
- The labor required to replace all six is just about the same as replacing only the three defective injectors.
- Replacing all six at the same time helps ensure that all of the injectors are flowing the same amount of fuel so that the engine is operating most efficiently.

With these ideas in mind, the customer should be informed and offered the choice. Complete sets of injectors such as those in Figure 60–20 can be purchased at a reasonable cost.

IDLE AIR SPEED CONTROL DIAGNOSIS

On an engine equipped with fuel injection (TBI or port injection), the idle speed is controlled by increasing or decreasing the amount of air bypassing the throttle plate. Again, an electronic stepper motor or pulse-width modulated solenoid is used to maintain the correct idle speed. This control is often called the **idle air control (IAC).** See Figures 60–21 through 60–23.

When the engine stops, most IAC units will retract outward to get ready for the next engine start. When the engine starts, the engine speed is high to provide for proper operation when the engine is cold. Then, as the engine gets warmer, the computer reduces engine idle speed gradually by reducing the number of counts or steps commanded by the IAC.



Figure 60–20 A set of six new injectors.

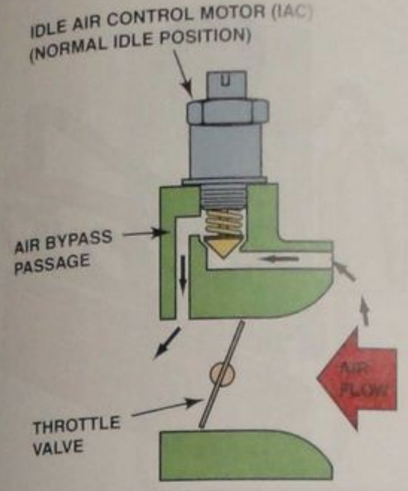


Figure 60–21 An IAC controls idle speed by controlling the amount of air that passes around the throttle plate. More airflow results in a higher idle speed.



Figure 60–22 A typical IAC.



Figure 60–23 Some IAC units are purchased with the housing as shown. Carbon buildup in these passages can cause a rough or unstable idling or stalling.

When the engine is warm and restarted, the idle speed should momentarily increase, then decrease to normal idle speed. This increase and then decrease in engine speed is often called an engine flare. If the engine speed does not flare, then the IAC may not be working (it may be stuck in one position).

REAL WORLD FIX **There Is No Substitute for a Thorough Visual Inspection**

An intermittent "check engine" light and a random-misfire diagnostic trouble code (DTC) P0300 was being diagnosed. A scan tool did not provide any help because all systems seemed to be functioning normally. Finally, the technician removed the engine cover and discovered a mouse nest. See Figure 60–24.

FUEL-INJECTION SERVICE

After many years of fuel-injection service, some service technicians still misunderstand the process of proper fuel-system handling. Much has been said over the years with regard to when and how to perform injector cleaning. Some manufacturers have suggested methods of cleaning while others have issued bulletins to prohibit any cleaning at all.

All engines using fuel injection do require some type of fuel-system maintenance. Normal wear and tear with today's underhood



(a)



(b)

Figure 60–24 (a) Nothing looks unusual when the hood is first opened. (b) When the cover is removed from the top of the engine, a mouse or some other animal nest is visible. The animal had already eaten through a couple of injector wires. At least the cause of the intermittent misfire was discovered.

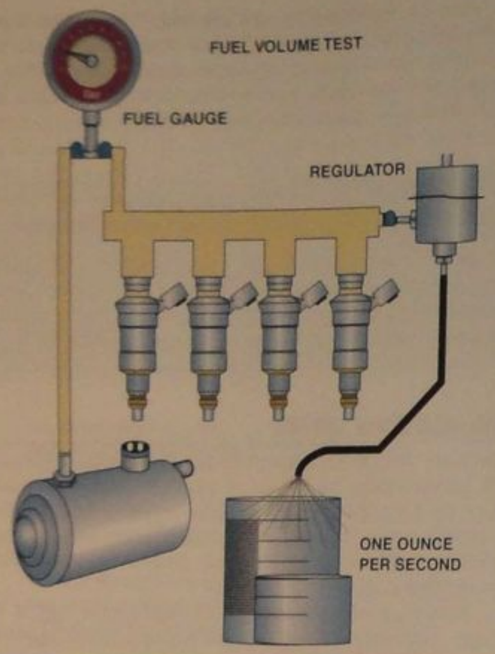


Figure 60–25 Checking fuel-pump volume using a hose from the outlet of the fuel-pressure regulator into a calibrated container.

temperatures and changes in gasoline quality contribute to the buildup of olefin wax, dirt, water, and many other additives. Unique to each engine is an air-control design that also may contribute different levels of carbon deposits, such as oil control.

Fuel-injection system service should include the following operations:

1. **Check fuel-pump operating pressure and volume.** The missing link here is volume. Most working technicians assume that if the pressure is correct, the volume is also okay. Hook up a fuel-pressure tester to the fuel rail inlet to quickly test the fuel pressure with the engine running. At the same time, test the volume of the pump by sending fuel into the holding tank. (One ounce per second is the usual specification.) See Figure 60–25. A two-line system tester is the recommended procedure to use and is attached to the fuel inlet and the return on the fuel rail. The vehicle onboard system is looped and returns fuel to the tank.
2. **Test the fuel-pressure regulator for operation and leakage.** At this time, the fuel-pressure regulator would be tested for operational pressure and proper regulation, including leakage. (This works well as the operator has total control of rail pressure with a unit control valve.) Below are some points to ponder:
   - Good pressure does not mean proper volume. For example, a clogged filter may test okay on pressure but the restriction may not allow proper volume under load. See Figure 60–26.
   - It is a good idea to use the vehicle's own gasoline to service the system versus a can of shop gasoline that has been sitting around for some time.
   - Pressure regulators do fail and a lot more do not properly shut off fuel, causing higher than-normal pump wear and shorter service life.
3. **Flush the entire fuel rail and upper fuel-injector screens including the fuel-pressure regulator.** Raise the input pressure to a point above regulator setting to allow a constant flow of fuel through the inlet pressure side of the system, through the fuel rail, and out the open fuel-pressure regulator. In most cases the applied pressure is 75 to 90 PSI, (517 to 620kPa) but will be maintained by the presence of a regulator. At this point, cleaning chemical is added to the fuel at a 5:1 mixture and allowed to flow through the system for 15 to 30 minutes. See Figure 60–27. Results are best on a hot engine with the fuel supply looped and the engine not running. Below are some points to ponder:
   - This flush is the fix most vehicles need first. The difference is that the deposits are removed to a remote tank and filter versus attempting to soften the deposits and blow them through the upper screens.
   - Most injectors use a 10-micron final filter screen. A 25% restriction in the upper screen would increase the injector on-time approximately 25%.
   - **Clean the fuel injectors.** Start the engine and adjust the output pressure closer to regulator pressure or lower than in the previous steps. Lower pressure will cause the pulse width to open up somewhat longer and allow the injectors to be cleaned. Slow speed (idle) position will take a longer time frame and operating temperature will be reached. Clean injectors are the objective, but the chemical should also decarbon the engine valves, pistons, and oxygen sensor.

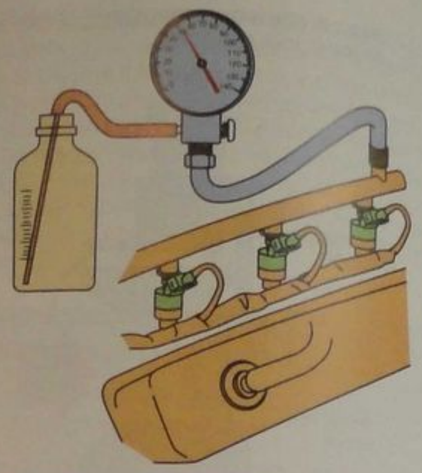


Figure 60–26 Testing fuel-pump volume using a fuel-pressure gauge with a bleed hose inserted into a suitable container. The engine is running during this test.

TECH TIP ✔ **Check the Injectors at the "Bends and the Ends"**

Injectors that are most likely to become restricted due to clogging of the filter basket screen are the injectors at the ends of the rail especially on returnless systems where dirt can accumulate. Also the injectors that are located at the bends of the fuel rail are also subject to possible clogging due to the dirt being deposited where the fuel makes a turn in the rail.

4. **Decarbon the engine assembly.** On most vehicles, the injector spray will help the decarboning process. On others, you may need to enhance the operation with external addition of a mixture through the PCV hose, throttle plates, or idle air controls.

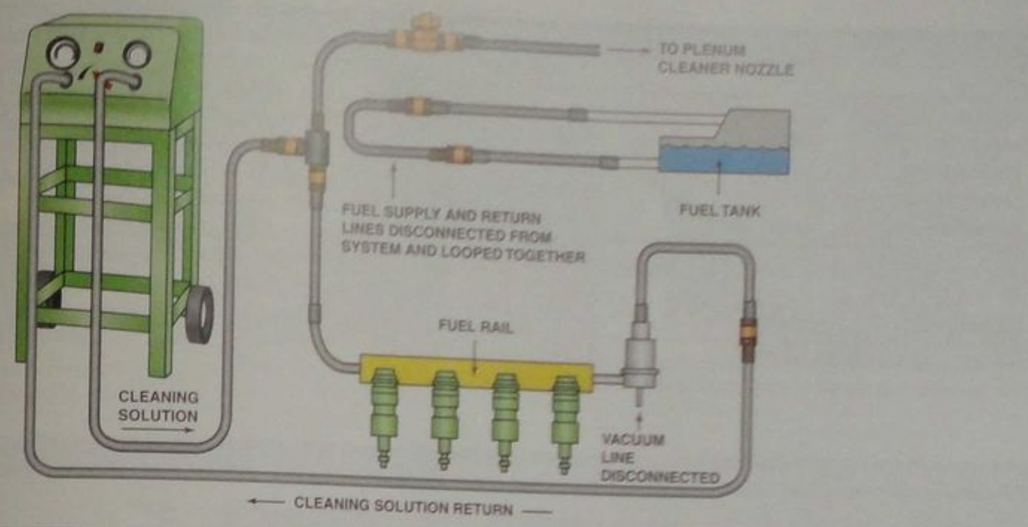


Figure 60–27 A typical two-line cleaning machine hookup, showing an extension hose that can be used to squirt a cleaning solution into the throttle body while the engine is running on the cleaning solution and gasoline mixture.

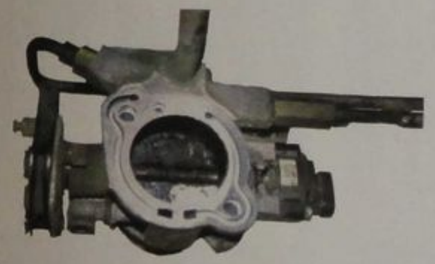


Figure 60–28 To thoroughly clean a throttle body, it is sometimes best to remove it from the vehicle.

5. **Clean the throttle plate and idle air control passages.** Doing this service alone on most late-model engines will show a manifold vacuum increase of up to 2 in. Hg. Stop the engine and clean the areas as needed, then use a handheld fuel injector connected in parallel with the pressure hose, along with a pulser to allow cleaning of the throttle plates with the same chemical as injectors are running on. See Figure 60–28. This works well as air is drawn into IAC passages on a running engine and will clean the passages without IAC removal.
6. **Relearn the onboard computer.** Some vehicles may have been running in such a poor state of operation that the onboard computer may need to be relearned. Consult service information for the suggested relearn procedures for each particular vehicle.

This service usually takes approximately one hour for the vehicle to run out of fuel and the entire service to be performed. The good thing is that the technician may do other services while this is being performed. Some technicians may install a set of plugs or change the fuel filter while the engine is flushing. This service should restore the fuel system to original operations.

All of the previously listed steps may be performed using a *two-line* fuel-injector service unit such as: Carbon Clean, Auto Care, Injector Test, DeCarbon, or Motor-Vac.

TECH TIP ✔ **Be Sure to Clean the Fuel Rail**

Whenever you service the fuel injectors, or if you suspect that there may be a fuel-injector problem, remove the entire fuel rail assembly and check the passages for contamination. Always thoroughly clean the rail when replacing fuel injectors.

Fuel-Injection Symptoms/Action Chart

Symptom	Possible Causes
Hard cold starts	• Low fuel pressure • Leaking fuel injectors • Contaminated fuel • Low-volatility fuel • Dirty throttle plate
Garage stalls	• Low fuel pressure • Insufficient fuel volume • Restricted fuel injector • Contaminated fuel • Low-volatility fuel
Poor cold performance	• Low fuel pressure • Insufficient fuel volume • Contaminated fuel • Low-volatility fuel
Tip-in hesitation (hesitation just as the accelerator pedal is depressed)	• Low fuel pressure • Insufficient fuel volume • Intake valve deposits • Contaminated fuel • Low-volatility fuel

FUEL-SYSTEM SCAN TOOL DIAGNOSTICS

Diagnosing a faulty fuel system can be a difficult task. However, it can be made easier by utilizing the information available via the serial data stream. By observing the long-term fuel trim and the short-term fuel trim, we can determine how the fuel system is performing. Short-term fuel trim and long-term fuel trim can help us to zero in on specific areas of trouble. Readings should be taken at idle and at 3000 RPM. Use the following chart as a guide.

Condition	Long-Term Fuel Trim at Idle	Long-Term Fuel Trim at 3000 RPM
System normal	0% ± 10%	0% ± 10%
Vacuum leak	HIGH	OK
Fuel flow problem	OK	HIGH
Low fuel pressure	HIGH	HIGH
High fuel pressure	*OK or LOW	*OK or LOW

*High fuel pressure will affect trim at idle, at 3000 RPM, or both.

SUMMARY

1. A typical throttle-body fuel injector uses a computer-controlled injector solenoid to spray fuel into the throttle-body unit above the throttle plates.
2. A typical port fuel-injection system uses an individual fuel injector for each cylinder and squirts fuel directly into the intake manifold about 3 inches (80 millimeters) from the intake valve.
3. A typical fuel-injection system fuel pressure should not drop more than 20 PSI in 20 minutes.
4. A noid light can be used to check for the presence of an injector pulse.
5. Injectors can be tested for resistance and should be within 0.3 to 0.4 ohms of each other.
6. Different designs of injectors have a different scope waveform depending on how the computer pulses the injector on and off.
7. An idle air control unit controls idle speed and can be tested for proper operation using a scan tool or scope.

PHOTO SEQUENCE Fuel-Pump Relay Circuit Diagnosis



P60–1 The tools needed to diagnose a circuit containing a relay include a digital multimeter (DMM), a fused jumper wire, and an assortment of wiring terminals.



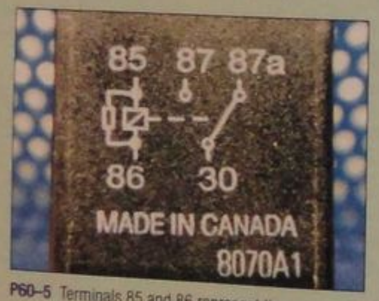
P60–2 Start the diagnosis by locating the relay center. It is under the hood on this General Motors vehicle, so access is easy. Not all vehicles are this easy.



P60–3 The chart under the cover for the relay center indicates the location of the relay that controls the electric fuel pump.



P60–4 Locate the fuel-pump relay and remove by using a puller if necessary. Try to avoid rocking or twisting the relay to prevent causing damage to the relay terminals or the relay itself.



P60–5 Terminals 85 and 86 represent the coil inside the relay. Terminal 30 is the power terminal, 87a is the normally closed contact, and 87 is the normally open contact.



P60–6 The terminals are also labeled on most relays.



P60–7 To help make good electrical contact with the terminals without doing any harm, select the proper-size terminal from the terminal assortment.



P60–8 Insert the terminals into the relay socket in 30 and 87.



P60–9 To check for voltage at terminal 30, use a test light or a voltmeter. Start by connecting the alligator clip of the test light to the positive (+) terminal of the battery

PHOTO SEQUENCE Fuel-Pump Relay Circuit Diagnosis—continued



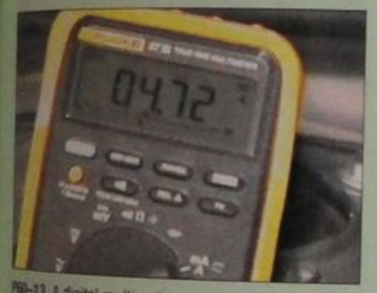
P60–10 Touch the test light to the negative (−) terminal of the battery or a good engine ground to check the test light.



P60–11 Use the test light to check for voltage at terminal 30 of the relay. The ignition may have to be in the on (run) position.



P60–12 To check to see if the electric fuel pump can be operated from the relay contacts, use a fused jumper wire and touch the relay contacts that correspond to terminals 30 and 87 of the relay.



P60–13 A digital multimeter could also be used to measure the current draw of the pump. Connect the leads of the meter to contacts 30 and 87 of the relay socket. The reading of 4.7 amperes is okay because the specification is 4 to 8 amperes.



P60–14 Set the meter to read ohms (Ω) and measure the resistance of the relay coil. The usual reading for most relays is between 60 and 100 ohms.



P60–15 Measure between terminal 30 and 87a. Terminal 87a is the normally closed contact, and there should be little, if any, resistance between these two terminals, as shown.



P60–16 To test the normally open contacts, connect one meter lead to terminal 30 and the other lead to terminal 87. The ohmmeter should show an open circuit by displaying OL.



P60–17 Connect a fused jumper wire to supply 12 volts to terminal 86 and a ground to terminal 85 of the relay. If the relay clicks, then the relay coil is able to move the armature (movable arm) of the relay.



P60–18 After testing, be sure to reinstall the relay and the relay cover.

(continued)

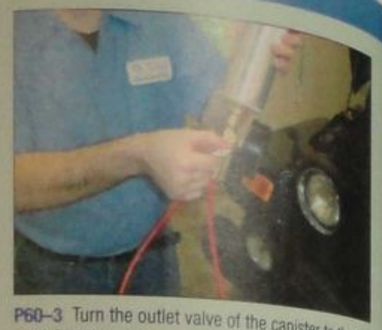
PHOTO SEQUENCE Fuel Injector Cleaning



P60–1 Start the fuel injector cleaning process by bringing the vehicle's engine up to operating temperature. Shut off the engine, remove the cap from the fuel rail test port, and install the appropriate adapter.



P60–2 The vehicle's fuel pump is disabled by removing its relay or fuse. In some cases, it may be necessary to disconnect the fuel pump at the tank if the relay or fuse powers more than just the pump.



P60–3 Turn the outlet valve of the canister to the OFF or CLOSED position.



P60–4 Remove the fuel injector cleaning canister's top and regulator assembly. Note that there is an O-ring seal located here that must be in place for the canister's top to seal properly.



P60–5 Pour the injection system cleaning fluid into the open canister. Rubber gloves are highly recommended for this step as the fluid is toxic.



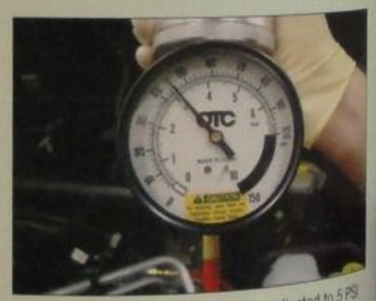
P60–6 Replace the canister's top (making sure it is tight) and connect its hose to the fuel rail adapter. Be sure that the hose is routed away from exhaust manifolds and other hazards.



P60–7 Hang the canister from the vehicle's hood and adjust the air pressure regulator to full OPEN position (CCW).



P60–8 Connect shop air to the canister and adjust the air pressure regulator to the desired setting. Canister pressure can be read directly from the gauge.



P60–9 Canister pressure should be adjusted to 5 PSI below system fuel pressure. An alternative for return-type systems is to block the fuel return line to the tank.



P60–10 Open the outlet valve on the canister.



P60–11 Start the vehicle's engine and let run at 1000–1500 RPM. The engine is now running on fuel injector cleaning fluid provided by the canister.



P60–12 Continue the process until the canister is empty and the engine stalls. Remove the cleaning equipment, enable the vehicle's fuel pump, and run the engine to check for leaks.

REVIEW QUESTIONS

1. List the ways fuel injectors can be tested.
2. List the steps necessary to test a fuel-pressure regulator.
3. Describe why it may be necessary to clean the throttle plate of a port-fuel-injected engine.

CHAPTER QUIZ

1. Most port fuel-injected engines should be able to supply how much fuel pressure?
   a. 3 to 5 PSI (21 to 35 kPa)
   b. 9 to 13 PSI (62 to 90 kPa)
   c. 35 to 45 PSI (240 to 310 kPa)
   d. 55 to 65 PSI (380 to 450 kPa)
2. Fuel injectors can be tested using _____.
   a. An ohmmeter
   b. A stethoscope
   c. A scope
   d. All of the above
3. Throttle-body fuel-injection systems use what type of injector driver?
   a. Peak and hold
   b. Saturated switch
   c. Pulse-width modulated
   d. Pulsed
4. Port fuel-injection systems generally use what type of injector driver?
   a. Peak and hold
   b. Saturated switch
   c. Pulse-width modulated
   d. Pulsed
5. The vacuum hose from the fuel-pressure regulator was removed from the regulator and gasoline dripped out of the hose. Technician A says that is normal and that everything is okay. Technician B says that one or more of the injectors may be defective, causing the fuel to get into the hose. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. The fuel pressure drops rapidly when the engine is turned off. Technician A says that one or more injectors could be leaking. Technician B says that a defective check valve in the fuel pump could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. In a typical port fuel-injection system, which injectors are most subject to becoming restricted?
   a. Any of them equally
   b. The injectors at the end of the rail on a returnless system
   c. The injectors at the bends in the rail
   d. Either b or c
8. What component pulses the fuel injector on most vehicles?
   a. Electronic control unit (computer)
   b. Ignition module
   c. Crankshaft sensor
   d. Both b and c
9. Fuel injection service is being discussed. Technician A says that the throttle plate(s) should be cleaned. Technician B says that the fuel rail should be cleaned. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. If the throttle plate needs to be cleaned, what symptoms will be present regarding the operation of the engine?
    a. Stalls
    b. Rough idle
    c. Hesitation on acceleration
    d. All of the above

CHAPTER 61

Vehicle Emission Standards and Testing

OBJECTIVES: After studying Chapter 61, the reader will be able to: Prepare for ASE A8 certification test content area "D" (Emissions Control Systems Diagnosis and Repair) and ASE L1 certification test content area "F" (I/M Failure Diagnosis). • Discuss emission standards. • Identify the reasons why excessive amounts of HC, CO, and NO_x exhaust emissions are created. • Describe how to baseline a vehicle after an exhaust emission failure. • List acceptable levels of HC, CO, CO_2, and O_2 with and without a catalytic converter. • List four possible causes for high readings for HC, CO, and NO_x.

KEY TERMS: acceleration simulation mode (ASM) • ASM 25/25 test • ASM 50/15 test • Federal Test Procedure (FTP) • I/M 240 test • lean indicator • non-methane hydrocarbon (NMHC) • ozone • Sealed Housing for Evaporative Determination (SHED) test • smog • State Implementation Plan (SIP)

EMISSION STANDARDS IN THE UNITED STATES

In the United States, emissions standards are managed by the Environmental Protection Agency (EPA) as well as some U.S. state governments. Some of the strictest standards in the world are formulated in California by the California Air Resources Board (CARB).

Tier 1 and Tier 2 Federal emission standards are set by the clean air act amendments (CAAA) of 1990 grouped by tier. All vehicles sold in the United States must meet Tier 1 standards that went into effect in 1994 and are the least stringent. Additional Tier 2 standards have been optional since 2001, and are currently being phased-in to be fully adopted by 2009. The current Tier 1 standards are different between automobiles and light trucks (SUVs, pickup trucks, and minivans), but Tier 2 standards will be the same for both types.

There are several ratings that can be given to vehicles, and a certain percentage of a manufacturer's vehicles must meet different levels in order for the company to sell its products in affected regions. Beyond Tier 1, and in order by stringency, are the following levels:

- **TLEV—Transitional Low-Emission Vehicle**—More stringent for HC than Tier 1.
- **LEV**—(also known as: **LEV I**) **Low-Emission Vehicle,** an intermediate California standard about twice as stringent as Tier 1 for HC and NO_x.
- **ULEV** (also known as **ULEV I**),—**Ultra-Low-Emission Vehicle**—A stronger California standard emphasizing very low HC emissions.
- **ULEV II—Ultra-Low-Emission Vehicle**—A cleaner-than-average vehicle certified under the Phase II LEV standard. Hydrocarbon and carbon monoxide emissions levels are nearly 50% lower than those of a LEV II-certified vehicle. See Figure 61–1.
- **SULEV—Super-Ultra-Low-Emission Vehicle**—A California standard even tighter than ULEV, including much lower HC and NO_x emissions; roughly equivalent to Tier 2 Bin 2 vehicles.
- **ZEV—Zero-Emission Vehicle**—A California standard prohibiting any tailpipe emissions. The ZEV category is largely restricted to electric vehicles and hydrogen-fueled vehicles. In these cases, any emissions that are created are produced at another site, such as a power plant or hydrogen reforming center, unless such sites run on renewable energy.

NOTE: A battery-powered electric vehicle charged from the power grid will still be up to 10 times cleaner than even the cleanest gasoline vehicles over their respective lifetimes.

- **PZEV—Partial Zero-Emission Vehicle**—Compliant with the SULEV standard; additionally has near-zero evaporative emissions and a 15-year/150,000-mile warranty on its emission control equipment.

Tier 2 standards are even more stringent. Tier 2 variations are appended with "II," such as LEV II or SULEV II. Other categories have also been created:

- **ILEV—Inherently Low-Emission Vehicle**
- **AT-PZEV—Advanced Technology Partial Zero-Emission Vehicle**—If a vehicle meets the PZEV standards and is using high-technology features, such as an electric motor or high-pressure gaseous fuel tanks for compressed natural gas, it qualifies as an AT-PZEV. Hybrid electric vehicles such as the Toyota Prius can qualify, as can internal combustion engine vehicles that run on natural gas (CNG), such as the Honda Civic GX. These vehicles are classified as "partial" ZEV because they receive partial credit for the number of ZEV vehicles that automakers would otherwise be required to sell in California.
- **NLEV—National Low-Emission Vehicle**—All vehicles nationwide must meet this standard, which started in 2001.

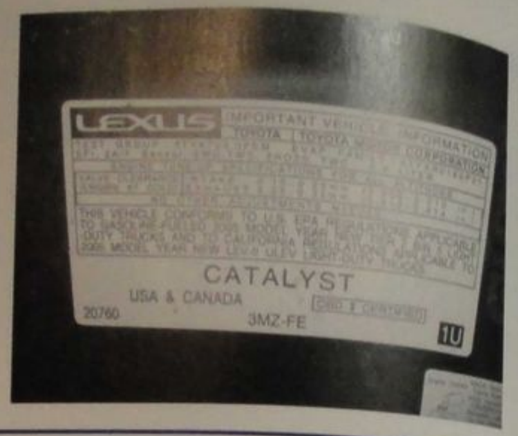


Figure 61–1 The underhood decal showing that this Lexus RX-330 meets both national (Tier 2; BIN 5) and California LEV-II (ULEV) regulation standards.

Federal EPA Bin Number The higher the tier number, the newer the regulation; the lower the bin number, the cleaner the vehicle. The 2004 Toyota Prius is a very clean Bin 3, while the Hummer H2 is a dirty Bin 11. See Tables 61.1, 61.2, and 61.3.

Smog Emission Information New vehicles are equipped with a sticker that shows the relative level of smog-causing emissions created by the vehicle compared to others on the market. Smog-causing emissions include unburned hydrocarbons (HC) and oxides of nitrogen (NO_x). See Figure 61–2.

TABLE 61.1 EPA Tier 2—120,000-Mile Tailpipe Emission Limits

Certification Level	NMOG (g/mi)	CO (g/mi)	NO_x (g/mi)
Bin 1	0.0	0.0	0.0
Bin 2	0.010	2.1	0.02
Bin 3	0.055	2.1	0.03
Bin 4	0.070	2.1	0.04
Bin 5	0.090	4.2	0.07
Bin 6	0.090	4.2	0.10
Bin 7	0.090	4.2	0.15
Bin 8a	0.125	4.2	0.20
Bin 8b	0.156	4.2	0.20
Bin 9a	0.090	4.2	0.30
Bin 9b	0.130	4.2	0.30
Bin 9c	0.180	4.2	0.30
Bin 10a	0.156	4.2	0.60
Bin 10b	0.230	6.4	0.60
Bin 10c	0.230	6.4	0.60
Bin 11	0.230	7.3	0.90

NOTE: The bin number is determined by the type and weight of the vehicle.

Source: Data compiled from the Environmental Protection Agency (EPA).

TABLE 61.2 Air Pollution Score

U.S. EPA Vehicle Information Program (The Higher the Score, the Lower the Emissions)	
Selected Emissions Standards	**Score**
Bin 1 and ZEV	10
PZEV	9.5
Bin 2	9
Bin 3	8
Bin 4	7
Bin 5 and LEV II cars	6
Bin 6	5
Bin 7	4
Bin 8	3
Bin 9a and LEV I cars	2
Bin 9b	2
Bin 10a	1
Bin 10b and Tier 1 cars	1
Bin 11	0

Source: Courtesy of the Environmental Protection Agency (EPA).

TABLE 61.3 Greenhouse Gas Score

	Minimum Fuel Economy (mpg) Combined City-Highway Label Value				
Score	**Gasoline**	**Diesel**	**E-85**	**LPG**	**CNG***
10	44	50	31	28	33
9	36	41	26	23	27
8	30	35	22	20	23
7	26	30	19	17	20
6	23	27	17	15	18
5	21	24	15	14	16
4	19	22	14	12	14
3	17	20	12	11	13
2	16	18	—	—	12
1	15	17	11	10	11
0	14	16	10	9	10

*CNG assumes a gallon equivalent of 121.5 cubic feet.

Source: Courtesy of the Environmental Protection Agency (EPA).

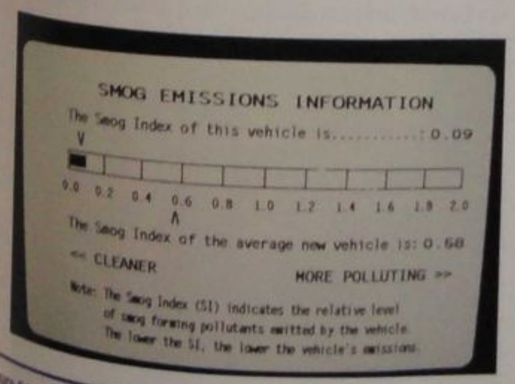


Figure 61–2 This label on a Toyota Camry hybrid shows the relative smog-producing emissions, but this does not include carbon dioxide (CO_2), which may increase global warming.

California Standards The pre-2004 California Air Resources Board (CARB) standards as a whole were known as LEV I. Within that, there were four possible ratings: Tier 1, TLEV, LEV, and ULEV. The newest CARB rating system (since January 1, 2004) is known as LEV II. Within that rating system there are three primary ratings: LEV, ULEV, and SULEV. States other than California are given the option to use the federal EPA standards, or they can adopt California's standards.

EUROPEAN STANDARDS

Europe has its own set of standards that vehicles must meet, which includes the following tiers:

- Euro I (1992–1995)
- Euro II (1995–1999)
- Euro III (1999–2005)
- Euro IV (2005–2008)
- Euro V (2008+)

Vehicle emission standards and technological advancements have successfully reduced pollution from cars and trucks by about 90% since the 1970s. Unfortunately, there currently are more vehicles on the road and they are being driven more miles each year, partially offsetting the environmental benefits of individual vehicle emissions reductions.

EXHAUST ANALYSIS TESTING

The Clean Air Act Amendments require enhanced I/M programs in areas of the country that have the worst air quality and the Northeast Ozone Transport region. The states must submit to the EPA a **State Implementation Plan (SIP)** for their programs. Each enhanced I/M program is required to include as a minimum the following items:

- Computerized emission analyzers
- Visual inspection of emission control items
- Minimum waiver limit (to be increased based on the inflation index)
- Remote on-road testing of one-half of 1% of the vehicle population
- Registration denial for vehicles not passing an I/M test
- Denial of waiver for vehicles that are under warranty or that have been tampered with
- Annual inspections
- OBD-II systems check for 1996 and newer vehicles

Federal Test Procedure (FTP) The **Federal Test Procedure (FTP)** is the test used to certify all new vehicles before they can be sold. Once a vehicle meets these standards, it is certified by the EPA for sale in the United States. The FTP test procedure is a loaded-mode test lasting for a total duration of 505 seconds and is designed to simulate an urban driving trip. A cold start-up representing a morning start and a hot start after a soak period is part of the test. In addition to this drive cycle, a vehicle must undergo evaporative testing. Evaporative emissions are determined using the **Sealed Housing for Evaporative Determination (SHED)** test, which measures the evaporative emissions from the vehicle after a heat-up period representing a vehicle sitting in the sun. In addition, the vehicle is driven and then tested during the hot soak period.

NOTE: A SHED is constructed entirely of stainless steel. The walls, floors, and ceiling, plus the door, are all constructed of stainless steel because it does not absorb hydrocarbons, which could offset test results.

The FTP is a much more stringent test of vehicle emissions than is any test type that uses equipment that measures percentages of exhaust gases. The federal emission standards for each model year vehicle are the same for that model regardless of what size engine the vehicle is equipped with. This is why larger V-8 engines often are equipped with more emission control devices than smaller four- and six-cylinder engines.

I/M Test Programs There are a variety of I/M testing programs that have been implemented by the various states. These programs may be centralized testing programs or decentralized testing programs. Each state is free to develop a testing program suitable to their needs as long as they can demonstrate to the EPA that their plan will achieve the attainment levels set by the EPA. This approach has led to a variety of different testing programs. See Figure 61–3.

Visual Tampering Checks Visual tampering checks may be part of an I/M testing program and usually include checking for the following items:

- Catalytic converter
- Fuel tank inlet restrictor
- Exhaust gas recirculation (EGR)
- Evaporative emission system
- Air-injection reaction system (AIR)
- Positive crankcase ventilation (PCV)

If any of these systems are missing, not connected, or tampered with, the vehicle will fail the emissions test and will have to be repaired/replaced by the vehicle owner before the vehicle can pass the emission test. Any cost associated with repairing or replacing these components may not be used toward the waiver amount required for the vehicle to receive a waiver.

One-Speed and Two-Speed Idle Test The one-speed and two-speed idle test measures the exhaust emissions from the tailpipe of the vehicle at idle and/or at 2500 RPM. This uses standalone exhaust gas sampling equipment that measures the emissions in percentages. Each state chooses the standards that the vehicle has to meet in order to pass the test. The advantage to using this type of testing is that the equipment is relatively cheap and allows states to have decentralized testing programs because many facilities can afford the necessary equipment required to perform this test.

Loaded Mode Test The loaded mode test uses a dynamometer that places a "single weight" load on the vehicle. The load applied to the vehicle varies with the speed of the vehicle. Typically, a four-cylinder vehicle speed would be 24 mph, a six-cylinder vehicle speed would be 30 mph, and an eight-cylinder vehicle speed would be 34 mph. Conventional stand-alone sampling equipment is used to measure HC and CO emissions. This type of test is classified as a Basic I/M test by the EPA. See Figure 61–4.

Acceleration Simulation Mode (ASM) The ASM-type of test uses a dynamometer that applies a heavy load on the vehicle at a steady-state speed. The load applied to the vehicle is based on the acceleration rate on the second simulated hill of the FTP. This acceleration rate is 3.3 mph/sec/sec (read as 3.3 mph per second per second, which is the unit of acceleration). There are different ASM tests used by different states.

The **ASM 50/15** test places a load of 50% on the vehicle at a steady 15 mph. This load represents 50% of the horsepower required to simulate the FTP acceleration rate of 3.3 mph/sec. This type of test produces relatively high levels of NO_x emissions; therefore, it is useful in detecting vehicles that are emitting excessive NO_x.

The **ASM 25/25** test places a 25% load on the vehicle while it is driven at a steady 25 mph. This represents 25% of the load required to simulate the FTP acceleration rate of 3.3 mph/sec. Because this applies a smaller load on the vehicle at a higher speed, it will produce a higher level of HC and CO emissions than the ASM 50/15. NO_x emissions will tend to be lower with this type of test.

I/M 240 Test The **I/M 240** test is the EPA's enhanced test. It is actually a portion of the 505-second FTP test used by the manufacturers to certify their new vehicles. The "240" stands for 240 seconds of drive time on a dynamometer. This is a loaded-mode transient test that uses constant volume sampling equipment to measure the exhaust emissions in mass just as is done during the FTP. The I/M 240 test simulates the first two hills of the FTP drive cycle. Figure 61–5 shows the I/M 240 drive trace.

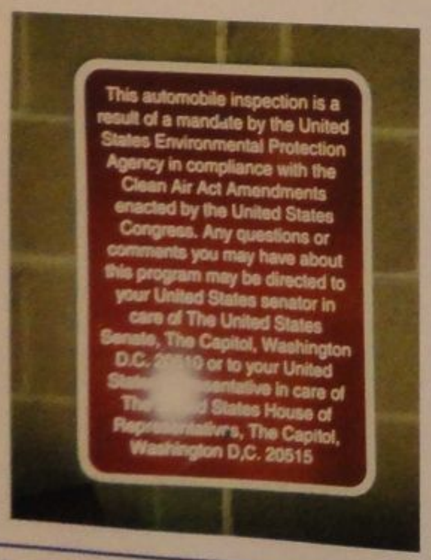


Figure 61–3 Photo of a sign taken at an emissions test facility.



Figure 61–4 A vehicle being tested during an enhanced emission test.

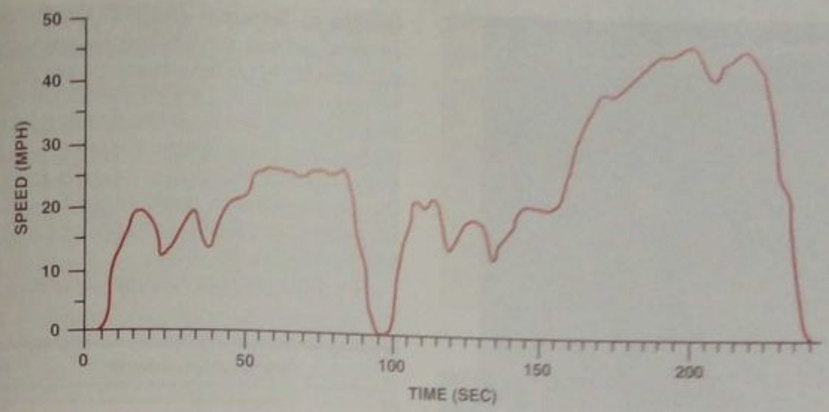


Figure 61–5 Trace showing the Inspection/Maintenance 240 test. The test duplicates an urban test loop around Los Angeles, California. The first "hump" in the curve represents the vehicle being accelerated to about 20 mph, then driving up a small hill to about 30 mph and coming to a stop. At about 94 seconds, the vehicle stops and again accelerates while climbing a hill and speeding up to about 50 mph during this second phase of the test.

OBD-II Testing In 1999, the EPA requested that states adopt OBD-II systems testing for 1996 and newer vehicles. The OBD-II system is designed to illuminate the MIL light and store trouble codes any time a malfunction exists that would cause the vehicle emissions to exceed 1½ times the FTP limits. If the OBD-II system is working correctly, the system should be able to detect a vehicle failure that would cause emissions to increase to an unacceptable level. The EPA has determined that the OBD-II system should detect emission failures of a vehicle even before that vehicle would fail an emissions test of the type that most states are employing. Furthermore, the EPA has determined that, as the population of OBD-II-equipped vehicles increases and the population of older non-OBD-II-equipped vehicles decreases, tailpipe testing will no longer be necessary.

The OBD-II testing program consists of a computer that can scan the vehicle OBD-II system using the DLC connector. The technician first performs a visual check of the vehicle MIL light to determine if it is working correctly. Next, the computer is connected to the vehicle's DLC connector. The computer will scan the vehicle OBD-II system and determine if there are any codes stored that are commanding the MIL light on. In addition, it will scan the status of the readiness monitors and determine if they have all run and passed. If the readiness monitors have all run and passed, it indicates that the OBD-II system has tested all the components of the emission control system. An OBD-II vehicle would fail this OBD-II test if:

- The MIL light does not come on with the key on, engine off
- The MIL is commanded on
- A number (varies by state) of the readiness monitors have not been run

If none of these conditions are present, the vehicle will pass the emissions test.

Remote Sensing The EPA requires that, in high-enhanced areas, states perform on-the-road testing of vehicle emissions. The state must sample 0.5% of the vehicle population base in high-enhanced areas. This may be accomplished by using a remote sensing device. This type of sensing may be done through equipment that projects an infrared light through the exhaust stream of a passing vehicle. The reflected beam can then be analyzed to determine the pollutant levels coming from the vehicle. If a vehicle fails this type of test, the vehicle owner will receive notification in the mail that he or she must take the vehicle to a test facility to have the emissions tested.

Random Roadside Testing Some states may implement random roadside testing that would usually involve visual checks of the emission control devices to detect tampering. Obviously, this method is not very popular as it can lead to traffic tie-ups and delays on the part of commuters.

Exhaust analysis is an excellent tool to use for the diagnosis of engine performance concerns. In areas of the country that require exhaust testing to be able to get license plates, exhaust analysis must be able to:

- Establish a baseline for failure diagnosis and service.
- Identify areas of engine performance that are and are not functioning correctly.
- Determine that the service and repair of the vehicle have been accomplished and are complete.

EXHAUST ANALYSIS AND COMBUSTION EFFICIENCY

A popular method of engine analysis, as well as emission testing, involves the use of five-gas exhaust analysis equipment. See Figure 61–6. The five gases analyzed and their significance include:

Hydrocarbons Hydrocarbons (HC) are unburned gasoline and are measured in parts per million (ppm). A correctly operating engine should burn (oxidize) almost all the gasoline; therefore, very little unburned gasoline should be present in the exhaust. Acceptable levels of HC are 50 ppm or less. High levels of HC could be due to excessive oil consumption caused by weak piston rings or worn valve guides. The most common cause of excessive HC emissions is a fault in the ignition system. Items that should be checked include:

- Spark plugs
- Spark plug wires
- Distributor cap and rotor (if the vehicle is so equipped)
- Ignition timing (if possible)
- Ignition coil

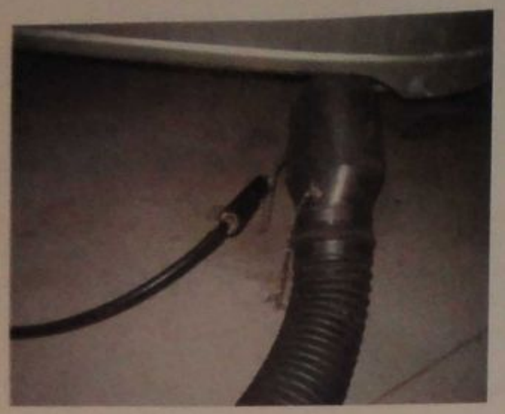


Figure 61–6 A partial stream sampling exhaust probe being used to measure exhaust gases in parts per million (ppm) or percent (%).

FREQUENTLY ASKED QUESTION ???

What Does NMHC Mean?

NMHC means **non-methane hydrocarbon** and it is the standard by which exhaust emission testing for hydrocarbons is evaluated. Methane is natural gas and can come from animals, animal waste, and other natural sources. By not measuring methane gas, all background sources are eliminated, giving better results as to the true amount of unburned hydrocarbons that are present in the exhaust stream.

Carbon Monoxide Carbon monoxide (CO) is unstable and will easily combine with any oxygen to form stable carbon dioxide (CO_2). The fact that CO combines with oxygen is the reason that CO is a poisonous gas (in the lungs, it combines with oxygen to form CO_2 and deprives the brain of oxygen). CO levels of a properly operating engine should be less than 0.5%. High levels of CO can be caused by clogged or restricted crankcase ventilation devices such as the PCV valve, hose(s), and tubes. Other items that might cause excessive CO include:

- Clogged air filter
- Incorrect idle speed
- Too-high fuel-pump pressure
- Any other items that can cause a rich condition

Carbon Dioxide (CO_2) Carbon dioxide (CO_2) is the result of oxygen in the engine combining with the carbon of the gasoline. An acceptable level of CO_2 is between 12% and 15%. A high reading indicates an efficiently operating engine. If the CO_2 level is low, the mixture may be either too rich or too lean.

Oxygen The next gas is oxygen (O_2). There is about 21% oxygen in the atmosphere, and most of this oxygen should be "used up" during the combustion process to oxidize all the hydrogen and carbon (hydrocarbons) in the gasoline. Levels of O_2 should be very low (about 0.5%). High levels of O_2, especially at idle, could be due to an exhaust system leak.

NOTE: Adding 10% alcohol to gasoline provides additional oxygen to the fuel and will result in lower levels of CO and higher levels of O_2 in the exhaust.

Oxides of Nitrogen (NO_X) An oxide of nitrogen (NO) is a colorless, tasteless, and odorless gas when it leaves the engine, but as soon as it reaches the atmosphere and mixes with more oxygen, nitrogen oxides (NO_2) are formed. NO_2 is reddish-brown and has an acid and pungent smell. NO and NO_2 are grouped together and referred to as NO_X, where x represents any number of oxygen atoms. NO_X, the symbol used to represent all oxides of nitrogen, is the fifth gas commonly tested using a five-gas analyzer. The exhaust gas recirculation (EGR) system is the major controlling device limiting the formation of NO_X.

Acceptable exhaust emissions include:

	Without Catalytic Converter	With Catalytic Converter
HC	300 ppm or less	30 to 50 ppm or less
CO	3% or less	0.3% to 0.5% or less
O_2	0% to 2%	0% to 2%
CO_2	12% to 15% or higher	12% to 15% or higher
NO_X	Less than 100 ppm at idle and less than 1,000 ppm at WOT	Less than 100 ppm at idle and less than 1,000 ppm at WOT

See Figure 61–7.

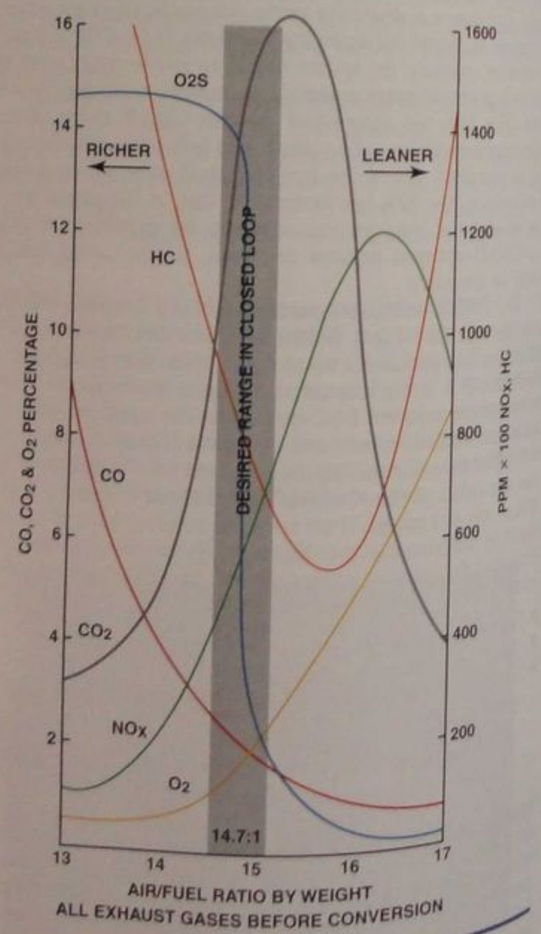


Figure 61–7 Exhaust emissions are very complex. When the air–fuel mixture becomes richer, some exhaust emissions are reduced, while others increase.

FREQUENTLY ASKED QUESTION ???

How Can My Worn-Out, Old, High-Mileage Vehicle Pass an Exhaust Emission Test?

Age and mileage of a vehicle are generally not factors when it comes to passing an exhaust emission test. Regular maintenance is the most important factor for passing an enhanced Inspection and Maintenance (I/M) exhaust analysis test. Failure of the vehicle owner to replace broken accessory drive belts, leaking AIR pump tubes, defective spark plug wires, or a cracked exhaust manifold can lead to failure of other components such as the catalytic converter. Tests have shown that if the vehicle is properly cared for, even an engine that has 300,000 miles (483,000 km) can pass an exhaust emission test.

HC TOO HIGH

High hydrocarbon exhaust emissions are usually caused by an engine misfire. What burns the fuel in an engine? The ignition system ignites a spark at the spark plug to ignite the *proper* mixture inside the combustion chamber. If a spark plug does not ignite the mixture, the resulting unburned fuel is pushed out of the cylinder on the exhaust stroke by the piston through the exhaust valves and into the exhaust system. Therefore, if any of the following ignition components or adjustments are not correct, excessive HC emission is likely.

1. Defective or worn spark plugs
2. Defective or loose spark plug wires
3. Defective distributor cap and/or rotor
4. Incorrect ignition timing (either too far advanced or too far retarded)
5. A lean air–fuel mixture can also cause a misfire. This condition is referred to as a lean misfire.

HINT: To make discussion easier in future reference to these items, this list of ignition components and checks will be referred to simply as "spark stuff."

CO TOO HIGH

Excessive carbon monoxide is an indication of too rich an air–fuel mixture. High concentrations of CO indicate that not enough oxygen was available for the amount of fuel. Common causes of high CO include:

- Too-high fuel-pump pressure
- Defective fuel-pressure regulator
- Clogged air filter or PCV valve

HINT: One technician remembers "CO" as meaning "clogged oxygen" and always looks for restricted airflow into the engine whenever high CO levels are detected.

- Defective injectors

TECH TIP ✓ CO Equals O_2

If the exhaust is rich, CO emissions will be higher than normal. If the exhaust is lean, O_2 emissions will be higher than normal. Therefore, if the CO reading is the same as the O_2 reading, then the engine is operating correctly. For example, if both CO and O_2 are 0.5% and the engine develops a vacuum leak, the O_2 will rise. If a fuel-pressure regulator were to malfunction, the resulting richer air–fuel mixture would increase CO emissions. Therefore, if both the rich indicator (CO) and the lean indicator (O_2) are equal, the engine is operating correctly.

MEASURING OXYGEN (O_2) AND CARBON DIOXIDE (CO_2)

Two gas exhaust analyzers (HC and CO) work well, but both HC and CO are consumed (converted) inside the catalytic converter. The amount of leftover oxygen coming out of the tailpipe is an indication of leanness. The higher the O_2 level, the leaner the exhaust. Oxygen therefore is the **lean indicator.** Acceptable levels of O_2 are 0% to 2%.

NOTE: A hole in the exhaust system can draw outside air (oxygen) into the exhaust system. Therefore, to be assured of an accurate reading, carefully check the exhaust system for leaks. Using a smoke machine is an easy method to locate leaks in the exhaust system.

Carbon dioxide (CO_2) is a measure of efficiency. The higher the level of CO_2 in the exhaust stream, the more efficiently the engine is operating. Levels of 12% to 17% are considered to be acceptable. Because CO_2 levels peak at an air–fuel mixture of 14.7:1, a lower level of CO_2 indicates either a too-rich or a too-lean condition. The CO_2 measurement by itself does not indicate which condition is present. For example:

CO_2 = 8% (This means efficiency is low and the air–fuel mixture is not correct.)

Look at O_2 and CO levels.

A high O_2 indicates lean and a high CO indicates rich.

TECH TIP ✓ How to Find a Leak in the Exhaust System

A hole in the exhaust system can dilute the exhaust gases with additional oxygen (O_2). See Figure 61–8.

This additional O_2 in the exhaust can lead the service technician to believe that the air–fuel mixture is too lean. To help identify an exhaust leak, perform an exhaust analysis at idle and at 2500 RPM (fast idle) and compare with the following:

- If the O_2 is high at idle and at 2500 RPM, the mixture is lean at both idle and at 2500 RPM.
- If the O_2 is low at idle and high at 2500 RPM, this usually means that the vehicle is equipped with a working AIR pump.
- If the O_2 is high at idle, but okay at 2500 RPM, a hole in the exhaust or a small vacuum leak that is "covered up" at higher speed is indicated.

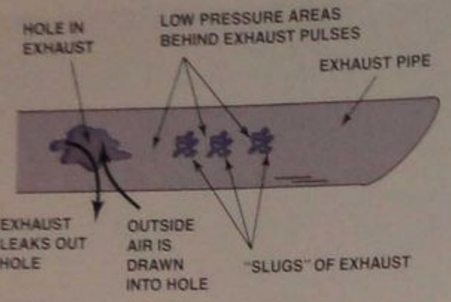


Figure 61–8 A hole in the exhaust system can cause outside air (containing oxygen) to be drawn into the exhaust system. This extra oxygen can be confusing to a service technician because the extra O_2 in the exhaust stream could be misinterpreted as a too-lean air–fuel mixture.

TECH TIP ✔ **Your Nose Knows**

Using the nose, a technician can often identify a major problem without having to connect the vehicle to an exhaust analyzer. For example,

- The strong smell of exhaust is due to excessive unburned hydrocarbon (HC) emissions. Look for an ignition system fault that could prevent the proper burning of the fuel. A vacuum leak could also cause a lean misfire and cause excessive HC exhaust emissions.
- If your eyes start to burn or water, suspect excessive oxides of nitrogen (NO_X) emissions. The oxides of nitrogen combine with the moisture in the eyes to form a mild solution of nitric acid. The acid formation causes the eyes to burn and water. Excessive NO_X exhaust emissions can be caused by:
  - A vacuum leak causing higher-than-normal combustion chamber temperature
  - Overadvanced ignition timing causing higher-than-normal combustion chamber temperature
  - Lack of proper amount of exhaust gas recirculation (EGR) (This is usually noticed above idle on most vehicles.)
- Dizzy feeling or headache. This is commonly caused by excessive carbon monoxide (CO) exhaust emissions. Get into fresh air as soon as possible. A probable cause of high levels of CO is an excessively rich air–fuel mixture.

PHOTOCHEMICAL SMOG FORMATION

Oxides of nitrogen are formed by high temperature—over 2500°F (1370°C)—and/or pressures inside the combustion chamber. Oxides of nitrogen contribute to the formation of photochemical **smog** when sunlight reacts chemically with NO_X and unburned hydrocarbons (HC). Smog is a term derived by combining the words *smoke* and *fog*. Ground-level ozone is a constituent of smog. **Ozone** is an enriched oxygen molecule with three atoms of oxygen (O_3) instead of the normal two atoms of oxygen (O_2).

Ozone in the upper atmosphere is beneficial because it blocks out harmful ultraviolet rays that contribute to skin cancer. However, at ground level, this ozone (smog) is an irritant to the respiratory system.

TESTING FOR OXIDES OF NITROGEN

Because the formation of NO_X occurs mostly under load, the most efficient method to test for NO_X is to use a portable exhaust analyzer that can be carried in the vehicle while the vehicle is being driven under a variety of conditions.

Specifications for NO_X From experience, a maximum reading of 1,000 parts per million (ppm) of NO_X under loaded driving conditions will generally mean that the vehicle will pass an enhanced I/M roller test. A reading of over 100 ppm at idle should be considered excessive.

TECH TIP ✔ **Check for Dog Food?**

A commonly experienced problem in many parts of the country involves squirrels or other animals placing dog food into the air intake ducts of vehicles. Dog food is often found packed tight in the ducts against the air filter. An air intake restriction occurs and drives the fuel mixture richer than normal and reduces engine power and vehicle performance as well as creating high CO exhaust emissions.

REAL WORLD FIX **The Case of the Retarded Exhaust Camshaft**

A Toyota equipped with a double overhead camshaft (DOHC) inline six-cylinder engine failed the state-mandated enhanced exhaust emission test for NO_X. The engine ran perfectly without spark knocking (ping), which is usually a major reason for excessive NO_X emissions. The technician checked the following:

- The ignition timing, which was found to be set to specifications (if too far advanced, can cause excessive NO_X)
- The cylinders, which were decarbonized using top engine cleaner
- The EGR valve, which was inspected and the EGR passages cleaned

After all the items were completed, the vehicle was returned to the inspection station where the vehicle again failed for excessive NO_X emissions (better, but still over the maximum allowable limit).

After additional hours of troubleshooting, the technician decided to go back to basics and start over again. A check of the vehicle history with the owner indicated that the only previous work performed on the engine was a replacement timing belt over a year before. The technician discovered that the exhaust cam timing was retarded two teeth, resulting in late closing of the exhaust valve. The proper exhaust valve timing resulted in a slight amount of exhaust being retained in the cylinder. This extra exhaust was added to the amount supplied by the EGR valve and helped reduce NO_X emissions. After repositioning the timing belt, the vehicle passed the emissions test well within the limits.

Exhaust Gas Summary Chart

Gas	Cause and Correction
High HC	Engine misfire or incomplete burning of fuel caused by: 1. Ignition system fault 2. Lean misfire 3. Too low an engine temperature (thermostat)
High CO	Rich condition caused by: 1. Leaking fuel injectors or fuel-pressure regulator 2. Clogged air filter or PCV system 3. Excessive fuel pressure
High HC and CO	Excessively rich condition caused by: 1. All items included under high CO 2. Fouled spark plugs causing a misfire to occur 3. Possible nonoperating catalytic converter
High NO_X	Excessive combustion chamber temperature: 1. Nonoperating EGR valve 2. Clogged EGR passages 3. Engine operating temperature too high due to cooling system restriction, worn water pump impeller, or other faults in the cooling system 4. Lean air–fuel mixture

REAL WORLD FIX **O2S Shows Rich, but Pulse Width Is Low**

A service technician was attempting to solve a driveability problem. The computer did not indicate any diagnostic trouble codes (DTCs). A check of the oxygen sensor voltage indicated a higher-than-normal reading almost all the time. The pulse width to the port injectors was lower than normal. The lower-than-normal pulse width indicates that the computer is attempting to reduce fuel flow into the engine by decreasing the amount of on-time for all the injectors.

What could cause a rich mixture if the injectors were being commanded to deliver a lean mixture? Finally the technician shut off the engine and took a careful look at the entire fuel-injection system. Although the vacuum hose was removed from the fuel-pressure regulator, fuel was found dripping from the vacuum hose. The problem was a defective fuel-pressure regulator that allowed an uncontrolled amount of fuel to be drawn by the intake manifold vacuum into the cylinders. While the computer tried to reduce fuel by reducing the pulse width signal to the injectors, the extra fuel being drawn directly from the fuel rail caused the engine to operate with too rich an air–fuel mixture.

SUMMARY

1. Excessive hydrocarbon (HC) exhaust emissions are created by a lack of proper combustion such as a fault in the ignition system, too lean an air–fuel mixture, or too cold engine operation.
2. Excessive carbon monoxide (CO) exhaust emissions are usually created by a rich air–fuel mixture.
3. Excessive oxides of nitrogen (NO_X) exhaust emissions are usually created by excessive heat or pressure in the combustion chamber or a lack of the proper amount of exhaust gas recirculation (EGR).
4. Carbon dioxide (CO_2) levels indicate efficiency. The higher the CO_2, the more efficient the engine operation.
5. Oxygen (O_2) indicates leanness. The higher the O_2, the leaner the air–fuel mixture.
6. A vehicle should be driven about 20 miles, especially during cold weather, to allow the engine to be fully warm before an enhanced emissions test.

REVIEW QUESTIONS

1. List the five exhaust gases and their maximum allowable readings for a fuel-injected vehicle equipped with a catalytic converter.
2. List two causes of a rich exhaust.
3. List two causes of a lean exhaust.
4. List those items that should be checked if a vehicle fails an exhaust test for excessive NO_X emissions.

CHAPTER QUIZ

1. Technician A says that high HC emission levels are often caused by a fault in the ignition system. Technician B says that high CO_2 emissions are usually caused by a richer-than-normal air–fuel mixture. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. HC and CO are high and CO_2 and O_2 are low. This could be caused by a _____.
   a. Rich mixture
   b. Lean mixture
   c. Defective ignition component
   d. Clogged EGR passage
3. Which gas is generally considered to be the rich indicator? (The higher the level of this gas, the richer the air–fuel mixture.)
   a. HC
   b. CO
   c. CO_2
   d. O_2
4. Which gas is generally considered to be the lean indicator? (The higher the level of this gas, the leaner the air–fuel mixture.)
   a. HC
   b. CO
   c. CO_2
   d. O_2
5. Which exhaust gas indicates efficiency? (The higher the level of this gas, the more efficient the engine operates.)
   a. HC
   b. CO
   c. CO_2
   d. O_2
6. All of the gases are measured in percentages except _____.
   a. HC
   b. CO
   c. CO_2
   d. O_2
7. After the following exhaust emissions were measured, how was the engine operating?
   HC = 766 ppm CO_2 = 8.2% CO = 4.6% O_2 = 0.1%
   a. Too rich
   b. Too lean
8. Technician A says that carbon inside the engine can cause excessive NO_X to form. Technician B says that excessive NO_X could be caused by a cooling system fault causing the engine to operate too hot. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A clogged EGR passage could cause excessive _____ exhaust emissions.
   a. HC
   b. CO
   c. NO_X
   d. CO_2
10. An ignition fault could cause excessive _____ exhaust emissions.
    a. HC
    b. CO
    c. NO_X
    d. CO_2

CHAPTER 62

Emission Control Devices Operation and Diagnosis

OBJECTIVES: After studying Chapter 62, the reader will be able to: Prepare for the ASE Engine Performance (A8) certification test content area "D" (Emission Control Systems). • Describe the purpose and function of the exhaust gas recirculation system. • Explain methods for diagnosing and testing for faults in the exhaust gas recirculation system. • Describe the purpose and function of the positive crankcase ventilation and the air injection reaction system. • Explain methods for diagnosing and testing faults in the PCV and AIR systems. • Describe the purpose and function of the catalytic converter. • Explain the method for diagnosing and testing the catalytic converter. • Describe the purpose and function of the evaporative emission control system. • Discuss how the evaporative emission control system is tested under OBD-II regulations. • Explain methods for diagnosing and testing faults in the evaporative emission control system.

KEY TERMS: absorption • air injection reaction (AIR) • backpressure • blowby • canister purge (CANP) • catalyst • catalytic converter • cerium • check valves • delta pressure feedback EGR (DPFE) • digital EGR • EGR valve position (EVP) • electronic vacuum regulator valve (EVR) • evaporative control system • exhaust gas recirculation (EGR) • heated oxygen sensor (HO2S) • inert • infrared pyrometer • leak detection pump (LDP) • light-off • light-off converter (LOC) • linear EGR • mini-converter • negative backpressure • nitrogen oxides (NO_x) • oxygen storage capacity (OSC) • palladium • platinum • positive backpressure • positive crankcase ventilation (PCV) • pressure feedback EGR (PFE) • preconverter • pup converter • rhodium • secondary air injection (SAI) • smog pump • thermactor pump • three-way catalytic converter (TWC) • washcoat

SMOG

The common term used to describe air pollution is *smog*, a word that combines the two words *smoke* and *fog*. Smog is formed in the atmosphere when sunlight combines with unburned fuel (hydrocarbon, or HC) and oxides of nitrogen (NO_x) produced during the combustion process inside the cylinders of an engine. Smog is ground level ozone (O_3), a strong irritant to the lungs and eyes.



Figure 62–1 Notice the reddish-brown haze caused by nitrogen oxides that is often over many major cities.

NOTE: Although upper-atmospheric ozone is desirable because it blocks out harmful ultraviolet rays from the sun, ground-level ozone is considered to be unhealthy smog.

- **HC (unburned hydrocarbons).** Excessive HC emissions (unburned fuel) are controlled by the evaporative system (charcoal canister), the positive crankcase ventilation (PCV) system, the air-pump system, and the catalytic converter.
- **CO (carbon monoxide).** Excessive CO emissions are controlled by the PCV system, the air-pump system, and the catalytic converter.
- **NO_x (oxides of nitrogen).** Excessive NO_x emissions are controlled by the exhaust gas recirculation (EGR) system and the catalytic converter. An oxide of nitrogen (NO) is a colorless, tasteless, and odorless gas when it leaves the engine, but as soon as it reaches the atmosphere and mixes with more oxygen, nitrogen oxides (NO_2) are formed, which appear as reddish-brown. See Figure 62–1.

EXHAUST GAS RECIRCULATION SYSTEMS

Exhaust gas recirculation (EGR) is an emission control that lowers the amount of **nitrogen oxides (NO_x)** formed during combustion. In the presence of sunlight, NO_x reacts with hydrocarbons in the atmosphere to form ozone (O_3) or photochemical smog, an air pollutant.

NO_x Formation Nitrogen N_2 and oxygen O_2 molecules are separated into individual atoms of nitrogen and oxygen during the combustion process. These then bond to form NO_x (NO, NO_2). When combustion flame-front temperatures exceed 2500°F (1370°C), NO_x formation increases dramatically.

Controlling NO_x To handle the NO_x generated above 2500°F (1370°C), the most efficient methods to meet NO_x emissions without significantly affecting engine performance, fuel economy, and other exhaust emissions is to use exhaust gas recirculation. The EGR system routes small quantities, usually between 6% and 10%, of exhaust gas into the intake manifold. Here, the exhaust gas mixes with and takes the place of some of the intake charge. This leaves less room for the intake charge to enter the combustion chamber. The recirculated exhaust gas is **inert** (chemically inactive) and does not enter into the combustion process. The result is a lower peak combustion temperature. As the combustion temperature is lowered, the production of oxides of nitrogen is also reduced.

The EGR system has some means of interconnecting the exhaust and intake manifolds. See Figures 62–2 and 62–3. The interconnecting passage is controlled by the EGR valve. On V-type engines, the intake manifold crossover is used as a source of exhaust gas for the EGR system. A cast passage connects the exhaust crossover to the EGR valve. The gas is sent from the EGR valve to openings in the manifold. On inline-type engines, an external tube is generally used to carry exhaust gas to the EGR valve. This tube is often designed to be long so that the exhaust gas is cooled before it enters the EGR valve.

NOTE: The amount of EGR is subtracted from the mass airflow calculations. While the EGR gases do occupy space, they do not affect the air–fuel mixture.

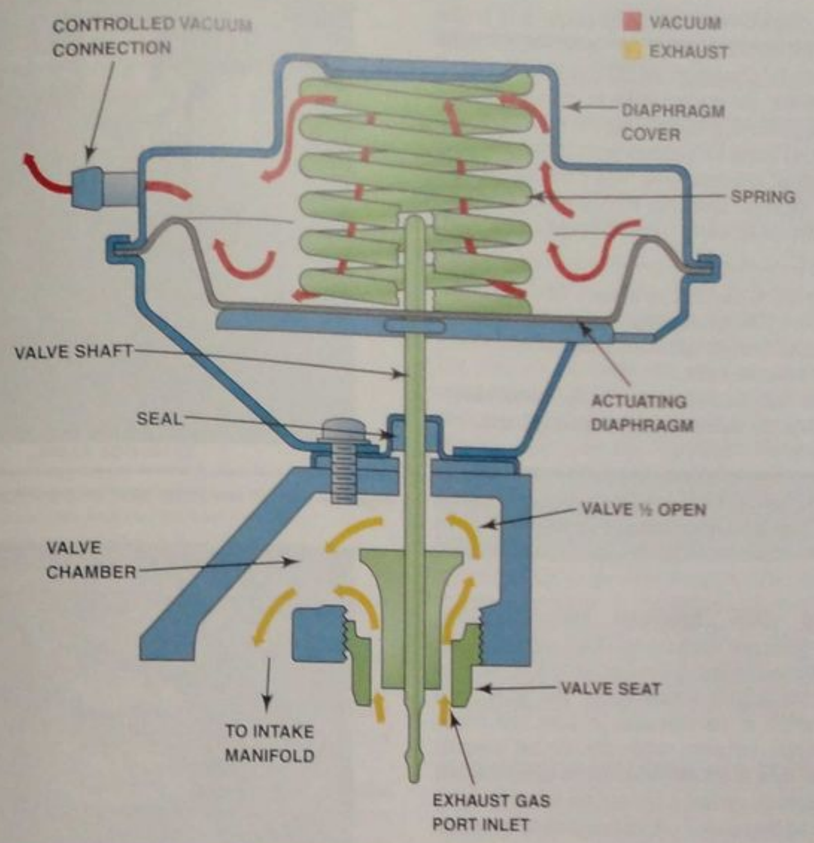


Figure 62–2 When the EGR valve opens, exhaust gases flow through the valve and into passages in the intake manifold.



Figure 62–3 A vacuum-operated EGR valve. The vacuum to the EGR valve is computer controlled by the EGR valve control solenoid.

EGR System Operation Since small amounts of exhaust are all that is needed to lower peak combustion temperatures, the orifice that the exhaust passes through is small. Because combustion temperatures are low, EGR is usually *not* required during the following conditions because the combustion temperatures are low.

- Idle speed
- When the engine is cold
- At wide-open throttle (WOT)

The level of NO_x emission changes according to engine speed, temperature, and load. EGR is not used at wide-open throttle (WOT) because it would reduce engine performance and the engine does not operate under these conditions for a long period of time.

In addition to lowering NO_x levels, the EGR system also helps control detonation. Detonation, or ping, occurs when high pressure and heat cause the air–fuel mixture to ignite. This uncontrolled combustion can severely damage the engine.

Using the EGR system allows for greater ignition timing advance and for the advance to occur sooner without detonation problems, which increases power and efficiency.

Positive and Negative Backpressure EGR Valves Some EGR valves used on older engines are designed with a small valve inside that bleeds off any applied vacuum and prevents the valve from opening. These types of EGR valves require a positive backpressure in the exhaust system. This is called a **positive backpressure** EGR valve. At low engine speeds and light engine loads,

the EGR system is not needed, and the backpressure in it is also low. Without sufficient backpressure, the EGR valve does not open even though vacuum may be present at the EGR valve.

On each exhaust stroke, the engine emits an exhaust "pulse." Each pulse represents a positive pressure. Behind each pulse is a small area of low pressure. Some EGR valves react to this low pressure area by closing a small internal valve, which allows the EGR valve to be opened by vacuum. This type of EGR valve is called a **negative backpressure** EGR valve. The following conditions must occur:

1. Vacuum must be applied to the EGR valve itself. This is usually ported vacuum on some TBI fuel-injected systems. The vacuum source is often manifold vacuum and is controlled by the computer through a solenoid valve.
2. Exhaust backpressure must be present to close an internal valve inside the EGR to allow the vacuum to move the diaphragm.

NOTE: The installation of a low-restriction exhaust system could prevent the proper operation of the backpressure-controlled EGR valve.

Computer-Controlled EGR Systems Many computer-controlled EGR systems have one or more solenoids controlling the EGR vacuum. The computer controls a solenoid to shut off vacuum to the EGR valve at cold engine temperatures, idle speed, and wide-open throttle operation. If two solenoids are used, one acts as an off/on control of supply vacuum, while the second solenoid vents vacuum when EGR flow is not desired or needs to be reduced. The second solenoid is used to control a vacuum air bleed, allowing atmospheric pressure in to modulate EGR flow according to vehicle operating conditions.

EGR Valve Position Sensors Late-model, computer-controlled EGR systems use a sensor to indicate EGR operation. On-board diagnostics generation-II (OBD-II) EGR system monitors require an EGR sensor to do their job. A linear potentiometer on the top of the EGR valve stem indicates valve position for the computer. This is called an **EGR valve position (EVP)** sensor. Some later-model Ford EGR systems, however, use a feedback signal provided by an EGR exhaust backpressure sensor which converts the exhaust backpressure to a voltage signal. This sensor is called a **pressure feedback EGR (PFE)** sensor.

TECH TIP ✓ **Find the Root Cause**

Excessive backpressure, such as that caused by a partially clogged exhaust system, could cause the plastic sensors on the EGR valve to melt. Always check for a restricted exhaust whenever replacing a failed EGR valve sensor.

The top of the valve contains a vacuum regulator and EGR pintle-position sensor in one assembly sealed inside a nonremovable plastic cover. The pintle-position sensor provides a voltage output to the PCM, which increases as the duty cycle increases, allowing the PCM to monitor valve operation. See Figure 62–4.

Digital EGR Valves GM introduced a **digital EGR** valve design on some engines. Unlike vacuum-operated EGR valves, the digital EGR valve consists of three solenoids controlled by the PCM. Each solenoid controls a different size orifice in the base—small, medium, and large. The PCM controls each solenoid ground individually. It can produce any of seven different flow rates, using the solenoids to open the three valves in different combinations. The digital EGR valve offers precise control, and using a swivel pintle design helps prevent carbon deposit problems.

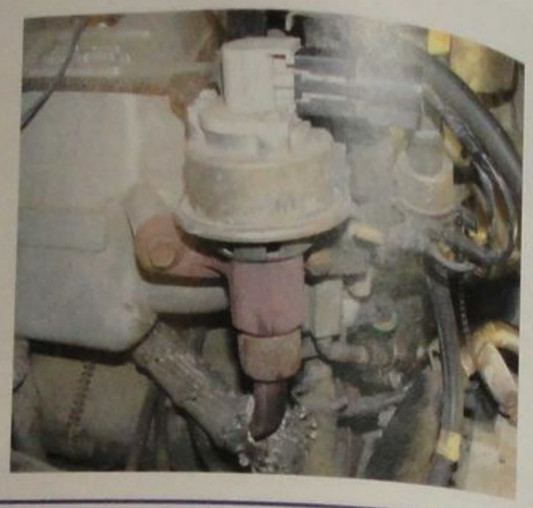


Figure 62–4 An EGR valve position sensor on top of an EGR valve.



Figure 62–5 A General Motors linear EGR value.

Linear EGR Most General Motors and many other vehicles use a **linear EGR** that contains a pulse-width modulated solenoid to precisely regulate exhaust gas flow and a feedback potentiometer that signals the computer regarding the actual position of the valve. See Figures 62–5 and 62–6.

OBD-II EGR MONITORING STRATEGIES

In 1996, the U.S. EPA began requiring OBD-II systems in all passenger cars and most light-duty trucks. These systems include emissions system monitors that alert the driver and the technician if an emissions system is malfunctioning. To be certain the EGR system is operating, the PCM runs a functional test of the system, when specific operating conditions exist. The OBD-II system tests by opening and closing the EGR valve. The PCM monitors an EGR function sensor for a change in signal voltage. If the EGR system fails, a diagnostic trouble code (DTC) is set. If the system fails two consecutive times, the malfunction indicator light (MIL) is lit.

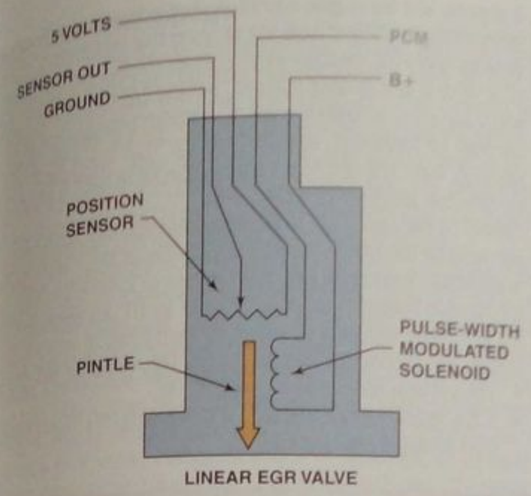


Figure 62–6 The EGR value pintle is pulse-width modulated and a three-wire potentiometer provides pintle-position information back to the PCM.

Chrysler monitors the difference in the exhaust oxygen sensor's voltage activity as the EGR valve opens and closes. Oxygen in the exhaust decreases when the EGR valve is open and increases when the EGR valve is closed. The PCM sets a DTC if the sensor signal does not change.

Most Fords use an EGR monitor test sensor called a **Delta Pressure Feedback EGR (DPFE) sensor.** This sensor measures the pressure differential between two sides of a metered orifice positioned just below the EGR valve's exhaust side. Pressure between the orifice and the EGR valve decreases when the EGR opens because it becomes exposed to the lower pressure in the intake. The DPFE sensor recognizes this pressure drop, compares it to the relatively higher pressure on the exhaust side of the orifice, and signals the value of the pressure difference to the PCM. See Figure 62–7. When the EGR valve is closed, the exhaust-gas pressure on both sides of the orifice is equal.

DPFE EGR Sensor Chart

Pressure			Voltage
PSI	In. Hg	kPa	Volts
4.34	8.83	29.81	4.56
3.25	6.62	22.36	3.54
2.17	4.41	14.90	2.51
1.08	2.21	7.46	1.48
0	0	0	0.45

The OBD-II EGR monitor for this second system runs when programmed operating conditions (enable criteria) have been met. The monitor evaluates the pressure differential while the PCM commands the EGR valve to open. Like other systems, the monitor compares the measured value with the look-up table value. If the pressure differential falls outside the acceptable value, a DTC sets.

Many vehicle manufacturers use the manifold absolute pressure (MAP) sensor as the EGR monitor on some applications. After meeting the enable criteria (operating condition requirements), the EGR monitor is run. The PCM monitors the MAP sensor while it commands the EGR valve to open. The MAP sensor signal should change in response to the sudden change in manifold pressure or the fuel trim changes created by a change in the oxygen sensor voltage. If the signal value falls outside the acceptable value in the look-up table, a DTC sets. See Figure 62–8. If the EGR fails on two consecutive trips the PCM lights the MIL.

DIAGNOSING A DEFECTIVE EGR SYSTEM

If the EGR valve is not opening or the flow of the exhaust gas is restricted, then the following symptoms are likely:

- Ping (spark knock or detonation) during acceleration or during cruise (steady-speed driving)
- Excessive oxides of nitrogen (NO_x) exhaust emissions

If the EGR valve is stuck open or partially open, then the following symptoms are likely:

- Rough idle or frequent stalling
- Poor performance/low power, especially at low engine speed

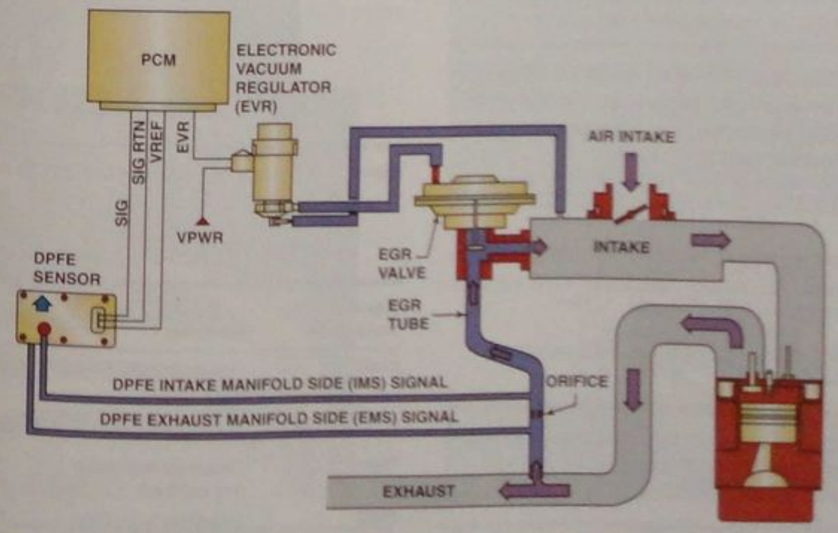


Figure 62–7 A DPFE sensor and related components.

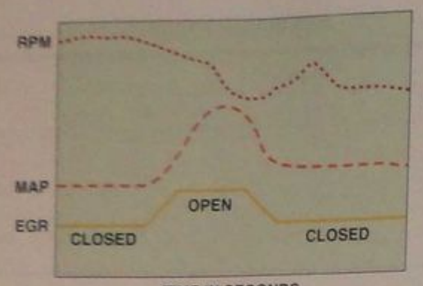


Figure 62–8 An OBD-II active test. The PCM opens the EGR valve and then monitors the MAP sensor and/or engine speed (RPM) to meet acceptable values.

TECH TIP ✔ **Watch Out for Carbon Balls!**

Exhaust gas recirculation (EGR) valves can get stuck partially open by a chunk of carbon. The EGR valve or solenoid will test as defective. When the valve (or solenoid) is removed, small chunks or balls of carbon often fall into the exhaust manifold passage. When the replacement valve is installed, the carbon balls can be drawn into the new valve again, causing the engine to idle roughly or stall.

To help prevent this problem, start the engine with the EGR valve or solenoid removed. Any balls or chunks of carbon will be blown out of the passage by the exhaust. Stop the engine and install the replacement EGR valve or solenoid.

REAL WORLD FIX **The Blazer Story**

The owner of a Chevrolet Blazer equipped with a 4.3-L, V-6 engine complained that the engine would stumble and hesitate at times. Everything seemed to be functioning correctly, except that the service technician discovered a weak vacuum going to the EGR valve at idle. This vehicle was equipped with an EGR valve-control solenoid, called an **electronic vacuum regulator valve** or **EVRV** by General Motors Corporation. The computer pulses the solenoid to control the vacuum that regulates the operation of the EGR valve. The technician checked the service manual for details on how the system worked. The technician discovered that vacuum should be present at the EGR valve only when the gear selector indicates a drive gear (drive, low, reverse). Because the technician discovered the vacuum at the solenoid to be leaking, the solenoid was obviously defective and required replacement. After replacement of the solenoid (EVRV), the hesitation problem was solved.

NOTE: The technician also discovered in the service manual that blower-type exhaust hoses should not be connected to the tailpipe on any vehicle while performing an inspection of the EGR system. The vacuum created by the system could cause false EGR valve operation to occur.

The first step in almost any diagnosis is to perform a thorough visual inspection. To check for proper operation of a vacuum-operated EGR valve, follow these steps:

1. Check the vacuum diaphragm to see if it can hold vacuum.

NOTE: Because many EGR valves require exhaust backpressure to function correctly, the engine should be running at a fast idle.

2. Apply vacuum from a hand-operated vacuum pump and check for proper operation. The valve itself should move when vacuum is applied, and the engine operation should be affected. The EGR valve should be able to hold the vacuum that was applied. If the vacuum drops off, then the valve is likely to be defective. If the EGR valve is able to hold vacuum, but the engine is not affected when the valve is opened, then the exhaust passage(s) must be checked for restriction. See the Tech Tip "The Snake Trick." If the EGR valve will not hold vacuum, the valve itself is likely to be defective and require replacement.
3. Connect a vacuum gauge to an intake manifold vacuum source and monitor the engine vacuum at idle (should be 17 to 21 in. Hg at sea level). Raise the speed of the engine to 2500 RPM and note the vacuum reading (should be 17 to 21 in. Hg or higher). Activate the EGR valve using a scan tool or vacuum pump, if vacuum controlled, and observe the vacuum gauge. The results are as follows:
   - The vacuum should drop 6 to 8 in. Hg.
   - If the vacuum drops less than 6 to 8 in. Hg, the valve or the EGR passages are clogged.

TECH TIP ✔ **The Snake Trick**

The EGR passages on many intake manifolds become clogged with carbon, which reduces the flow of exhaust and the amount of exhaust gases in the cylinders. This reduction can cause spark knock (detonation) and increased emissions of oxides of nitrogen (NO_x) (especially important in areas with enhanced exhaust emissions testing).

To quickly and easily remove carbon from exhaust passages, cut an approximately 1-foot (30-cm) length from stranded wire, such as garage door guide wire or an old speedometer cable. Flare the end and place the end of the wire into the passage. Set your drill on reverse, turn it on, and the wire will pull its way through the passage, cleaning the carbon as it goes, just like a snake in a drain pipe. Some vehicles, such as Hondas, require that plugs be drilled out to gain access to the EGR passages, as shown in Figure 62–9.



Figure 62–9 Removing the EGR passage plugs from the intake manifold on a Honda.

EGR-Related OBD-II Diagnostic Trouble Codes

Diagnostic Trouble Code	Description	Possible Causes
P0400	Exhaust gas recirculation flow problems	• EGR valve • EGR valve hose or electrical connection • Defective PCM
P0401	Exhaust gas recirculation flow insufficient	• EGR valve • Clogged EGR ports or passages
P0402	Exhaust gas recirculation flow excessive	• Stuck-open EGR valve • Vacuum hose(s) misrouted • Electrical wiring shorted

CRANKCASE VENTILATION

The problem of crankcase ventilation has existed since the beginning of the automobile, because no piston ring, new or old, can provide a perfect seal between the piston and the cylinder wall. When an engine is running, the pressure of combustion forces the piston downward. This same pressure also forces gases and unburned fuel from the combustion chamber, past the piston rings, and into the crankcase. This process of gases leaking past the rings is called **blowby,** and the gases form crankcase vapors.

These combustion by-products, particularly unburned hydrocarbons caused by blowby, must be ventilated from the crankcase. However, the crankcase cannot be vented directly to the atmosphere, because the hydrocarbon vapors add to air pollution. **Positive crankcase ventilation (PCV)** systems were developed to ventilate the crankcase and recirculate the vapors to the engine's induction system so they can be burned in the cylinders. All systems use a PCV valve, calibrated orifice or separator, an air inlet filter, and connecting hoses. See Figure 62–10. An oil/vapor or oil/water separator is used in some systems instead of a valve or orifice, particularly with turbocharged and fuel-injected engines. The oil/vapor separator lets oil condense and drain back into the crankcase. The oil/water separator accumulates moisture and prevents it from freezing during cold engine starts.

The air for the PCV system is drawn after the air cleaner filter, which acts as a PCV filter.

NOTE: Some older designs drew from the dirty side of the air cleaner, where a separate crankcase ventilation filter was used.

PCV VALVES

The PCV valve in most systems is a one-way valve containing a spring-operated plunger that controls valve flow rate. See Figure 62–11. Flow rate is established for each engine and a valve for a different engine should not be substituted. The flow rate is determined by the size of the plunger and the holes inside the valve. PCV valves usually are located in the valve cover or intake manifold.

The PCV valve regulates airflow through the crankcase under all driving conditions and speeds. When manifold vacuum is high (at idle, cruising, and light-load operation), the PCV valve restricts the airflow to maintain a balanced air–fuel ratio. See Figure 62–12. It also prevents high intake manifold vacuum from pulling oil out of the crankcase and into the intake manifold. Under high speed or heavy loads, the valve opens and allows maximum air flow. See Figure 62–13. If the engine backfires, the valve will close instantly to prevent a crankcase explosion. See Figure 62–14.



Figure 62–10 A PCV valve shown in a cutaway valve cover showing the baffles that prevent liquid oil from being drawn into the intake manifold.

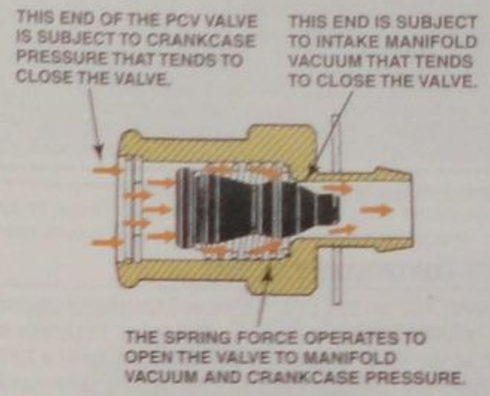


Figure 62–11 Spring force, crankcase pressure, and intake manifold vacuum work together to regulate the flow rate through the PCV valve.

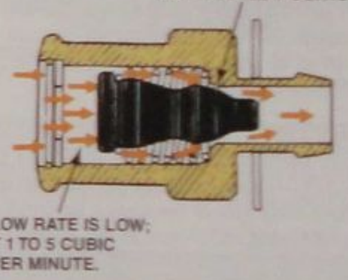


Figure 62–12 Air flows through the PCV valve during idle, cruising, and light-load conditions.

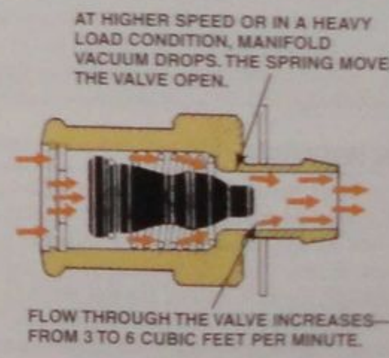


Figure 62–13 Air flows through the PCV valve during acceleration and when the engine is under a heavy load.

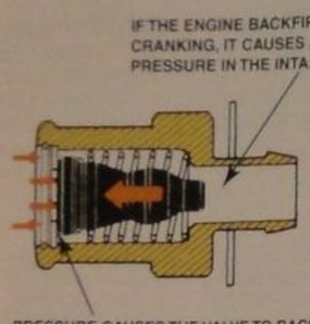


Figure 62–14 PCV valve operation in the event of a backfire.

ORIFICE-CONTROLLED SYSTEMS

The closed PCV system used on some four-cylinder engines contains a calibrated orifice instead of a PCV valve. The orifice may be located in the valve cover or intake manifold, or in a hose connected between the valve cover, air cleaner, and intake manifold.

While most orifice flow control systems work the same as a PCV valve system, they may not use fresh air scavenging of the crankcase. Crankcase vapors are drawn into the intake manifold in calibrated amounts depending on manifold pressure and the orifice size. If vapor availability is low, as during idle, air is drawn in with the vapors. During off-idle operation, excess vapors are sent to the air cleaner.

At idle, PCV flow is controlled by a 0.050-inch (1.3-mm) orifice. As the engine moves off-idle, ported vacuum pulls a spring-loaded valve off of its seat, allowing PCV flow to pass through a 0.090-inch (2.3-mm) orifice.

Separator Systems Turbocharged and many fuel-injected engines use an oil/vapor or oil/water separator and a calibrated orifice instead of a PCV valve. In the most common applications, the air intake throttle body acts as the source for crankcase ventilation vacuum and a calibrated orifice acts as the metering device.

REAL WORLD FIX — **The Whistling Engine**

An older vehicle was being diagnosed for a whistling sound whenever the engine was running, especially at idle. It was finally discovered that the breather in the valve cover was plugged and caused high vacuum in the crankcase. The engine was sucking air from what was likely the rear main seal lip, making the "whistle" noise. After replacing the breather and PCV, the noise stopped.

PCV SYSTEM DIAGNOSIS

When intake air flows freely, the PCV system functions properly, as long as the PCV valve or orifice is not clogged. Modern engine design includes the air and vapor flow as a calibrated part of the air–fuel mixture. In fact, some engines receive as much as 30% of their idle air through the PCV system. For this reason, a flow problem in the PCV system results in driveability problems.

A blocked or plugged PCV system is a major cause of high oil consumption, and contributes to many oil leaks. Before expensive engine repairs are attempted, check the condition of the PCV system.

TECH TIP — **Check for Oil Leaks with the Engine Off**

The owner of an older vehicle equipped with a V-6 engine complained to his technician that he smelled burning oil, but only after shutting off the engine. The technician found that the rocker cover gaskets were leaking. But why did the owner only notice the smell of hot oil when the engine was shut off? Because of the positive crankcase ventilation (PCV) system, engine vacuum tends to draw oil away from gasket surfaces. But when the engine stops, engine vacuum disappears and the oil remaining in the upper regions of the engine will tend to flow down and out through any opening. Therefore, a good technician should check an engine for oil leaks not only with the engine running but also shortly after shutdown.

PCV System Performance Check A properly operating positive crankcase ventilation system should be able to draw vapors from the crankcase and into the intake manifold. If the pipes, hoses, and PCV valve itself are not restricted, vacuum is applied to the crankcase. A slight vacuum is created in the crankcase (usually less than 1 in. Hg if measured at the dipstick) and is also applied to other areas of the engine. Oil drainback holes provide a path for oil to drain back into the oil pan. These holes also allow crankcase vacuum to be applied under the rocker covers and in the valley area of most V-type engines. There are several methods that can be used to test a PCV system.

The Rattle Test The rattle test is performed by simply removing the PCV valve and shaking it in your hand.

- If the PCV valve does *not* rattle, it is definitely defective and must be replaced.
- If the PCV valve *does* rattle, it does not necessarily mean that the PCV valve is good. All PCV valves contain springs that can become weaker with age and heating and cooling cycles. Replace any PCV valve with the *exact* replacement according to vehicle manufacturers' recommended intervals (usually every 3 years or 36,000 miles, or 60,000 km).

The 3 × 5 Card Test Remove the oil-fill cap (where oil is added to the engine) and start the engine.

NOTE: Use care on some overhead camshaft engines. With the engine running, oil may be sprayed from the open oil-fill opening.

Hold a 3 × 5 card over the opening (a dollar bill or any other piece of paper can be used for this test).

- If the PCV system, including the valve and hoses, is functioning correctly, the card should be held down on the oil-fill opening by the slight vacuum inside the crankcase.
- If the card will not stay, carefully inspect the PCV valve, hose(s), and manifold vacuum port for carbon buildup (restriction). Clean or replace as necessary.

NOTE: On some four-cylinder engines, the 3 × 5 card may vibrate on the oil-fill opening when the engine is running at idle speed. This is normal because of the time intervals between intake strokes on a four-cylinder engine.



Figure 62–15 Using a gauge that measures vacuum in units of inches of water to test the vacuum at the dipstick tube, being sure that the PCV system is capable of drawing a vacuum in the crankcase (28 inches of water equals 1 PSI or about 2 in. Hg of vacuum).

The Snap-Back Test The proper operation of the PCV valve can be checked by placing a finger over the inlet hole in the valve when the engine is running and removing the finger rapidly. Repeat several times. The valve should "snap back." If the valve does not snap back, replace the valve.

Crankcase Vacuum Test Sometimes the PCV system can be checked by testing for a weak vacuum at the oil dipstick tube using an inches-of-water manometer or gauge as follows:

Step #1 Remove the oil-filler cap and cover the opening.

Step #2 Remove the oil-level indicator (dipstick).

Step #3 Connect a water manometer or gauge to the dipstick tube.

Step #4 Start the engine and observe the gauge at idle and at 2500 RPM. See Figure 62–15.

The gauge should show some vacuum, especially at 2500 RPM. If not, carefully inspect the PCV system for blockages or other faults.

PCV MONITOR

Starting with 2004 and newer vehicles, all vehicles must be checked for proper operation of the PCV system. The PCV monitor will fail if the PCM detects an opening between the crankcase and the PCV valve or between the PCV valve and the intake manifold. See Figure 62–16.

PCV-Related Diagnostic Trouble Code

Diagnostic Trouble Code	Description	Possible Causes
P1490	PCV solenoid circuit fault	• Defective PCV solenoid • Loose or corroded electrical connection • Loose defective vacuum hoses/connections

AIR PUMP SYSTEM

An air pump provides the air necessary for the oxidizing process inside the catalytic converter. The system of adding air to the exhaust is commonly called **secondary air injection (SAI).**



Figure 62–16 Most PCV valves used on newer vehicles are secured with fasteners, which makes it more difficult to disconnect and thereby less likely to increase emissions.

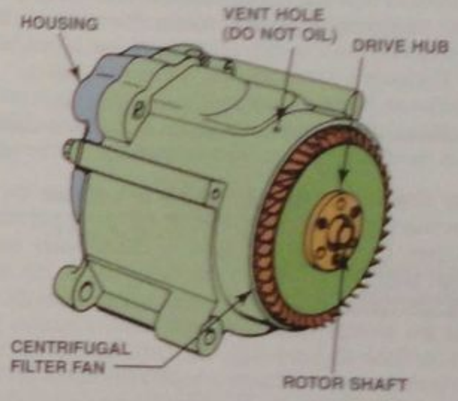


Figure 62–17 A typical belt-driven AIR pump. Air enters through the revolving fins behind the drive pulley. The fins act as an air filter because dirt is heavier than air and therefore the dirt is deflected off of the fins at the same time air is being drawn into the pump.

NOTE: This system is commonly called **AIR,** meaning **air injection reaction.** Therefore, an AIR pump does pump air.

The AIR pump, sometimes referred to as a **smog pump** or **thermactor pump,** is mounted at the front of the engine and driven by a belt from the crankshaft pulley. It pulls fresh air in through an external filter and pumps the air under slight pressure to each exhaust port through connecting hoses or a manifold.

- A belt-driven pump with inlet air filter (older models). See Figure 62–17.
- An electronic air pump (newer models)
- One or more air distribution manifolds and nozzles
- One or more exhaust check valves
- Connecting hoses for air distribution
- Air management valves and solenoids on all newer applications

With the introduction of NO_x reduction converters (also called dual-bed, three-way converters, or TWC), the output of the AIR pump is sent to the center of the converter where the extra air can help oxidize HC and CO into H_2O and CO_2.

The computer controls the airflow from the pump by switching on and off various solenoid valves. When the engine is cold, the air pump output is directed to the exhaust manifold to help provide enough oxygen to convert HC (unburned gasoline) and CO (carbon monoxide) to H_2O (water) and CO_2 (carbon dioxide). When the engine becomes warm and is operating in closed loop, the computer operates the air valves so as to direct the air pump output to the catalytic converter. When the vacuum rapidly increases above the normal idle level, as during rapid deceleration, the computer diverts the air pump output to the air cleaner assembly to silence the air. Diverting the air to the air cleaner prevents exhaust backfire during deceleration.

AIR DISTRIBUTION MANIFOLDS AND NOZZLES

The air-injection system sends air from the pump to a nozzle installed near each exhaust port in the cylinder head. This provides equal air injection for the exhaust from each cylinder and makes it available at a point in the system where exhaust gases are the hottest.

Air is delivered to the exhaust system in one of two ways:

- An external air manifold, or manifolds, distributes the air through injection tubes with stainless steel nozzles. The nozzles are threaded into the cylinder heads or exhaust manifolds close to each exhaust valve. This method is used primarily with smaller engines.
- An internal air manifold distributes the air to the exhaust ports near each exhaust valve through passages cast in the cylinder head or the exhaust manifold. This method is used mainly with larger engines.

Exhaust Check Valves All air-injection systems use one or more one-way check valves to protect the air pump and other components from reverse exhaust flow. A **check valve** contains a spring-type metallic disc or reed that closes the air line under exhaust backpressure. Check valves are located between the air manifold and the diverter valve. If exhaust pressure exceeds injection pressure, or if the air pump fails, the check valve spring closes the valve to prevent reverse exhaust flow.

All air pump systems use one-way check valves to allow air to flow into the exhaust manifold and to prevent the hot exhaust from flowing into the valves on the air pump itself. See Figure 62–18.

NOTE: These check valves commonly fail, resulting in excessive exhaust emissions (CO especially). When the check valve fails, hot exhaust can travel up to and destroy the switching valve(s) and air pump itself.

Belt-Driven Air Pumps The belt-driven air pump uses a centrifugal filter just behind the drive pulley. As the pump rotates, underhood air is drawn into the pump and slightly compressed. The air is then directed to:

- The exhaust manifold when the engine is cold to help oxidize CO and HC into carbon dioxide (CO_2) and water vapor (H_2O)
- The catalytic converter on many models to help provide the extra oxygen needed for the efficient conversion of CO and HC into CO_2 and H_2O
- The air cleaner during deceleration or wide-open throttle (WOT) engine operation.

Electric Motor-Driven Air Pumps This style of pump is generally used only during cold engine operation and is computer controlled. The air injection reaction (AIR) system helps reduce hydrocarbon (HC) and carbon monoxide (CO). It also helps to warm up the three-way catalytic converters quickly on engine start-up so conversion of exhaust gases may occur sooner.

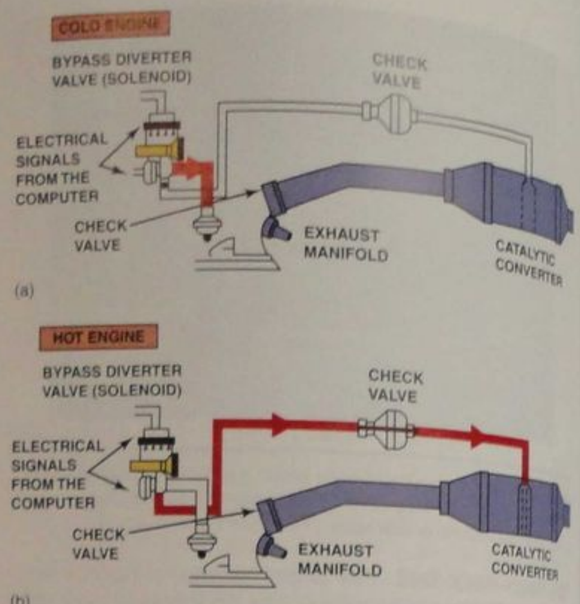


Figure 62–18 (a) When the engine is cold and before the oxygen sensor is hot enough to achieve closed-loop, the airflow from the air pump is directed to the exhaust manifold(s) through the one-way check valves which keep the exhaust gases from entering the switching solenoids and the pump itself. (b) When the engine achieves closed-loop, the air is directed to the catalytic converter.



Figure 62–19 A typical electric motor-driven AIR pump. This unit is on a Chevrolet Corvette and only works when the engine is cold.

The AIR pump and solenoid is controlled by the PCM. The PCM turns on the AIR pump by providing the ground to complete the circuit which energizes the AIR pump solenoid relay. When air to the exhaust ports is desired, the PCM energizes the relay in order to turn on the solenoid and the AIR pump. See Figure 62–19.

The PCM turns on the AIR pump during start-up any time the engine coolant temperature is above 32°F (0°C). A typical electric AIR pump operates for a maximum of 240 seconds, or until the system enters closed-loop operation. The AIR system is disabled under the following conditions:

- The PCM recognizes a problem and sets a diagnostic trouble code.
- The AIR pump has been on for 240 seconds.
- The engine speed is more than 2825 RPM.

- The manifold absolute pressure (MAP) is less than 6 in. Hg (20 kPa).
- Increased temperature detected in three-way catalytic converter during warm-up.
- The short- and long-term fuel trim are not in their normal ranges.
- Power enrichment is detected.

If no air (oxygen) enters the exhaust stream at the exhaust ports, the HC and CO emission levels will be higher than normal. Air flowing to the exhaust ports at all times could increase temperature of the three-way catalytic converter (TWC).

The diagnostic trouble codes P0410 and/or P0418 set if there is a malfunction in the following components:

- The AIR pump
- The AIR solenoid
- The AIR pump solenoid relay
- Leaking hoses or pipes
- Leaking check valves
- The circuits going to the AIR pump and the AIR pump solenoid relay

The AIR pump is an electric-type pump that requires no periodic maintenance. To check the operation of the AIR pump, the engine should be at normal operating temperature in neutral at idle. Using a scan tool, enable the AIR pump system and watch the heated oxygen sensor (HO2S) voltages for both bank 1 and bank 2 HO2S. The HO2S voltages for both sensors should remain under 350 mV because air is being directed to the exhaust ports. If the HO2S voltages remain low during this test, the AIR pump, solenoid, and shut-off valve are operating satisfactorily. If the HO2S voltage does not remain low when the AIR pump is enabled, inspect for the following:

- Voltage at the AIR pump when energized
- A seized AIR pump
- The hoses, vacuum lines, pipes, and all connections for leaks and proper routing
- Airflow going to the exhaust ports
- AIR pump for proper mounting
- Hoses and pipes for deterioration or holes

If a leak is suspected on the pressure side of the system, or if a hose or pipe has been disconnected on the pressure side, the connections should be checked for leaks with a soapy water solution. With the AIR pump running, bubbles form if a leak exists.

The check valves should be inspected whenever the hose is disconnected or whenever check valve failure is suspected. An AIR pump that had become inoperative and had shown indications of having exhaust gases in the outlet port would indicate check valve failure.

SECONDARY AIR INJECTION SYSTEM DIAGNOSIS

The air pump system should be inspected if an exhaust emissions test failure occurs. In severe cases, the exhaust will enter the air cleaner assembly, resulting in a horribly running engine because the extra exhaust displaces the oxygen needed for proper combustion. With the engine running, check for normal operation:

Engine Operation	Normal Operation of a Typical Air Injection Reaction (AIR) Pump System
Cold engine (open-loop operation)	Air is diverted to the exhaust manifold(s) or cylinder head
Warm engine (closed-loop operation)	Air is diverted to the catalytic converter
Deceleration	Air is diverted to the air cleaner assembly
Wide-open throttle	Air is diverted to the air cleaner assembly

Visual Inspection Carefully inspect all air injection reaction (AIR) system hoses and pipes. Any pipes that have holes and leak air or exhaust require replacement. The check valve(s) should be checked when a pump has become inoperative. Exhaust gases could have gotten past the check valve and damaged the pump. Check the drive belt on an engine-driven pump for wear and proper tension.

Four-Gas Exhaust Analysis An AIR system can be easily tested using an exhaust gas analyzer. Follow these steps:

1. Start the engine and allow it to run until normal operating temperature is achieved.
2. Connect the analyzer probe to the tailpipe and observe the exhaust readings for hydrocarbons (HC) and carbon monoxide (CO).
3. Using the appropriate pinch-off pliers, shut off the airflow from the AIR system. Observe the HC and CO readings. If the AIR system is working correctly, the HC and CO should increase when the AIR system is shut off.
4. Record the O_2 reading with the AIR system still inoperative. Unclamp the pliers and watch the O_2 readings. If the system is functioning correctly, the O_2 level should increase by 1% to 4%.

Air-Related Diagnostic Trouble Code

Diagnostic Trouble Code	Description	Possible Causes
P1485	AIR solenoid circuit fault	• Defective AIR solenoid • Loose or corroded electrical connections • Loose, missing, or defective rubber hose(s)

CATALYTIC CONVERTERS

A **catalytic converter** is an after-treatment device used to reduce exhaust emissions outside of the engine. This device is installed in the exhaust system between the exhaust manifold and the muffler, and usually is positioned beneath the passenger compartment. The location of the converter is important, since as much of the exhaust heat as possible must be retained for effective operation. The nearer it is to the engine, the better. See Figure 62–20.



Figure 62–20 Most catalytic converters are located as close to the exhaust manifold as possible as seen in this display of a Chevrolet Corvette.

CERAMIC MONOLITH CATALYTIC CONVERTER

Most catalytic converters are constructed of a ceramic material in a honeycomb shape with square openings for the exhaust gases. There are approximately 400 openings per square inch (62 per sq cm) and the wall thickness is about 0.006 in. (1.5 mm). The substrate is then coated with a porous aluminum material called the **washcoat,** which makes the surface rough. The catalytic materials are then applied on top of the washcoat. The substrate is contained within a round or oval shell made by welding together two stamped pieces of aluminum or stainless steel. See Figure 62–21.

The ceramic substrate in monolithic converters is not restrictive, but the converter breaks more easily when subject to shock or severe jolts and is more expensive to manufacture. Monolithic converters can be serviced only as a unit.

An exhaust pipe is connected to the manifold or header to carry gases through a catalytic converter and then to the muffler or silencer. V-type engines usually route the exhaust into one catalytic converter.

Catalytic Converter Operation The converter contains small amounts of **rhodium, palladium,** and **platinum.** These elements act as catalysts. A **catalyst** is an element that starts a chemical reaction without becoming a part of, or being consumed in, the process. In a **three-way catalytic converter (TWC)** all three exhaust emissions (NO_x, HC, and CO) are converted to carbon dioxide (CO_2) and water (H_2O). As the exhaust gas passes through the catalyst, oxides of nitrogen (NO_x) are chemically reduced (that is, nitrogen and oxygen are separated) in the first section of the catalytic converter. In the second section of the catalytic converter, most of the hydrocarbons and carbon monoxide remaining in the exhaust gas are oxidized to form harmless carbon dioxide (CO_2) and water vapor (H_2O). See Figure 62–22.

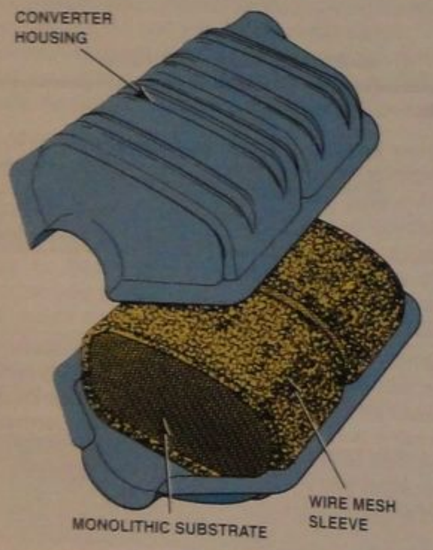


Figure 62–21 A typical catalytic converter with a monolithic substrate.

Since the early 1990s, many converters also contain **cerium,** an element that can store oxygen. The purpose of the cerium is to provide oxygen to the oxidation bed of the converter when the exhaust is rich and lacks enough oxygen for proper oxidation. When the exhaust is lean, the cerium absorbs the extra oxygen. The converter must have a varying rich-to-lean exhaust for proper operation:

- A rich exhaust is required for reduction—stripping the oxygen (O_2) from the nitrogen in NO_x
- A lean exhaust is required to provide the oxygen necessary to oxidize HC and CO (combining oxygen with HC and CO to form H_2O and CO_2)

If the catalytic converter is not functioning correctly, check to see that the air–fuel mixture being supplied to the engine is correct and that the ignition system is free of defects.

Converter Light-Off The catalytic converter does not work when cold and it must be heated to its **light-off** temperature of close to 500°F (260°C) before it starts working at 50% effectiveness. When fully effective, the converter reaches a temperature range of 900° to 1600°F (482° to 871°C). In spite of the intense heat, however, catalytic reactions do not generate a flame associated with a simple burning reaction. Because of the extreme heat (almost as hot as combustion chamber temperatures), a converter remains hot long after the engine is shut off. Most vehicles use a series of heat shields to protect the passenger compartment and other parts of the chassis from excessive heat. Vehicles have been known to start fires because of the hot converter causing tall grass or dry leaves beneath the just-parked vehicle to ignite, especially if the engine is idling.

Converter Usage A catalytic converter must be located as close as possible to the exhaust manifold to work effectively. The farther back the converter is positioned in the exhaust system, the more gases cool before they reach the converter. Since positioning in the exhaust system affects the oxidation process, cars that use only an oxidation converter generally locate it underneath the front of the passenger compartment.

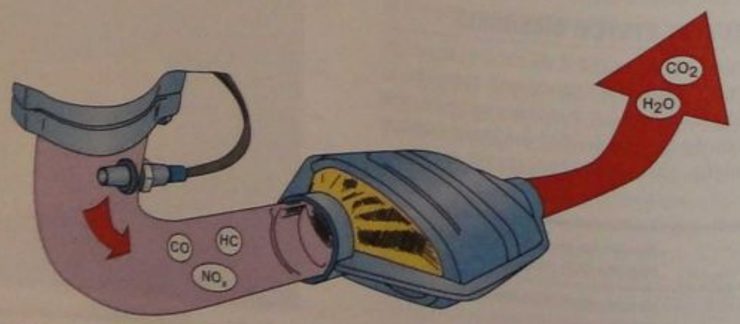


Figure 62–22 The three-way catalytic converter first separates the NO_x into nitrogen and oxygen and then converts the HC and CO into harmless water (H_2O) and carbon dioxide (CO_2).

Some vehicles have used a small, quick-heating oxidation converter called a **preconverter, pup,** or **mini-converter** that connects directly to the exhaust manifold outlet. These have a small catalyst surface area close to the engine that heats up rapidly to start the oxidation process more quickly during cold engine warm-up. For this reason, they were often called **light-off converters,** or **LOC.** The oxidation reaction started in the LOC is completed by the larger main converter under the passenger compartment.

OBD-II CATALYTIC CONVERTER PERFORMANCE

With OBD-II-equipped vehicles, catalytic converter performance is monitored by **heated oxygen sensors (HO2Ss),** both before and after the converter. The converters used on these vehicles have what is known as **OSC** or **oxygen storage capacity.** OSC is due mostly to the cerium coating in the catalyst rather than the precious metals used. When the TWC is operating as it should, the postconverter HO2S is far less active than the preconverter sensor. The converter stores, then releases the oxygen during normal reduction and oxidation of the exhaust gases, smoothing out the variations in O_2 being released.

Where a cycling sensor voltage output is expected before the converter, because of the converter action, the postconverter HO2S should read a steady signal without much fluctuation. See Figure 62–23.

CONVERTER-DAMAGING CONDITIONS

Since converters have no moving parts, they require no periodic service. Under federal law, catalyst effectiveness is warranted for 80,000 miles or eight years.

The three main causes of premature converter failure are:

- **Contamination.** Substances that can destroy the converter include exhaust that contains excess engine oil, antifreeze, sulfur (from poor fuel), and various other chemical substances.
- **Excessive temperatures.** Although a converter operates at high temperature, it can be destroyed by excessive temperatures. This most often occurs either when too much unburned fuel enters the converter, or with excessively lean mixtures. Excessive temperatures may be caused by long idling periods on some vehicles, since more heat develops at those times than when driving at normal highway speeds. Severe high temperatures can cause the converter to melt down, leading to the internal parts breaking apart and either clogging the converter or moving downstream to plug the muffler. In either case, the restricted exhaust flow severely reduces engine power.
- **Improper air–fuel mixtures.** Rich mixtures or raw fuel in the exhaust can be caused by engine misfiring, or an excessively rich air–fuel mixture resulting from a defective coolant temp sensor or defective fuel injectors. Lean mixtures are commonly caused by intake manifold leaks. When either of these circumstances occurs, the converter can become a catalytic furnace, causing the previously described damage.

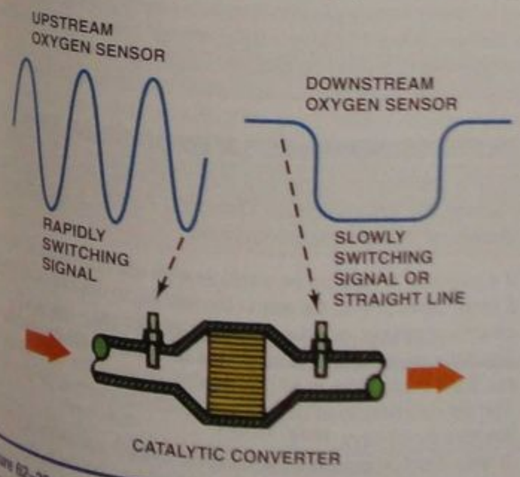


Figure 62–23 The OBD-II catalytic converter monitor compares the signals of the upstream and downstream O2Ss to determine converter efficiency.

To avoid excessive catalyst temperatures and the possibility of fuel vapors reaching the converter, follow these rules:

1. Do not try to start the engine by pushing the vehicle. Use jumper cables or a jump box to start the engine.
2. Do not crank an engine for more than 40 seconds when it is flooded or firing intermittently.
3. Do not turn off the ignition switch when the vehicle is in motion.
4. Do not disconnect a spark plug wire for more than 30 seconds.
5. Repair engine problems such as dieseling, misfiring, or stumbling as soon as possible.

FREQUENTLY ASKED QUESTION ???

Can a Catalytic Converter Be Defective Without Being Clogged?

Yes. Catalytic converters can fail by being chemically damaged or poisoned without being mechanically clogged. Therefore, the catalytic converter should not only be tested for physical damage (clogging) by performing a backpressure or vacuum test and a rattle test but also a test for temperature rise, usually with a pyrometer, or propane test, to check the efficiency of the converter.

DIAGNOSING CATALYTIC CONVERTERS

The Tap Test The simple tap test involves tapping (not pounding) on the catalytic converter using a rubber mallet. If the substrate inside the converter is broken, the converter will rattle when hit. If the converter rattles, a replacement converter is required.

Testing Backpressure with a Vacuum Gauge A vacuum gauge can be used to measure manifold vacuum at a high idle (2000 to 2500 RPM). If the exhaust system is restricted, pressure increases in the exhaust system. This pressure is called **backpressure.** Manifold vacuum will drop gradually if the engine is kept at a constant speed if the exhaust is restricted.

The reason the vacuum will drop is that all the exhaust leaving the engine at the higher engine speed cannot get through the restriction. After a short time (within 1 minute), the exhaust tends to "pile up" above the restriction and eventually remains in the cylinder of the engine at the end of the exhaust stroke. Therefore, at the beginning of the intake stroke, when the piston traveling downward should be lowering the pressure (raising the vacuum) in the intake manifold, the extra exhaust in the cylinder *lowers* the normal vacuum. If the exhaust restriction is severe enough, the vehicle can become undriveable because cylinder filling cannot occur except at idle.

Testing Backpressure with a Pressure Gauge Exhaust system backpressure can be measured directly by installing a pressure gauge in an exhaust opening. This can be accomplished in one of the following ways:

1. To test an oxygen sensor, remove the inside of an old, discarded oxygen sensor and thread in an adapter to connect it to a vacuum or pressure gauge.

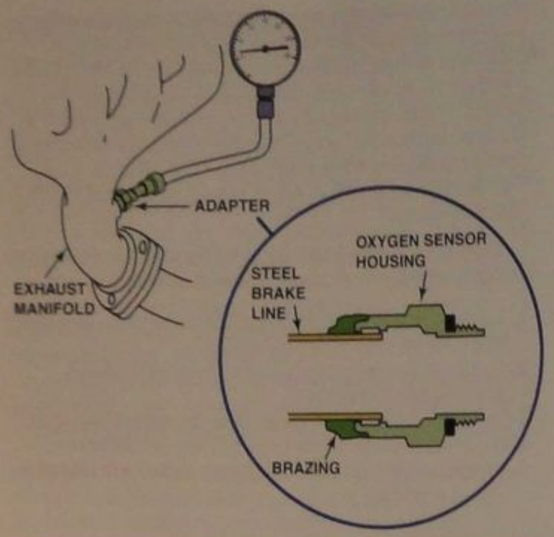


Figure 62–24 A backpressure tool can be made by using an oxygen sensor housing and using epoxy or braze to hold the tube to the housing.

NOTE: An adapter can be easily made by inserting a metal tube or pipe. A short section of brake line works great. The pipe can be brazed to the oxygen sensor housing or it can be glued with epoxy. An 18-millimeter compression gauge adapter can also be adapted to fit into the oxygen sensor opening. See Figure 62–24.

2. To test an exhaust gas recirculation (EGR) valve, remove the EGR valve and fabricate a plate.
3. To test an air injection reaction (AIR) check valve, remove the check valve from the exhaust tubes leading to the exhaust manifold. Use a rubber cone with a tube inside to seal against the exhaust tube. Connect the tube to a pressure gauge.

At idle the maximum backpressure should be less than 1.5 PSI (10 kPa), and it should be less than 2.5 PSI (15 kPa) at 2500 RPM.

Testing a Catalytic Converter for Temperature Rise A properly working catalytic converter should be able to reduce NO_x exhaust emissions into nitrogen (N) and oxygen (O_2) and oxidize unburned hydrocarbon (HC) and carbon monoxide (CO) into harmless carbon dioxide (CO_2) and water vapor (H_2O). During these chemical processes, the catalytic converter should increase in temperature at least 10% if the converter is working properly. To test the converter, operate the engine at 2500 RPM for at least 2 minutes to fully warm up the converter. Measure the inlet and the outlet temperatures using an **infrared pyrometer** as shown in Figure 62–25.

NOTE: If the engine is extremely efficient, the converter may not have any excessive unburned hydrocarbons or carbon monoxide to convert! In this case, a spark plug wire could be grounded out using a vacuum hose and a test light to create some unburned hydrocarbon in the exhaust. Do not ground out a cylinder for longer than 10 seconds or the excessive amount of unburned hydrocarbon could overheat and damage the converter.

Catalytic Converter Efficiency Tests The efficiency of a catalytic converter can be determined using an exhaust gas analyzer.

Oxygen Level Test With the engine warm and in closed-loop, check the oxygen (O_2) and carbon monoxide (CO) levels.

- If O_2 is zero, go to the snap-throttle test.
- If O_2 is greater than zero, check the CO level.
- If CO is greater than zero, the converter is *not* functioning correctly.

Snap-Throttle Test With the engine warm and in closed-loop, snap the throttle to wide open (WOT) in park or neutral and observe the oxygen reading.

- O_2 reading should not exceed 1.2%; if it does, the converter is not working.
- If the O_2 rises to 1.2%, the converter may have low efficiency.
- If the O_2 remains below 1.2%, then the converter is okay.

OBD-II CATALYTIC CONVERTER MONITOR

The catalytic converter monitor of OBD II uses an upstream and downstream HO2S to test catalyst efficiency. When the engine combusts a lean air–fuel mixture, higher amounts of oxygen flow through the exhaust into the converter. The catalyst materials absorb this oxygen for the oxidation process, thereby removing it from the exhaust stream. If a converter cannot absorb enough oxygen, oxidation does not occur. Engineers established a correlation between the amount of oxygen absorbed and converter efficiency.

The OBD-II system monitors how much oxygen the catalyst retains. A voltage waveform from the downstream HO2S of a good catalyst should have little or no activity. A voltage waveform from the downstream HO2S of a degraded catalyst shows a lot of activity. In other words, the closer the activity of the downstream HO2S matches that of the upstream HO2S, the greater the degree of converter degradation. In operation, the OBD-II monitor compares activity between the two exhaust oxygen sensors.

TECH TIP ✓ **Aftermarket Catalytic Converters**

Some replacement aftermarket (nonfactory) catalytic converters do not contain the same amount of cerium as the original part. Cerium is the element that is used in catalytic converters to store oxygen. As a result of the lack of cerium, the correlation between the oxygen storage and the conversion efficiency may be affected enough to set a false diagnostic trouble code (P0422).

CATALYTIC CONVERTER REPLACEMENT GUIDELINES

Because a catalytic converter is a major exhaust gas emission control device, the Environmental Protection Agency (EPA) has strict guidelines for its replacement, including:

- If a converter is replaced on a vehicle with less than 80,000 miles/8 years, depending on the year of the vehicle, an original equipment catalytic converter *must* be used as a replacement.
- The replacement converter must be of the same design as the original. If the original had an air pump fitting, so must the replacement.
- The old converter must be kept for possible inspection by the authorities for 60 days.
- A form must be completed and signed by both the vehicle owner and a representative from the service facility. This form must state the cause of the converter failure and must remain on file for 2 years.

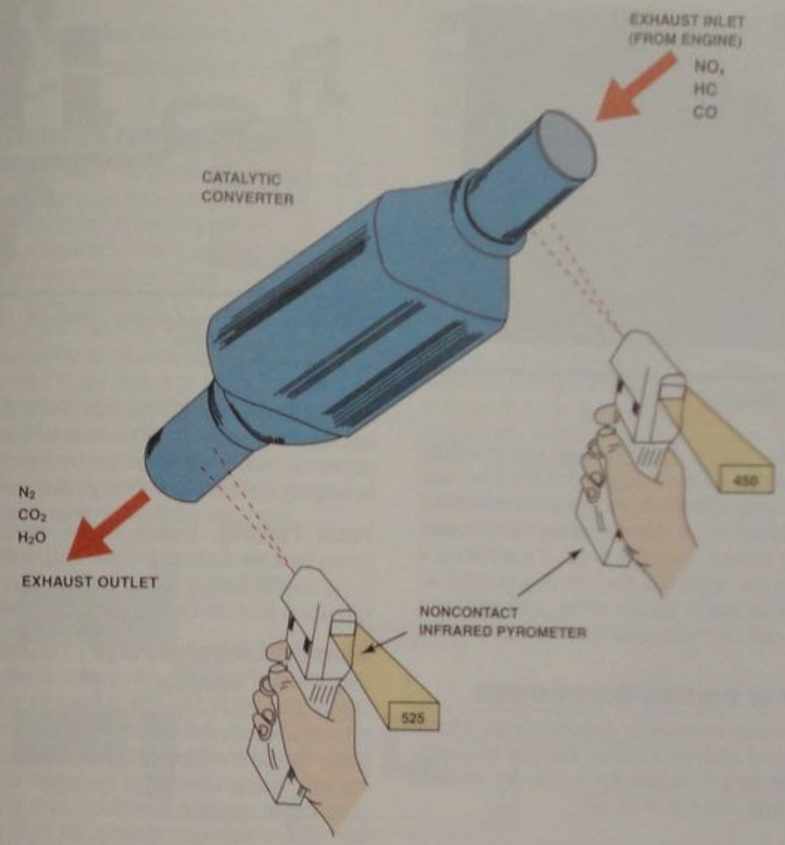


Figure 62–25 The temperature of the outlet should be at least 10% hotter than the temperature of the inlet. If a converter is not working, the inlet temperature will be hotter than the outlet temperature.

TECH TIP ✓ **Catalytic Converters Are Murdered**

Catalytic converters start a chemical reaction but do not enter into the chemical reaction. Therefore, catalytic converters do not wear out and they do not die of old age. If a catalytic converter is found to be defective (nonfunctioning or clogged), look for the *root* cause. Remember this:

"Catalytic converters do not commit suicide—they're murdered."

Items that should be checked when a defective catalytic converter is discovered include all components of the ignition and fuel systems. Excessive unburned fuel can cause the catalytic converter to overheat and fail. The oxygen sensor must be working and fluctuating from 0.5 to 5 Hz (times per second) to provide the necessary air–fuel mixture variations for maximum catalytic converter efficiency.

Catalytic Converter-Related Diagnostic Trouble Code

Diagnostic Trouble Code	Description	Possible Causes
P0422	Catalytic converter efficiency failure	• Engine mechanical fault • Exhaust leaks • Fuel contaminants, such as engine oil, coolant, or sulfur

EVAPORATIVE EMISSION CONTROL SYSTEM

The purpose of the evaporative (EVAP) emission control system is to trap and hold gasoline vapors also called volatile organic compounds, or VOCs. The charcoal canister is part of an entire system of hoses and valves called the **evaporative control system.** These vapors are instead routed into a charcoal canister, from where they go to the intake airflow so they are burned in the engine.

FREQUENTLY ASKED QUESTION ???

When Filling My Fuel Tank, Why Should I Stop When the Pump Clicks Off?

Every fuel tank has an upper volume chamber that allows for expansion of the fuel when hot. The volume of the chamber is between 10% and 20% of the volume of the tank. For example, if a fuel tank had a capacity of 20 gallons, the expansion chamber volume would be from 2 to 4 gallons. A hose is attached at the top of the chamber and vented to the charcoal canister. If extra fuel is forced into this expansion volume, liquid gasoline can be drawn into the charcoal canister. This liquid fuel can saturate the canister and create an overly rich air–fuel mixture when the canister purge valve is opened during normal vehicle operation. This extra-rich air–fuel mixture can cause the vehicle to fail an exhaust emissions test, reduce fuel economy, and possibly damage the catalytic converter. To avoid problems, simply add fuel to the next dime's worth after the nozzle clicks off. This will ensure that the tank is full, yet not overfilled.



Figure 62–26 A typical bayonet-type gas cap.

Common Components The fuel tank filler caps used on vehicles with modern EVAP systems are a special design. Most EVAP fuel tank filler caps have pressure-vacuum relief built into them. When pressure or vacuum exceeds a calibrated value, the valve opens. Once the pressure or vacuum has been relieved, the valve closes. If a sealed cap is used on an EVAP system that requires a pressure-vacuum relief design, a vacuum lock may develop in the fuel system, or the fuel tank may be damaged by fuel expansion or contraction. See Figure 62–26.

HOW THE EVAPORATIVE CONTROL SYSTEM WORKS

The canister is located under the hood or underneath the vehicle, and is filled with activated charcoal granules that can hold up to one-third of their own weight in fuel vapors. A vent line connects the canister to the fuel tank. See Figure 62–27.

NOTE: Some vehicles with large or dual fuel tanks may have dual canisters.

Activated charcoal is an effective vapor trap because of its great surface area. Each gram of activated charcoal has a surface area of 1,100 square meters, or more than a quarter acre. Typical canisters hold either 300 or 625 grams of charcoal *with a surface area equivalent to 80 or 165 football fields.* **Adsorption** attaches the fuel vapor molecules to the carbon surface. This attaching force is not strong, so the system purges the vapor molecules quite simply by sending a fresh airflow through the charcoal. See Figure 62–28.



Figure 62–27 A charcoal canister can be located under the hood or underneath the vehicle.

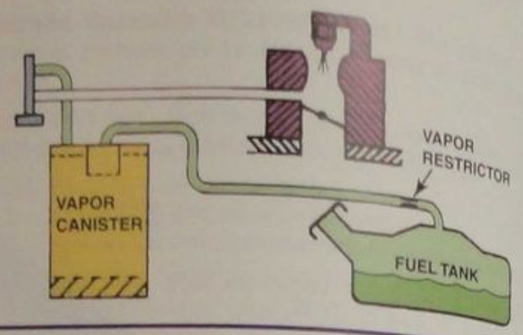


Figure 62–28 The evaporative emission control system includes all of the lines, hoses, and valves, plus the charcoal canister.

Vapor Purging During engine operation, stored vapors are drawn from the canister into the engine through a hose connected to the throttle body or the air cleaner. This "purging" process mixes HC vapors from the canister with the existing air–fuel charge.

Computer-Controlled Purge Canister purging on engines with electronic fuel management systems is regulated by the power-train control module (PCM). This is done by a microprocessor-controlled vacuum solenoid, and one or more purge valves. See Figure 62–29. Under normal conditions, most engine control systems permit purging only during closed-loop operation at cruising speeds. During other engine operation conditions, such as open-loop mode, idle, deceleration, or wide-open throttle, the PCM prevents canister purging.

Pressures can build inside the fuel system and are usually measured in units of inches of water, abbreviated in. H_2O (28 inches of water equals 1 PSI). Pressure buildup is a function of:

- Fuel evaporation rates (volatility)
- Gas tank size (fuel surface area and volume)
- Fuel level (liquid versus vapor)

Pressure Conversions

PSI	In. Hg	In. H_2O
14.7	29.93	407.19
1.0	2.036	27.7
0.9	1.8	24.93
0.8	1.63	22.16
0.7	1.43	19.39
0.6	1.22	16.62
0.5	1.018	13.85
0.4	0.814	11.08
0.3	0.611	8.31
0.2	0.407	5.54
0.1	0.204	2.77
0.09	0.183	2.49
0.08	0.163	2.22
0.07	0.143	1.94
0.06	0.122	1.66
0.05	0.102	1.385

1 PSI = 28 inches of water; 1/4 PSI = 7 inches of water.

- Fuel slosh (driving conditions)
- Temperature (ambient, in-tank, close to the tank)
- Returned fuel from the rail

NONENHANCED EVAPORATIVE CONTROL SYSTEMS

Prior to 1996, evaporative systems were referred to as evaporative (EVAP) control systems. This term refers to evaporative systems that had limited diagnostic capabilities. While they are often PCM controlled, their diagnostic capability is usually limited to their ability to detect if purge has occurred. Many systems have a diagnostic switch that could sense if purge is occurring and set a code if no purge is detected. This system does not check for leaks. On some vehicles, the PCM also has the capability of monitoring the integrity of the purge solenoid and circuit. These systems' limitations are their ability to check the integrity of the evaporative system on the vehicle. They could not detect leaks or missing or loose gas caps that could lead to excessive evaporative emissions from the vehicle. Nonenhanced evaporative systems use either a canister purge solenoid or a vapor management valve to control purge vapor.

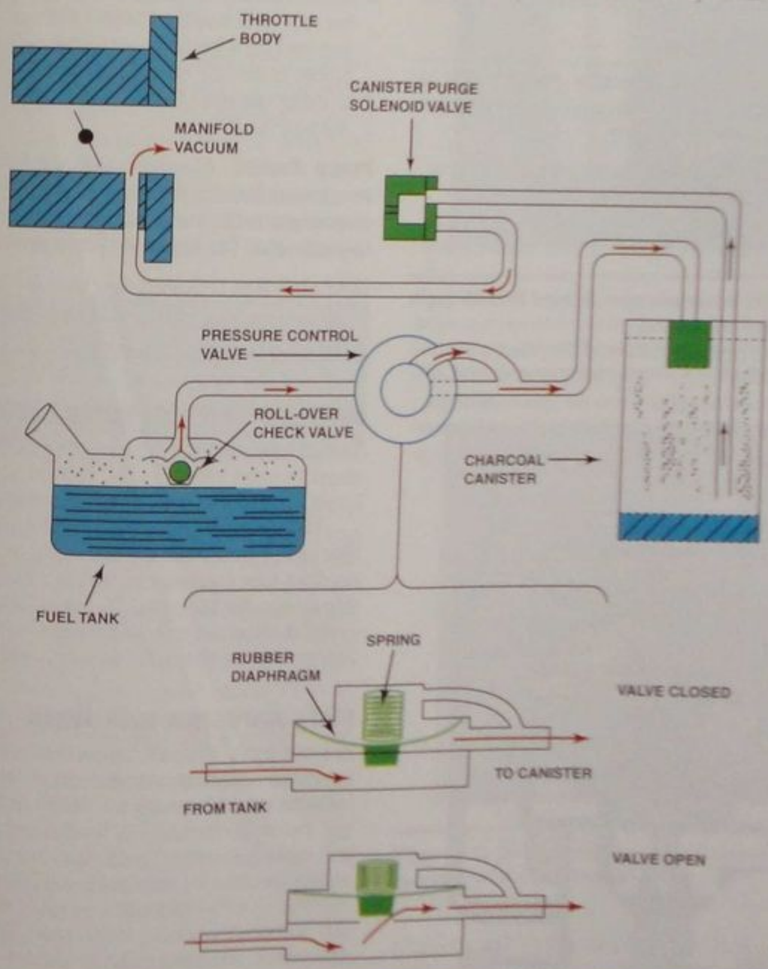


Figure 62–29 A typical evaporative emission control system. Note that when the computer turns on the canister purge solenoid valve, manifold vacuum draws any stored vapors from the canister into the engine. Manifold vacuum also is applied to the pressure control valve. When this valve opens, fumes from the fuel tank are drawn into the charcoal canister and eventually into the engine. When the solenoid valve is turned off (or the engine stops and there is no manifold vacuum), the pressure control valve is spring-loaded shut to keep vapors inside the fuel tank from escaping to the atmosphere.

ENHANCED EVAPORATIVE CONTROL SYSTEM

Beginning in 1996 with OBD-II vehicles, manufacturers were required to install systems that are able to detect both purge flow and evaporative system leakage. The systems on models produced between 1996 and 2000 have to be able to detect a leak as small as .040 in. diameter. Beginning in the model year 2000, the enhanced systems started a phase-in of .020-in.-diameter leak detection.

NOTE: Chrysler says that a 0.020 in.-diameter leak in an EVAP system can yield an average of about 1.35 grams of HC per mile driven.

All vehicles built after 1995 have enhanced evaporative systems that have the ability to detect purge flow and system leakage. If either of these two functions fails, the system is required to set a diagnostic trouble code and turn on the MIL light to warn the driver of the failure.

Canister Vent Solenoid Valve The canister vent valve is a normally open valve and is only closed when commanded by the

PCM during testing of the system. The vent solenoid is located under the vehicle in most cases and is exposed to the environment making this valve subject to rust and corrosion.

Canister Purge Solenoid (CPS) Valve The purge solenoid, also called the **canister purge (CANP)** solenoid is normally closed and is pulsed open by the PCM during purging.

TECH TIP **Problems After Refueling? Check the Purge Valve**

The purge valve is normally closed and open only when the PCM is commanding the system to purge. If the purge solenoid were to become stuck in the open position, gasoline fumes would be allowed to flow directly from the gas tank to the intake manifold. When refueling, this would result in a lot of fumes being forced into the intake manifold and as a result would cause a hard-to-start condition after refueling. This would also result in a rich exhaust and likely black exhaust when first starting the engine after refueling. While the purge solenoid is usually located under the hood of most vehicles and is less subject to rust and corrosion than the vent valve, it can still fail.

LEAK DETECTION PUMP SYSTEM

Many Chrysler vehicles use a **leak detection pump (LDP)** as part of the evaporative control system diagnosis equipment. See Figure 62–30. The system works as follows:

- The purge solenoid is normally closed. The conventional purge solenoid is ground-side controlled by the PCM. The proportional purge solenoid is feed-side controlled by the PCM. The PCM will energize the solenoid to purge fuel vapors from the canister and to lower tank pressure.
- The vent valve in the LDP is normally open. Filtered fresh air is drawn through the LDP to the canister.
- The solenoid on the LDP normally blocks manifold vacuum from the engine. When grounded by the PCM, manifold vacuum is allowed to pass through the solenoid and into the upper diaphragm chamber. Vacuum will pull the diaphragm back against spring pressure (rated at 7.5 in. H_2O). As the diaphragm is pulled up, fresh air is drawn into the pressure side of the LDP diaphragm through the inlet reed valve. This is the LDP intake stroke. When the diaphragm is pulled up against spring pressure, the normally closed contacts of the LDP reed switch open. The LDP reed switch is the only input regarding EVAP system pressure for the PCM. With the switch contacts open, the PCM knows the diaphragm has been drawn upwards. When the LDP solenoid is de-energized by the PCM, fresh air is allowed to enter the top side of the diaphragm chamber displacing the vacuum that was there. Spring pressure (7.5 in. H_2O) forces the air in the lower diaphragm chamber out through the outlet (exhaust) reed valve. This is the LDP exhaust stroke. The LDP switch contacts close once the diaphragm returns to its original at-rest position.
- The PCM checks for EVAP leaks by first de-energizing the purge solenoid (normally closed), and then rapidly cycling the LDP solenoid and watching the LDP switch. Once pressure (7.5 in. H_2O) is built up in the system, the diaphragm will be seated upwards against spring pressure. The PCM knows this since it is monitoring the LDP switch. So, the PCM compares LDP switch position against LDP solenoid cycling time to determine if leakage is present.
- When manually checking for leaks (for example, smoke machine), the vent valve must be closed. Closing the vent valve requires that the LDP solenoid be energized and that a vacuum source be applied to the LDP solenoid. This will enable the LDP diaphragm to stroke upwards, thereby allowing the vent valve spring to close the vent valve.

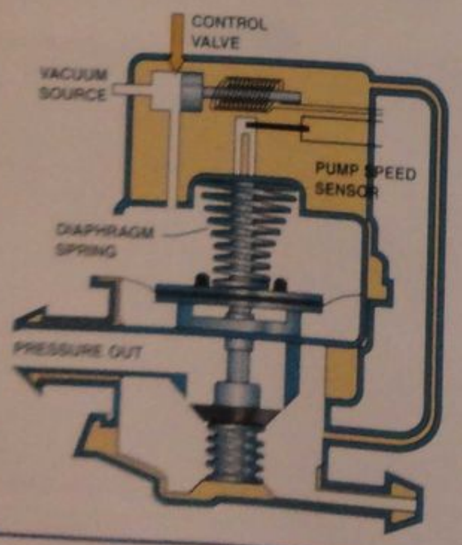


Figure 62–30 A leak detection pump (LDP) used on some Chrysler vehicles to pressurize slightly the fuel system to check for leaks.

Pump Period The time between LDP solenoid off and LDP switch close is called the pump period. This time period is inversely proportional to the size of the leak. The shorter the pump period, the larger the leak. The longer the pump period, the smaller the leak.

EVAP large leak (>0.080): less than 0.9 seconds
EVAP medium leak (0.040 to 0.080): 0.9 to 1.2 seconds
EVAP small leak (0.020 to 0.040): 1.2 to 6 seconds

ONBOARD REFUELING VAPOR RECOVERY

The onboard refueling vapor recovery (ORVR) system was first introduced on some 1998 vehicles. Previously designed EVAP systems allowed fuel vapor to escape to the atmosphere during refueling.

The primary feature of most ORVR systems is the restricted tank filler tube, which is about 1 inch (25 mm) in diameter. This reduced size filler tube creates an aspiration effect, which tends to draw outside air into the filler tube. During refueling, the fuel tank is vented to the charcoal canister, which captures the gas fumes and with air flowing into the filler tube, no vapors can escape to the atmosphere.

STATE INSPECTION EVAP TESTS

In some states, a periodic inspection and test of the fuel system are mandated along with a dynamometer test. The emissions inspection includes tests on the vehicle before and during the dynamometer test. Before the running test, the fuel tank and cap, fuel lines, canister, and other fuel system components must be inspected and tested to ensure that they are not leaking gasoline vapors into the atmosphere.

First, the fuel tank cap is tested to ensure that it is sealing properly and holds pressure within specs. Next, the cap is installed on the vehicle, and using a special adapter, the EVAP system is pressurized to approximately 0.5 PSI and monitored for 2 minutes. Pressure in the tank and lines should not drop below approximately 0.3 PSI.

If the cap or system leaks, hydrocarbon emissions are likely being released, and the vehicle fails the test. If the system leaks, an ultrasonic leak detector may be used to find the leak.

Finally, with the engine warmed up and running at a moderate speed, the canister purge line is tested for adequate flow using a special flow meter inserted into the system. In one example, if the flow from the canister to the intake system when the system is activated is at least one liter per minute, then the vehicle passes the canister purge test.

DIAGNOSING THE EVAP SYSTEM

Before vehicle emissions testing began in many parts of the country, little service work was done on the evaporative emission system. Common engine-performance problems that can be caused by a fault in this system include:

- **Poor fuel economy.** A leak in a vacuum-valve diaphragm can result in engine vacuum drawing in a constant flow of gasoline vapors from the fuel tank. This usually results in a drop in fuel economy of 2 to 4 miles per gallon (mpg). Use a hand-operated vacuum pump to check that the vacuum diaphragm can hold vacuum.
- **Poor performance.** A vacuum leak in the manifold or ported vacuum section of vacuum hose in the system can cause the engine to run rough. Age, heat, and time all contribute to the deterioration of rubber hoses.

Enhanced exhaust emissions (I/M-240) testing tests the evaporative emission system. A leak in the system is tested by pressurizing the entire fuel system to a level below 1 pound per square inch or 1 PSI (about 14 inches of water). The system is typically pressurized with nitrogen, a nonflammable gas that makes up 78% of our atmosphere. The pressure in the system is then shut off and the pressure monitored. If the pressure drops below a set standard, then the vehicle fails the test. This test determines if there is a leak in the system.

HINT: To help pass the evaporative section of an enhanced emissions test, arrive at the test site with less than a half-tank of fuel. This means that the rest of the volume of the fuel tank is filled with air. It takes longer for the pressure to drop from a small leak when the volume of the air is greater compared to when the tank is full and the volume of air remaining in the tank is small.

LOCATING LEAKS IN THE SYSTEM

Leaks in the evaporative emission control system will cause the malfunction check gas cap indication lamp to light on some vehicles. See Figure 62–31. A leak will also cause a gas smell, which would be most noticeable if the vehicle were parked in an enclosed garage. The first step is to determine if there is leak in the system by setting the EVAP tester to either a 0.040-inch or a 0.020-inch hole size leak. See Figure 62–32. After it has been determined that a leak exists and that it is larger than specified then there are two methods that can be used to check for leaks in the evaporative system.

- **Smoke machine testing.** The most efficient method of leak detection is to introduce smoke under low pressure from a machine specifically designed for this purpose. See Figure 62–33.
- **Nitrogen gas pressurization.** This method uses nitrogen gas under a very low pressure (lower than 1 PSI) in the fuel system. The service technician then listens for the escaping air, using amplified headphones. See Figure 62–34.

EVAPORATIVE SYSTEM MONITOR

OBD-II computer programs not only detect faults, but also *periodically test various systems* and alert the driver before emissions-related components are harmed by system faults. Serious faults cause a blinking malfunction indicator lamp (MIL) or even an engine shutdown; less serious faults may simply store a code but not illuminate the MIL.

The OBD-II requirements did not radically affect fuel system design. However, one new component, a fuel evaporative canister purge line pressure sensor, was added for monitoring purge line



Figure 62–31 Some vehicles will display a message if an evaporative control system leak is detected that could be the result of a loose gas cap.



Figure 62–32 To test for a leak, this tester was set to the 0.020-inch hole and turned on. The ball rose in the scale on the left and the red arrow was moved to that location. If when testing the system for leaks, the ball rises higher than the arrow, then the leak is larger than 0.020. If the ball does not rise to the level of the arrow, the leak is smaller than 0.020 inch.



Figure 62–33 This unit is applying smoke to the fuel tank through an adapter and the leak was easily found to be the gas cap seal.



Figure 62–34 An emission tester that uses nitrogen to pressurize the fuel system.

pressure during tests. The OBD-II requirements state that vehicle fuel systems are to be routinely tested *while underway* by the PCM management system.

All OBD-II vehicles—during normal driving cycles and under specific conditions—experience a canister purge system pressure test, as commanded by the PCM. While the vehicle is being driven, the vapor line between the canister and the purge valve is monitored for pressure changes. When the canister purge solenoid is open, the line should be under a vacuum since vapors must be drawn from the canister into the intake system. However, when the purge solenoid is closed, there should be no vacuum in the line. The pressure sensor detects if a vacuum is present or not, and the information is compared to the command given to the solenoid. If, during the canister purge cycle, no vacuum exists in the canister purge line, a code is set indicating a possible fault, which could be caused by an inoperative or clogged solenoid or a blocked or leaking canister purge fuel line. Likewise, if vacuum exists when no command for purge is given, a stuck solenoid is evident, and a code is set.

The EVAP system monitor tests for purge volume and leaks. Most applications purge the charcoal canister by venting the vapors into the intake manifold during cruise. To do this, the PCM typically opens a solenoid-operated purge valve installed in the purge line leading to the intake manifold.

A typical EVAP monitor first closes off the system to atmospheric pressure and opens the purge valve during cruise operation. A fuel tank pressure (FTP) sensor then monitors the rate with which vacuum increases in the system. The monitor uses this information to determine the purge volume flow rate. To test for leaks, the EVAP monitor closes the purge valve, creating a completely closed system. The fuel tank pressure sensor then monitors the leak down rate. If the rate exceeds PCM-stored values, a leak greater than or equal to the OBD-II standard of 0.040 in. (1.0 mm) or 0.020 in. (0.5 mm) exists. After two consecutive failed trips testing either purge volume or the presence of a leak, the PCM lights the MIL and sets a DTC.

The fuel tank pressure sensor is often the same part as the MAP sensor, and instead of monitoring intake manifold absolute pressure, it is used to monitor fuel tank pressure. See Figure 62–35.

Engine Off Natural Vacuum System integrity (leakage) can also be checked after the engine is shut off. The premise is that a warm evaporative system will cool down after the engine is shut off and the vehicle is stable. A slight vacuum will be created in the gas tank during this cool down period. If a specific level of vacuum is reached and maintained, the system is said to have integrity (no leakage).

TECH TIP ✓ **Always Tighten the Cap Correctly**

Many diagnostic trouble codes (DTCs) are set because the gas cap has not been properly installed. To be sure that a screw-type gas cap is properly sealed, tighten the cap until it clicks three times. The clicking is a ratchet device and the clicking does not harm the cap. Therefore, if a P0440 or similar DTC is set, check the cap. See Figure 62–36.



Figure 62–35 The fuel tank pressure sensor (black unit with three wires) looks like a MAP sensor and is usually located on top of the fuel pump module (white unit).



Figure 62–36 This Toyota cap has a warning—the check engine light will come on if not tightened until one click.

TYPICAL EVAP MONITOR

The PCM will run the EVAP monitor when the following enable criteria are met. Typical enable criteria include:

- Cold start
- BARO greater than 70 kPa (20.7 in. Hg or 10.2 PSI)
- IAT between 39° and 86°F at engine start-up
- ECT between 39° and 86°F at engine start-up
- ECT and IAT within 39°F of each other at engine start-up
- Fuel level within 15% to 85%
- TP sensor between 9% and 35%

Running the EVAP Monitor There are four tests which are performed during a typical GM EVAP monitor. A DTC is assigned to each test.

1. **Weak Vacuum Test (P0440—large leak).** This test identifies gross leaks. During the monitor, the vent solenoid is closed and the purge solenoid is duty cycled. The FTP should indicate a vacuum of approximately 6 to 10 in. H_2O.
2. **Small Leak Test (P0442—small leak).** After the large leak test passes, the PCM checks for a small leak by keeping the vent solenoid closed and closing the purge solenoid. The system is now sealed. The PCM measures the change in FTP voltage over time.
3. **Excess Vacuum Test (P0446).** This test checks for vent path restrictions. With the vent solenoid open and purge commanded, the PCM should not see excessive vacuum in the EVAP system. Typical EVAP system vacuum with the vent solenoid open is about 5 to 6 in. H_2O.
4. **Purge Solenoid Leak Test (P1442).** With the purge solenoid closed and vent solenoid closed, no vacuum should be present in the system. If there is vacuum present, the purge solenoid may be leaking.

TECH TIP ✓ **Keep the Fuel Tank Properly Filled**

Most evaporative system monitors will not run unless the fuel level is between 15% and 85%. In other words, if a driver always runs with close to an empty tank or always fills to keep the tank full, the EVAP monitor may not run. See Figure 62–37.



Figure 62–37 The fuel level must be above 15% and below 85% before the EVAP monitor will run on most vehicles.

EVAP System-Related Diagnostic Trouble Codes

Diagnostic Trouble Code	Description	Possible Causes
P0440	Evaporative system fault	• Loose gas cap • Defective EVAP vent • Cracked charcoal canister • EVAP vent or purge vapor line problems
P0442	Small leak detected	• Loose gas cap • Defective EVAP vent or purge solenoid • EVAP vent or purge line problems
P0446	EVAP canister vent blocked	• EVAP vent or purge solenoid electrical problems • Restricted EVAP canister vent line

SUMMARY

1. Recirculating 5% to 15% inert exhaust gases back into the intake system reduces peak temperature inside the combustion chamber and reduces NO_x exhaust emissions.
2. EGR is usually not needed at idle, at wide-open throttle, or when the engine is cold.
3. Many EGR systems use a feedback potentiometer to signal the PCM the position of the EGR valve pintle.
4. OBD-II regulation requires that the flow rate be tested and then is achieved by opening the EGR valve and observing the reaction of the MAP sensor.
5. Positive crankcase ventilation (PCV) systems use a valve or a fixed orifice to transfer and control the fumes from the crankcase back into the intake system.
6. A PCV valve regulates the flow of fumes depending on engine vacuum and seals the crankcase vent in the event of a backfire.
7. As much as 30% of the air needed by the engine at idle speed flows through the PCV system.
8. The AIR system forces air at low pressure into the exhaust to reduce CO and HC exhaust emissions.
9. A catalytic converter is an after-treatment device that reduces exhaust emissions outside of the engine. A catalyst is an element that starts a chemical reaction but is not consumed in the process.
10. The catalyst material used in a catalytic converter includes rhodium, palladium, and platinum.
11. The OBD-II system monitor compares the relative activity of a rear oxygen sensor to the precatalytic oxygen sensor to determine catalytic converter efficiency.
12. The purpose of the evaporative emission (EVAP) control system is to reduce the release of volatile organic compounds (VOCs) into the atmosphere.
13. A carbon (charcoal) canister is used to trap and hold gasoline vapors until they can be purged and run into the engine to be burned.
14. OBD-II regulation requires that the evaporative emission control system be checked for leakage and proper purge flow rates.
15. External leaks can best be located by pressurizing the fuel system with low-pressure smoke.

REVIEW QUESTIONS

1. How does the use of exhaust gas reduce NO_x exhaust emission?
2. How does the DPFE sensor work?
3. What exhaust emissions do the PCV valve and AIR system control?
4. How does a catalytic converter reduce NO_x to nitrogen and oxygen?
5. How does the computer monitor catalytic converter performance?
6. What components are used in a typical evaporative emission control system?
7. How does the computer control the purging of the vapor canister?

CHAPTER QUIZ

1. Two technicians are discussing clogged EGR passages. Technician A says clogged EGR passages can cause excessive NO_x exhaust emission. Technician B says that clogged EGR passages can cause the engine to ping (spark knock or detonation). Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. An EGR valve that is partially stuck open would most likely cause what condition?
   a. Rough idle/stalling
   b. Excessive NO_x exhaust emissions
   c. Ping (spark knock or detonation)
   d. Missing at highway speed

3. How much air flows through the PCV system when the engine is at idle speed?
   a. 1% to 3%
   b. 5% to 10%
   c. 10% to 20%
   d. Up to 30%

4. Technician A says that if a PCV valve rattles, then it is okay and does not need to be replaced. Technician B says that if a PCV valve does not rattle, it should be replaced. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

5. The switching valves on the AIR pump have failed several times. Technician A says that a defective exhaust check valve could be the cause. Technician B says that a restricted exhaust system could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

6. Two technicians are discussing testing a catalytic converter. Technician A says that a vacuum gauge can be used and observed to see if the vacuum drops with the engine at idle for 30 seconds. Technician B says that a pressure gauge can be used to check for backpressure. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. At about what temperature does oxygen combine with the nitrogen in the air to form NO_x?
   a. 500°F (260°C)
   b. 750°F (400°C)
   c. 1500°F (815°C)
   d. 2500°F (1370°C)

8. A P0401 is being discussed. Technician A says that a stuck-closed EGR valve could be the cause. Technician B says that clogged EGR ports could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. Which EVAP valve(s) is (are) normally closed?
   a. Canister purge valve
   b. Canister vent valve
   c. Both canister purge and canister vent valve
   d. Neither canister purge nor canister vent valve

10. Before an evaporative emission monitor will run, the fuel level must be where?
    a. At least 75% full
    b. Over 25%
    c. Between 15% and 85%
    d. The level of the fuel in the tank is not needed to run the monitor test

CHAPTER 63

Scan Tools and Engine Performance Diagnosis

OBJECTIVES: After studying Chapter 63, the reader will be able to: Prepare for the ASE computerized engine controls diagnosis (A8) certification test content area "E". • List the steps of the diagnostic process. • Describe the simple preliminary tests that should be performed at the start of the diagnostic process. • List six items to check as part of a thorough visual inspection. • Explain the troubleshooting procedures to follow if a diagnostic trouble code has been set. • Explain the troubleshooting procedures to follow if no diagnostic trouble code has been set. • Discuss the type of scan tools that are used to assess vehicle components. • Describe the methods that can be used to reprogram (reflash) a vehicle computer.

KEY TERMS: data link connector (DLC) • drive cycle • flash code retrieval • key-on–engine off test (KOEO) • key-on–engine running test (KOER) • paper test • pending code • self-test automatic readout (STAR) • smoke machine • technical service bulletin (TSB) • trip

THE EIGHT-STEP DIAGNOSTIC PROCEDURE

It is important that all automotive service technicians know how to diagnose and troubleshoot engine computer systems. The diagnostic process is a strategy that eliminates known-good components or systems in order to find the root cause of automotive engine performance problems. All vehicle manufacturers recommend a diagnostic procedure, and the plan suggested in this chapter combines most of the features of these plans plus additional steps developed over years of real-world problem solving.

Many different things can cause an engine performance problem or concern. The service technician has to narrow the possibilities to find the cause of the problem and correct it. A funnel is a way of visualizing a diagnostic procedure. See Figure 63–1. At the wide top are the symptoms of the problem; the funnel narrows as possible causes are eliminated until the root cause is found and corrected at the bottom of the funnel.

All problem diagnosis deals with symptoms that could be the result of many different causes. The wide range of possible solutions must be narrowed to the most likely and these must eventually be further narrowed to the actual cause. The following section describes eight steps the service technician can take to narrow the possibilities to one cause.

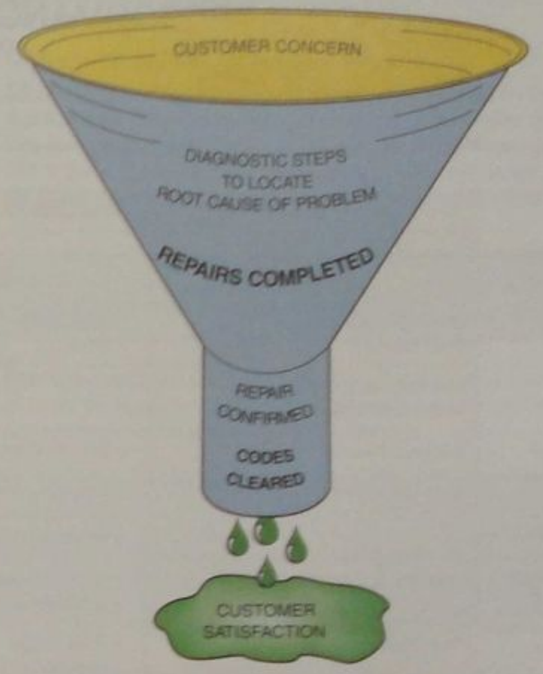


Figure 63–1 A funnel is one way to visualize the diagnostic process. The purpose is to narrow the possible causes of a concern until the root cause is determined and corrected.

Step 1 Verify the Problem (Concern) Before a minute is spent on diagnosis, be certain that a problem exists. If the problem cannot be verified, it cannot be solved or tested to verify that the repair was complete. See Figure 63–2.

The driver of the vehicle knows much about the vehicle and how it is driven. *Before* diagnosis, always ask the following questions:

- Is the malfunction indicator light (check engine) on?
- What was the temperature outside?
- Was the engine warm or cold?
- Was the problem during starting, acceleration, cruise, or some other condition?
- How far had the vehicle been driven?
- Were any dash warning lights on? If so, which one(s)?
- Has there been any service or repair work performed on the vehicle lately?

NOTE: This last question is very important. Many engine performance faults are often the result of something being knocked loose or a hose falling off during repair work. Knowing that the vehicle was just serviced before the problem began may be an indicator as to where to look for the solution to a problem.

After the nature and scope of the problem are determined, the complaint should be verified before further diagnostic tests are performed. A sample form that customers could fill out with details of the problem is shown in Figure 63–3.

NOTE: Because drivers differ, it is sometimes the best policy to take the customer on the test drive to verify the concern.

TECH TIP

"Original Equipment" Is Not a Four-Letter Word

To many service technicians, an original-equipment part is considered to be only marginal and to get the really "good stuff" an aftermarket (renewal market) part has to be purchased. However, many problems can be traced to the use of an aftermarket part that has failed early in its service life. Technicians who work at dealerships usually go immediately to an aftermarket part that is observed during a visual inspection. It has been their experience that simply replacing the aftermarket part with the factory original-equipment (OE) part often solves the problem.

Original equipment parts are *required* to pass quality and durability standards and tests at a level not required of aftermarket parts. The technician should be aware that the presence of a new part does not necessarily mean that the part is good.

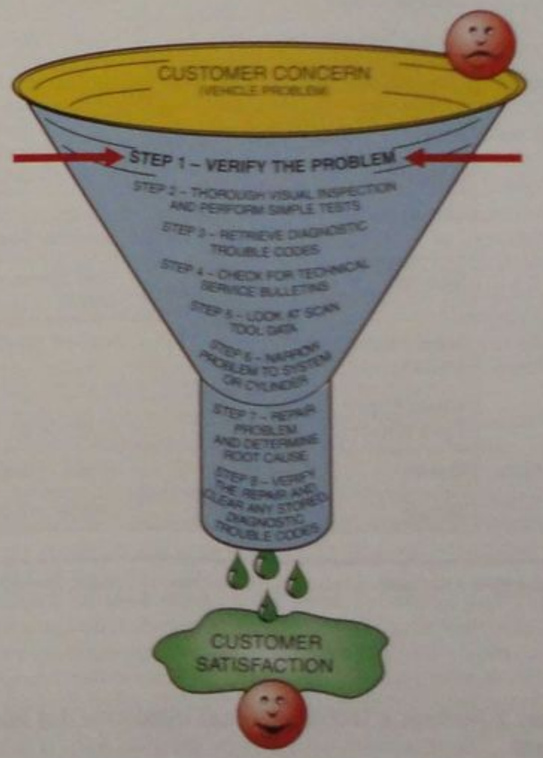


Figure 63–2 Step #1 is to verify the customer concern or problem. If the problem cannot be verified, then the repair cannot be verified.

ENGINE PERFORMANCE DIAGNOSIS WORKSHEET

(To Be Filled Out By the Vehicle Owner)

Name: _____ Mileage: _____ Date: _____

Make: _____ Model: _____ Year: _____ Engine: _____

	(Please Circle All That Apply in All Categories)
Describe Problem:	
When Did the Problem First Occur?	• Just Started • Last Week • Last Month • Other _____
List Previous Repairs in the Last 6 Months:	
Starting Problems	• Will Not Crank • Cranks, but Will Not Start • Starts, but Takes a Long Time
Engine Quits or Stalls	• Right after Starting • When Put into Gear • During Steady Speed Driving • Right after Vehicle Comes to a Stop • While Idling • During Acceleration • When Parking
Poor Idling Conditions	• Is Too Slow at All Times • Is Too Fast • Intermittently Too Fast or Too Slow • Is Rough or Uneven • Fluctuates Up and Down
Poor Running Conditions	• Runs Rough • Lacks Power • Bucks and Jerks • Poor Fuel Economy • Hesitates or Stumbles on Acceleration • Backfires • Misfires or Cuts Out • Engine Knocks, Pings, Rattles • Surges • Dieseling or Run-On
Auto. Transmission Problems	• Improper Shifting (Early/Late) • Changes Gear Incorrectly • Vehicle Does Not Move When in Gear • Jerks or Bucks
Usually Occurs	• Morning • Afternoon • Anytime
Engine Temperature	• Cold • Warm • Hot
Driving Conditions During Occurrence	• Short—Less Than 2 Miles • 2–10 Miles • Long—More Than 10 Miles • Stop and Go • While Turning • While Braking • At Gear Engagement • With A/C Operating • With Headlights On • During Acceleration • During Deceleration • Mostly Downhill • Mostly Uphill • Mostly Level • Mostly Curvy • Rough Road
Driving Habits	• Mostly City Driving • Highway • Park Vehicle Inside • Park Vehicle Outside **Drive Per Day:** • Less Than 10 Miles • 10–50 • More Than 50
Gasoline Used	**Fuel Octane:** • 87 • 89 • 91 • More Than 91 **Brand:** _____
Temperature When Problem Occurs	• 32–55° F • Below Freezing (32° F) • Above 55° F
Check Engine Light/ Dash Warning Light	• Light On Sometimes • Light On Always • Light Never On
Smells	• "Hot" • Gasoline • Oil Burning • Electrical
Noises	• Rattle • Knock • Squeak • Other

Figure 63–3 A form that the customer should fill out if there is a driveability concern to help the service technician more quickly find the root cause.

Step 2 Perform a Thorough Visual Inspection and Basic Tests The visual inspection is the most important aspect of diagnosis! Most experts agree that between 10% and 30% of all engine performance problems can be found simply by performing a *thorough* visual inspection. The inspection should include the following:

- **Check for obvious problems (basics, basics, basics).**
  - Fuel leaks
  - Vacuum hoses that are disconnected or split
  - Corroded connectors
  - Unusual noises, smoke, or smell
  - Check the air cleaner and air duct (squirrels and other small animals can build nests or store dog food in them). See Figure 63–4.
- **Check everything that does and does not work.** This step involves turning things on and observing that everything is working properly.
- **Look for evidence of previous repairs.** Any time work is performed on a vehicle, there is always a risk that something will be disturbed, knocked off, or left disconnected.

TECH TIP ✔ **Smoke Machine Testing**

Vacuum (air) leaks can cause a variety of driveability problems and are often difficult to locate. One good method is to use a machine that generates a stream of smoke. Connecting the outlet of the **smoke machine** to the hose that was removed from the vacuum brake booster allows smoke to enter the intake manifold. Any vacuum leaks will be spotted by observing smoke coming out of the leak. See Figure 63–5.

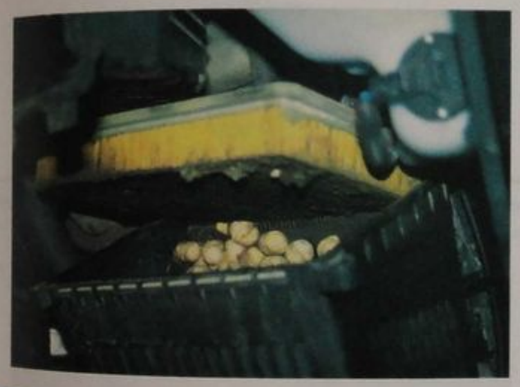


Figure 63–4 This is what was found when removing an air filter from a vehicle that had a lack-of-power concern. Obviously the nuts were deposited by squirrels or some other animal, blocking a lot of the airflow into the engine.



Figure 63–5 Using a bright light makes seeing where the smoke is coming from easier. In this case, smoke was added to the intake manifold with the inlet blocked with a yellow plastic bag and smoke was seen escaping past a gasket at the idle air control.

- **Check oil level and condition.** Another area for visual inspection is oil level and condition.

  Oil level. Oil should be to the proper level.

  Oil condition. Using a match or lighter, try to light the oil on the dipstick; if the oil flames up, gasoline is present in the engine oil. Drip some engine oil from the dipstick onto the hot exhaust manifold. If the oil bubbles or boils, coolant (water) is present in the oil. Check for grittiness by rubbing the oil between your fingers.

NOTE: Gasoline in the oil will cause the engine to run rich by drawing fuel through the positive crankcase ventilation (PCV) system.

- **Check coolant level and condition.** Many mechanical engine problems are caused by overheating. The proper operation of the cooling system is critical to the life of any engine.

NOTE: Check the coolant level in the radiator only if the radiator is cool. If the radiator is hot and the radiator cap is removed, the drop in pressure above the coolant will cause the coolant to boil immediately, which can cause severe burns because the coolant expands explosively upward and outward from the radiator opening.

- **Use the paper test.** A soundly running engine should produce even and steady exhaust at the tailpipe. For the **paper test,** hold a piece of paper (even a dollar bill works) or a 3- by 5-inch card within 1 inch (2.5 centimeters) of the tailpipe with the engine running at idle. The paper should blow evenly away from the end of the tailpipe without "puffing" or being drawn inward toward the end of the tailpipe. If the paper is at times drawn *toward* the tailpipe, the valves in one or more cylinders could be burned. Other reasons why the paper might be drawn toward the tailpipe include the following:
  1. The engine could be misfiring because of a lean condition that could occur normally when the engine is cold.
  2. Pulsing of the paper toward the tailpipe could also be caused by a hole in the exhaust system. If exhaust escapes through a hole in the exhaust system, air could be drawn—in the intervals between the exhaust puffs—from the tailpipe to the hole in the exhaust, causing the paper to be drawn toward the tailpipe.
- **Ensure adequate fuel level.** Make certain that the fuel tank is at least one-fourth to one-half full; if the fuel level is low it is possible that any water or alcohol at the bottom of the fuel tank is more concentrated and can be drawn into the fuel system.
- **Check the battery voltage.** The voltage of the battery should be at least 12.4 volts and the charging voltage (engine running) should be 13.5 to 15.0 volts at 2,000 RPM. Low battery voltage can cause a variety of problems including reduced fuel economy and incorrect (usually too high) idle speed. Higher-than-normal battery voltage can also cause the PCM problems and could cause damage to electronic modules.
- **Check the spark using a spark tester.** Remove one spark plug wire and attach the removed plug wire to the spark tester. Attach the grounding clip of the spark tester to a good clean engine ground, start or crank the engine, and observe the spark tester. See Figure 63–6. The spark at the spark tester should be steady and consistent. If an intermittent spark occurs, then this condition should be treated as a no-spark condition. If this test does not show satisfactory spark, carefully inspect and test all components of the primary and secondary ignition systems.

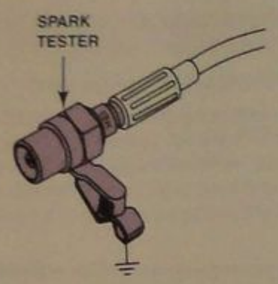


Figure 63–6 A spark tester connected to a spark plug wire or coil output. A typical spark tester will only fire if at least 25,000 volts is available from the coil, making a spark tester a very useful tool. Do not use one that just lights when a spark is present, because they do not require more than about 2,000 volts to light.

NOTE: Do not use a standard spark plug to check for proper ignition system voltage. An electronic ignition spark tester is designed to force the spark to jump about 0.75 inch (19 mm). This amount of gap requires between 25,000 and 30,000 volts (25 to 30 kV) at atmospheric pressure, which is enough voltage to ensure that a spark can occur under compression inside an engine.

- **Check the fuel-pump pressure.** Checking the fuel-pump pressure is relatively easy on many port-fuel-injected engines. Often the cause of intermittent engine performance is due to a weak electric fuel pump or clogged fuel filter. Checking fuel pump pressure early in the diagnostic process eliminates low fuel pressure as a possibility.

Step 3 Retrieve the Diagnostic Trouble Codes (DTCs)

If a diagnostic trouble code (DTC) is present in the computer memory, it may be signaled by illuminating a malfunction indicator lamp (MIL), commonly labeled "check engine" or "service engine soon." See Figure 63–7. Any code(s) that is displayed when the MIL is *not* on is called a **pending code.** Because the MIL is not on, this indicates that the fault has not repeated to cause the PCM to turn on the MIL. Although this pending code is helpful to the technician to know that a fault has, in the past, been detected, further testing will be needed to find the root cause of the problem.

Step 4 Check for Technical Service Bulletins (TSBs)

Check for corrections in **technical service bulletins (TSBs)** that match the symptoms. See Figure 63–8. According to studies performed by automobile manufacturers, as many as 30% of vehicles can be repaired following the information, suggestions, or replacement parts found in a service bulletin. DTCs must be known before searching for service bulletins, because bulletins often include information on solving problems that involve a stored diagnostic trouble code.

Step 5 Look Carefully at Scan Tool Data

Vehicle manufacturers have been giving the technician more and more data on a scan tool connected to the **data link connector (DLC).** See Figure 63–9. Beginning technicians are often observed scrolling through scan data without a real clue about what they are looking for. When asked, they usually reply that they are looking for something unusual, as if the screen will flash a big message "LOOK HERE—THIS IS NOT CORRECT." That statement does not appear on scan tool displays. The best way to look at scan data is in a definite sequence and with specific, selected bits of data that can tell the most about the operation of the engine, such as the following:

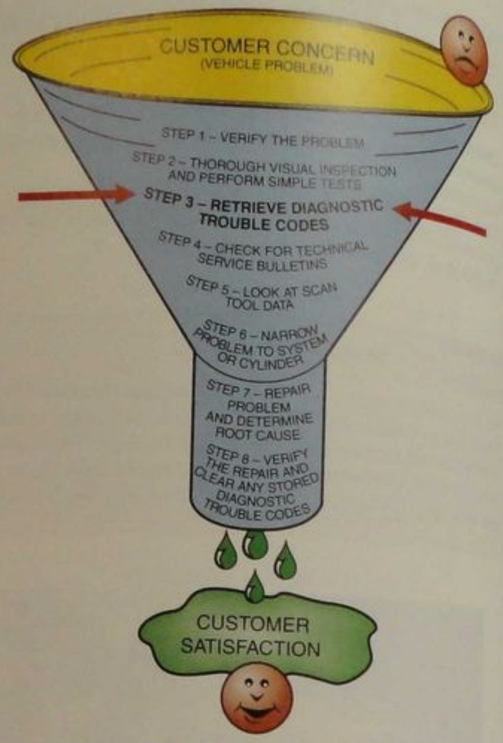


Figure 63–7 Step #3 in the diagnostic process is to retrieve any stored diagnostic trouble codes.

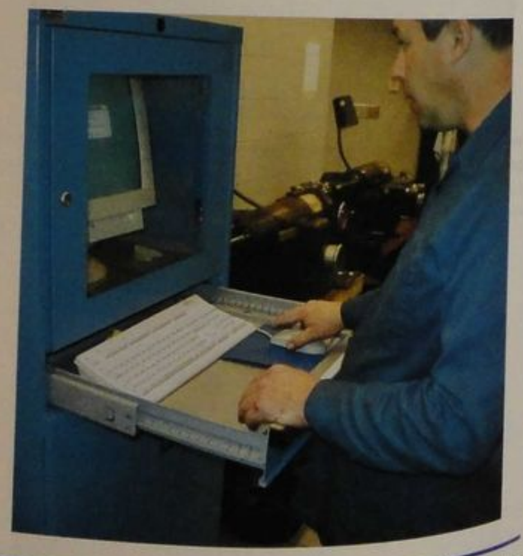


Figure 63–8 After checking for stored diagnostic trouble codes (DTCs), the wise technician checks service information for any technical service bulletins that may relate to the vehicle being serviced.

- Engine coolant temperature (ECT) is the same as intake air temperature (IAT) after the vehicle sits for several hours.
- Idle air control (IAC) valve is being commanded to an acceptable range.

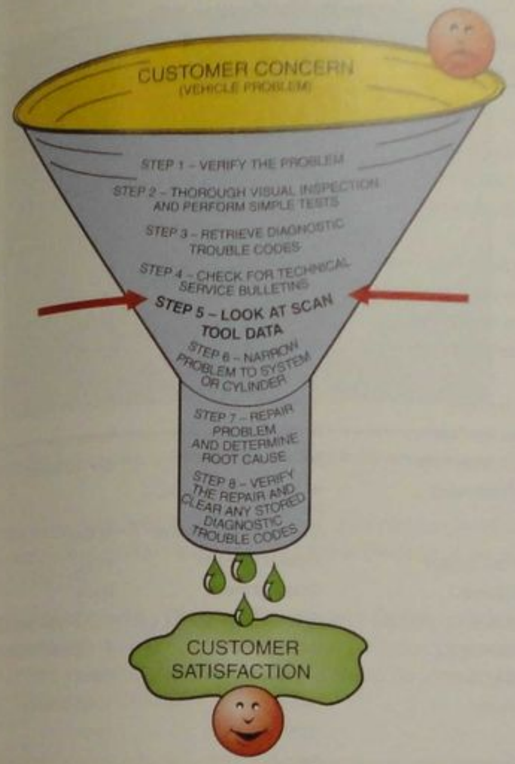


Figure 63–9 Looking carefully at the scan tool data is very helpful in locating the source of a problem.

- Oxygen sensor (O2S) is operating properly:
  1. Readings below 200 mV at times
  2. Readings above 800 mV at times
  3. Rapid transitions between rich and lean

Step 6 Narrow the Problem to a System or Cylinder

Narrowing the focus to a system or individual cylinder is the hardest part of the entire diagnostic process.

- Perform a cylinder power balance test.
- If a weak cylinder is detected, perform a compression and a cylinder leakage test to determine the probable cause.

Step 7 Repair the Problem and Determine the Root Cause

The repair or part replacement must be performed following vehicle manufacturer's recommendations and be certain that the root cause of the problem has been found. Also follow the manufacturer's recommended repair procedures and methods.

Step 8 Verify the Repair and Clear Any Stored DTCs

See Figure 63–10.

- Test-drive to verify that the original problem (concern) is fixed.
- Verify that no additional problems have occurred during the repair process.
- Check for and then clear all diagnostic trouble codes. (This step ensures that the computer will not make any changes based on a stored DTC, but should not be performed if the vehicle is going to be tested for emissions because all of the monitors will need to be run and pass.)

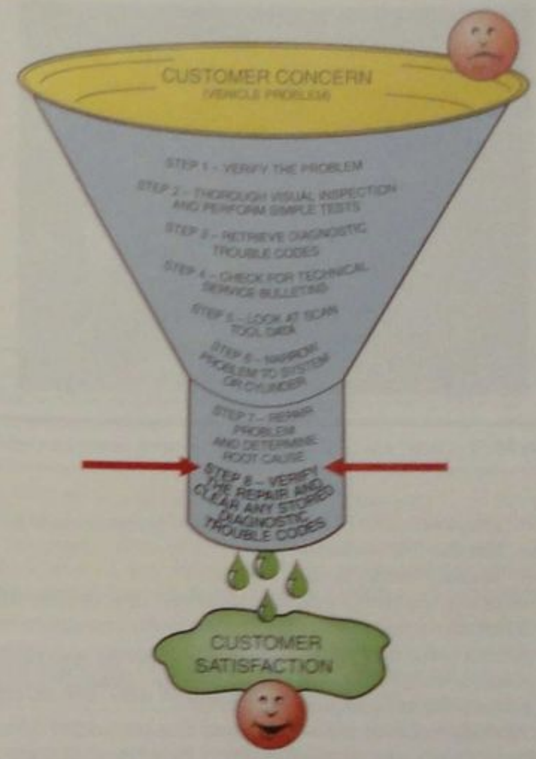


Figure 63–10 Step #8 is very important. Be sure that the customer's concern has been corrected.

- Return the vehicle to the customer and double-check the following:
  1. The vehicle is clean.
  2. The radio is turned off.
  3. The clock is set to the right time and the radio stations have been restored if the battery was disconnected during the repair procedure.

TECH TIP ✓ **One Test Is Worth 1,000 "Expert" Opinions**

Whenever any vehicle has an engine performance or driveability concern, certain people always say:

"Sounds like it's a bad injector."

"I'll bet you it's a bad computer."

"I had a problem just like yours yesterday and it was a bad EGR valve."

Regardless of the skills and talents of those people, it is still more accurate to perform tests on the vehicle than to rely on feelings or opinions of others who have not even seen the vehicle. Even your own opinion should not sway your thinking. Follow a plan, perform tests, and the test results will lead to the root cause.

SCAN TOOLS

Scan tools are the workhorse for any diagnostic work on all vehicles. Scan tools can be divided into two basic groups:

1. **Factory scan tools**—These are the scan tools required by all dealers that sell and service the brand of vehicle. Examples of factory scan tools include:
   - **General Motors**—Tech 2. See Figure 63–11.
   - **Ford**—New Generation Star (NGS)



Figure 63–11 A TECH 2 scan tool is the factory scan tool used on General Motors vehicles.

- **Chrysler**—DRB-III or Star Scan (CAN-equipped vehicles)
- **Honda**—HDS or Master Tech
- **Toyota**—Master Tech

All factory scan tools are designed to provide bidirectional capability which allows the service technician the opportunity to operate components using the scan tool thereby confirming that the component is able to work when commanded. Also all factory scan tools are capable of displaying all factory parameters.

2. **Aftermarket scan tools**—These scan tools are designed to function on more than one brand of vehicle. Examples of aftermarket scan tools include:
   - **Snap-on** (various models including the MT2500 and Modis)
   - **OTC** (various models including Genisys and Task Master)
   - **AutoEnginuity** and other programs that use a laptop or handheld computer for the display

While many aftermarket scan tools can display most if not all of the parameters of the factory scan tool, there can be a difference when trying to troubleshoot some faults. See Figure 63–12.

RETRIEVAL OF DIAGNOSTIC INFORMATION

To retrieve diagnostic information from the power train control module (PCM), a scan tool is needed. If the factory scan tool is used, then all of the data can be retrieved. If a generic OBD-II scan tool is used, only the emissions-related data can be retrieved. To retrieve diagnostic information from the PCM, use the following steps:

Step #1 Locate and gain access to the data link connector (DLC).

Step #2 Connect the scan tool to the DLC and establish communication.

NOTE: If no communication is established, follow the vehicle manufacturer's specified procedures.

Step #3 Follow the on-screen instructions of the scan tool to correctly identify the vehicle.

Step #4 Observe the scan data, as well as any diagnostic trouble codes.

Step #5 Follow vehicle manufacturer's instructions if any DTCs are stored. If no DTCs are stored, compare all sensor values with a factory acceptable range chart to see if any sensor values are out-of-range.

Parameter Identification (PID)

Scan Tool Parameter	Units Displayed	Typical Data Value (Engine Idling/Radiator Hose Hot/Closed Throttle/Park or Neutral/Closed Loop/Accessories Off/Brake Pedal Released)
3X Crank Sensor	RPM	Varies
24X Crank Sensor	RPM	Varies
Actual EGR position	Percent	0
BARO	kPa/Volts	65–110 kPa/3.5–4.9 Volts
CMP Sensor Signal Present	Yes/No	Yes
Commanded Fuel Pump	On/Off	On
Cycles of Misfire Data	Counts	0–99
Desired EGR position	Percent	0
ECT	°C/°F	Varies
EGR Duty Cycle	Percent	0
Engine Run Time	Hr: Min: Sec	Varies
EVAP Canister Purge	Percent	Low and Varying
EVAP Fault History	No Fault/Excess Vacuum/Purge Valve Leak/Small Leak/Weak Vacuum	No Fault
Fuel Tank Pressure	Inches of H_2O/Volts	Varies
HO2S Sensor 1	Ready/Not Ready	Ready
HO2S Sensor 1	millivolts	0–1,000 and Varying
HO2S Sensor 2	millivolts	0–1,000 and Varying
HO2S X Counts	Counts	Varies
IAC Position	Counts	15–25 preferred
IAT	°C/°F	Varies
Knock Retard	Degrees	0
Long Term FT	Percent	0–10
MAF	Grams per Second	3–7
MAF Frequency	Hz	1,200–3,000 (depends on altitude and engine load)
MAP	kPa/Volts	20–48 kPa/0.75–3 Volts (depends on altitude)
Misfire Current Cyl. 1–10	Counts	0
Misfire History Cyl. 1–10	Counts	0
Short Term FT	Percent	0–10
Start Up ECT	°C/°F	Varies
Start Up IAT	°C/°F	Varies
Total Misfire Current Count	Counts	0
Total Misfire Failures	Counts	0
Total Misfire Passes	Counts	0
TP Angle	Percent	0
TP Sensor	Volts	0.20–0.74
Vehicle Speed	MPH/Km/h	0

NOTE: Viewing the PID screen on the scanner is useful in determining if a problem is occurring at the present time.

TROUBLESHOOTING USING DIAGNOSTIC TROUBLE CODES

Pinning down causes of the actual problem can be accomplished by trying to set the opposite code. For example, if a code indicates an open throttle position (TP) sensor (high resistance), clear the code and create a shorted (low-resistance) condition. This can be accomplished by using a jumper wire and connecting the signal terminal to the 5-volt reference terminal. This should set a diagnostic trouble code.

- **If the opposite code sets,** this indicates that the wiring and connector for the sensor is okay and the sensor itself is defective (open).



Figure 63–12 Some scan tools use pocket PCs which make it very convenient to use.

- **If the same code sets,** this indicates that the wiring or electrical connection is open (has high resistance) and is the cause of the setting of the DTC.

Methods for Clearing Diagnostic Trouble Codes Clearing diagnostic trouble codes from a vehicle computer sometimes needs to be performed. There are three methods that can be used to clear stored diagnostic trouble codes.

CAUTION: Clearing diagnostic trouble codes (DTCs) also will clear all of the noncontinuous monitors.

- **Clearing codes—Method 1.** The preferred method of clearing codes is by using a scan tool. This is the method recommended by most vehicle manufacturers if the procedure can be performed on the vehicle. The computer of some vehicles cannot be cleared with a scan tool.
- **Clearing codes—Method 2.** If a scan tool is not available or a scan tool cannot be used on the vehicle being serviced, the power to the computer can be disconnected.
  1. Disconnect the fusible link (if so equipped) that feeds the computer.
  2. Disconnect the fuse or fuses that feed the computer.

NOTE: The fuse may not be labeled as a computer fuse. For example, many Toyotas can be cleared by disconnecting the fuel-injection fuse. Some vehicles require that two fuses be disconnected to clear any stored codes.

- **Clearing codes—Method 3.** If the other two methods cannot be used, the negative (−) battery cable can be disconnected to clear stored diagnostic trouble codes.

NOTE: Because of the adaptive learning capacity of the computer, a vehicle may fail an exhaust emissions test if the vehicle is not driven enough to allow the computer to run all of the monitors.

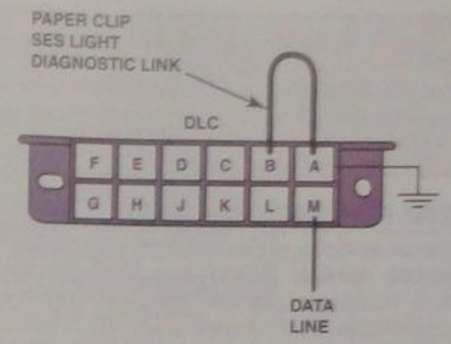


Figure 63–13 To retrieve flash codes from an OBD-I General Motors vehicle, connect terminals A and B with the ignition on–engine off. The M terminal is used to retrieve data from the sensors to a scan tool.

CAUTION: By disconnecting the battery, the radio presets and clock information will be lost. They should be reset before returning the vehicle to the customer. If the radio has a security code, the code must be entered before the radio will function. Before disconnecting the battery, always check with the vehicle owner to be sure that the code is available.

FLASH CODE RETRIEVAL ON OBD-I GENERAL MOTORS VEHICLES

The GM system uses a "check engine" or "check engine soon" MIL to notify the driver of possible system failure. Under the dash (on most GM vehicles) is a data link connector (DLC) previously called an assembly line communications link (ALCL) or assembly line diagnostic link (ALDL).

Most General Motors diagnostic trouble codes can be retrieved by using a metal tool and contacting terminals A and B of the 12-pin DLC. See Figure 63–13. This method is called **flash code retrieval** because the MIL will flash to indicate diagnostic trouble codes. The steps are as follows:

1. Turn the ignition switch to on (engine off). The "check engine" light or "service engine soon" light should be on. If the amber malfunction indicator light (MIL) is not on, a problem exists within the light circuit.
2. Connect terminals A and B at the DLC.
3. Observe the MIL. A code 12 (one flash, then a pause, then two flashes) reveals that there is no engine speed indication to the computer. Because the engine is not running, this simply indicates that the computer diagnostic system is working correctly.

NOTE: Refer to service manual diagnostic procedures if the MIL is on and does not flash a code 12 when terminals A and B are connected.

4. After code 12 is displayed three times, the MIL will flash any other stored DTCs in numeric order starting with the lowest-number code. If only code 12 is displayed another three times, the computer has not detected any other faults.

NOTE: Trouble codes can vary according to year, make, model, and engine. Always consult the service literature or service manual for the exact vehicle being serviced. Check service information for the meaning and recommended steps to follow if a diagnostic trouble code is retrieved.

TECH TIP **Do Not Lie to a Scan Tool!**

Because computer calibration may vary from year to year, using the incorrect year for the vehicle while using a scan tool can cause the data retrieved to be incorrect or inaccurate.

RETRIEVING FORD DIAGNOSTIC CODES

The best tool to use during troubleshooting of a Ford vehicle is a **self-test automatic readout (STAR)** tester, new generation STAR (NGS), WDS (Worldwide Diagnostic System), or another scan tool with Ford capabilities. If a STAR tester or scan tool is not available, a needle (analog) type of voltmeter can be used for all OBD-I (prior to 1996) systems. See the Tech Tip "Put a Wire in the Attic and a Light in the Basement!" to obtain flash codes. The test connector is usually located under the hood on the driver's side. See Figure 63–14.

Key On–Engine Off Test (On-Demand Codes or Hard Faults) With the ignition key on (engine off), watch the voltmeter pulses, which should appear within 5 to 30 seconds. (Ignore any initial surge of voltage when the ignition is turned on.)

The computer will send a two-digit code that will cause the voltmeter to pulse or move from left to right. For example, if the voltmeter needle pulses two times, then pauses for 2 seconds, and then pulses three times, the code is 23. There is normally a 4-second pause between codes.

Separator Pulse After all the codes have been reported, the computer will pause for about 6 to 9 seconds, then cause the voltmeter needle to pulse once, and then pause for another 6 to 9 seconds. This is the normal separation between current trouble codes and continuous memory codes (for intermittent problems). Code 11 is the normal pass code, which means that no fault has been stored in memory. Therefore, normal operation of the diagnostic procedure using a voltmeter should indicate the following if no codes are set: 1 pulse (2-second pause), 1 pulse (6- to 9-second pause), 1 pulse (6- to 9-second pause), 1 pulse (2-second pause), and finally, 1 pulse. These last two pulses that are separated by a 2-second interval represent a code 11, which is the code used between current and intermittent trouble codes.



Figure 63–14 A Ford OBD-I self-test connector. The location of this connector can vary with model and year of vehicle.

Continuous Memory Codes (Soft Codes) Continuous memory codes are set based on information stored while the vehicle was in normal operation. These codes represent an intermittent problem and should only be used for diagnosis if the KOEO test results in code 11 (no faults detected). Therefore, any codes displayed after the separation pulse represent failures that have been detected but may no longer be present.

TECH TIP **Put a Wire in the Attic and a Light in the Basement!**

Retrieving DTCs from a Ford using low-cost test equipment is easier when you remember the following: "*Put a wire in the attic and a light in the basement.*"

After warming the engine to operating temperature, perform these simple steps:

1. Locate the data link connector (DLC) under the hood. Connect a jumper wire from the single-wire pigtail called the self-test input to terminal #2 at the top (attic) of the connector.
2. To read DTCs, connect a standard 12-volt test light (not a self-powered continuity light) to the positive battery terminal and the lower (basement) terminal (#4) of the DLC. See Figure 63–15. Turn the ignition to on (engine off). The DTCs will be displayed by means of the flashes of the test light.

To clear stored Ford DTCs, simply disconnect the jumper wire from the self-test input while the codes are being flashed. This interruption is the signal to the computer to clear any stored DTCs.

Key On–Engine Running (KOER) Test During the KOER self-test, the sensors are checked by the computer under actual operating conditions and the output devices (actuators) are operated and checked for expected results. Start the engine and raise the speed to 2,500 to 3,000 RPM to warm the oxygen sensor within 20 seconds of starting. Hold a steady high engine speed until the initial pulses appear (2 pulses for a four-cylinder engine, 3 pulses for a six-cylinder, and 4 pulses for an eight-cylinder). These codes are used to verify the proper processor (computer) is in the vehicle and that the self-test has been entered. Continue to hold a high engine speed until the code pulses begin (10 to 14 seconds).

Steering, Brake, and Overdrive Switch Test To test the power steering pressure switch, the technician must turn the steering wheel one-half turn after the ID code has been displayed. The brake pedal and the overdrive cancel switch must also be cycled after the ID code to allow the system to detect a change of state of these switches.

Dynamic Response Check The dynamic response test checks the throttle position (TP) mass air flow (MAF) and manifold absolute pressure (MAP) sensors during a brief wide-open throttle (WOT) test performed by the technician. The signal for the technician to depress the throttle briefly to wide open is a single pulse or a code 10 on a STAR tester.

If any hard (on-demand) faults appear, these should be repaired first and then any soft (continuous) codes next. Use the factory "pinpoint tests" to trace the problem. Refer to service information for a description of Ford-specific alphanumeric DTCs.

FLASH CODE RETRIEVAL ON CHRYSLER VEHICLES

To put the computer into the self-diagnostic mode, the ignition switch must be turned on and off twice within a 5-second period

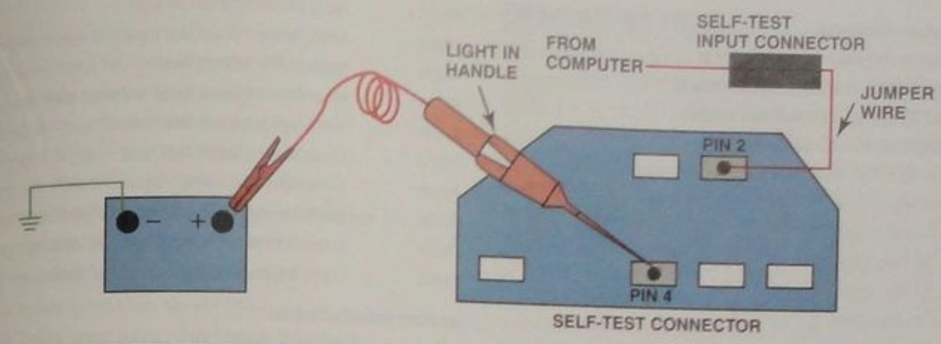


Figure 63–15 To retrieve Ford DTCs using a test light and a jumper wire, turn the ignition switch on (engine off) and make the connections shown. The test light will blink out the diagnostic trouble codes.

(on-off-on-off-on). The computer will flash a series of fault codes. Older Chrysler brand products flash the "check engine" lamp on the dash.

NOTE: Unlike other manufacturers, most Chrysler brand vehicles equipped with OBD II will display the P-codes on the odometer display by cycling the ignition key as previously performed on older vehicles.

OBD-II DIAGNOSIS

Starting with the 1996 model year, all vehicles sold in the United States must use the same type of 16-pin data link connector (DLC) and must monitor emission-related components. See Figure 63–16.

Retrieving OBD-II Codes A scan tool is required to retrieve diagnostic trouble codes from most OBD-II vehicles. Every OBD-II scan tool will be able to read all generic Society of Automotive Engineers (SAE) DTCs from any vehicle.



Figure 63–16 A typical OBD-II data link connector (DLC). The location varies with make and model and may even be covered, but a tool is not needed to gain access. Check service information for the exact location if needed.

Fuel and Air Metering System

P0100	Mass or Volume Airflow Circuit Problem
P0101	Mass or Volume Airflow Circuit Range or Performance Problem
P0102	Mass or Volume Airflow Circuit Low Input
P0103	Mass or Volume Airflow Circuit High Input
P0105	Manifold Absolute Pressure or Barometric Pressure Circuit Problem
P0106	Manifold Absolute Pressure or Barometric Pressure Circuit Range or Performance Problem
P0107	Manifold Absolute Pressure or Barometric Pressure Circuit Low Input
P0108	Manifold Absolute Pressure or Barometric Pressure Circuit High Input
P0110	Intake Air Temperature Circuit Problem
P0111	Intake Air Temperature Circuit Range or Performance Problem
P0112	Intake Air Temperature Circuit Low Input
P0113	Intake Air Temperature Circuit High Input
P0115	Engine Coolant Temperature Circuit Problem
P0116	Engine Coolant Temperature Circuit Range or Performance Problem
P0117	Engine Coolant Temperature Circuit Low Input
P0118	Engine Coolant Temperature Circuit High Input
P0120	Throttle Position Circuit Problem
P0121	Throttle Position Circuit Range or Performance Problem
P0122	Throttle Position Circuit Low Input
P0123	Throttle Position Circuit High Input
P0125	Excessive Time to Enter Closed-Loop Fuel Control
P0130	02 Sensor Circuit Problem (Bank 1* Sensor 1)
P0131	02 Sensor Circuit Low Voltage (Bank 1* Sensor 1)
P0132	02 Sensor Circuit High Voltage (Bank 1* Sensor 1)
P0133	02 Sensor Circuit Slow Response (Bank 1* Sensor 1)
P0134	02 Sensor Circuit No Activity Detected (Bank 1* Sensor 1)
P0135	02 Sensor Heater Circuit Problem (Bank 1* Sensor 1)
P0136	02 Sensor Circuit Problem (Bank 1* Sensor 2)
P0137	02 Sensor Circuit Low Voltage (Bank 1* Sensor 2)
P0138	02 Sensor Circuit High Voltage (Bank 1* Sensor 2)
P0139	02 Sensor Circuit Slow Response (Bank 1* Sensor 2)
P0140	02 Sensor Circuit No Activity Detected (Bank 1* Sensor 2)
P0141	02 Sensor Heater Circuit Problem (Bank 1* Sensor 2)
P0142	02 Sensor Circuit Problem (Bank 1* Sensor 3)
P0143	02 Sensor Circuit Low Voltage (Bank 1* Sensor 3)
P0144	02 Sensor Circuit High Voltage (Bank 1* Sensor 3)
P0145	02 Sensor Circuit Slow Response (Bank 1* Sensor 3)
P0146	02 Sensor Circuit No Activity Detected (Bank 1* Sensor 3)
P0147	02 Sensor Heater Circuit Problem (Bank 1* Sensor 3)
P0150	02 Sensor Circuit Problem (Bank 2 Sensor 1)
P0151	02 Sensor Circuit Low Voltage (Bank 2 Sensor 1)
P0152	02 Sensor Circuit High Voltage (Bank 2 Sensor 1)
P0153	02 Sensor Circuit Slow Response (Bank 2 Sensor 1)
P0154	02 Sensor Circuit No Activity Detected (Bank 2 Sensor 1)
P0155	02 Sensor Heater Circuit Problem (Bank 2 Sensor 1)
P0156	02 Sensor Circuit Problem (Bank 2 Sensor 2)
P0157	02 Sensor Circuit Low Voltage (Bank 2 Sensor 2)
P0158	02 Sensor Circuit High Voltage (Bank 2 Sensor 2)
P0159	02 Sensor Circuit Slow Response (Bank 2 Sensor 2)
P0160	02 Sensor Circuit No Activity Detected (Bank 2 Sensor 2)
P0161	02 Sensor Heater Circuit Problem (Bank 2 Sensor 2)

Fuel and Air Metering System—continued

P0162	02 Sensor Circuit Problem (Bank 2 Sensor 3)
P0163	02 Sensor Circuit Low Voltage (Bank 2 Sensor 3)
P0164	02 Sensor Circuit High Voltage (Bank 2 Sensor 3)
P0165	02 Sensor Circuit Slow Response (Bank 2 Sensor 3)
P0166	02 Sensor Circuit No Activity Detected (Bank 2 Sensor 3)
P0167	02 Sensor Heater Circuit Problem (Bank 2 Sensor 3)
P0170	Fuel Trim Problem (Bank 1*)
P0171	System Too Lean (Bank 1*)
P0172	System Too Rich (Bank 1*)
P0173	Fuel Trim Problem (Bank 2)
P0174	System Too Lean (Bank 2)
P0175	System Too Rich (Bank 2)
P0176	Fuel Composition Sensor Circuit Problem
P0177	Fuel Composition Sensor Circuit Range or Performance
P0178	Fuel Composition Sensor Circuit Low Input
P0179	Fuel Composition Sensor Circuit High Input
P0180	Fuel Temperature Sensor Problem
P0181	Fuel Temperature Sensor Circuit Range or Performance
P0182	Fuel Temperature Sensor Circuit Low Input
P0183	Fuel Temperature Sensor Circuit High Input

* The side of the engine where number one cylinder is located.

Fuel and Air Metering (Injector Circuit)

P0201	Injector Circuit Problem—Cylinder 1
P0202	Injector Circuit Problem—Cylinder 2
P0203	Injector Circuit Problem—Cylinder 3
P0204	Injector Circuit Problem—Cylinder 4
P0205	Injector Circuit Problem—Cylinder 5
P0206	Injector Circuit Problem—Cylinder 6
P0207	Injector Circuit Problem—Cylinder 7
P0208	Injector Circuit Problem—Cylinder 8
P0209	Injector Circuit Problem—Cylinder 9
P0210	Injector Circuit Problem—Cylinder 10
P0211	Injector Circuit Problem—Cylinder 11
P0212	Injector Circuit Problem—Cylinder 12
P0213	Cold Start Injector 1 Problem
P0214	Cold Start Injector 2 Problem

Ignition System or Misfire

P0300	Random Misfire Detected
P0301	Cylinder 1 Misfire Detected
P0302	Cylinder 2 Misfire Detected
P0303	Cylinder 3 Misfire Detected
P0304	Cylinder 4 Misfire Detected
P0305	Cylinder 5 Misfire Detected
P0306	Cylinder 6 Misfire Detected
P0307	Cylinder 7 Misfire Detected
P0308	Cylinder 8 Misfire Detected
P0309	Cylinder 9 Misfire Detected
P0310	Cylinder 10 Misfire Detected
P0311	Cylinder 11 Misfire Detected
P0312	Cylinder 12 Misfire Detected
P0320	Ignition or Distributor Engine Speed Input Circuit Problem
P0321	Ignition or Distributor Engine Speed Input Circuit Range or Performance
P0322	Ignition or Distributor Engine Speed Input Circuit No Signal
P0325	Knock Sensor 1 Circuit Problem
P0326	Knock Sensor 1 Circuit Range or Performance
P0327	Knock Sensor 1 Circuit Low Input
P0328	Knock Sensor 1 Circuit High Input
P0330	Knock Sensor 2 Circuit Problem
P0331	Knock Sensor 2 Circuit Range or Performance
P0332	Knock Sensor 2 Circuit Low Input
P0333	Knock Sensor 2 Circuit High Input
P0335	Crankshaft Position Sensor Circuit Problem
P0336	Crankshaft Position Sensor Circuit Range or Performance
P0337	Crankshaft Position Sensor Circuit Low Input
P0338	Crankshaft Position Sensor Circuit High Input

Auxiliary Emission Controls

P0400	Exhaust Gas Recirculation Flow Problem
P0401	Exhaust Gas Recirculation Flow Insufficient Detected
P0402	Exhaust Gas Recirculation Flow Excessive Detected
P0405	Air Conditioner Refrigerant Charge Loss
P0410	Secondary Air Injection System Problem
P0411	Secondary Air Injection System Insufficient Flow Detected
P0412	Secondary Air Injection System Switching Valve or Circuit Problem
P0413	Secondary Air Injection System Switching Valve or Circuit Open
P0414	Secondary Air Injection System Switching Valve or Circuit Shorted
P0420	Catalyst System Efficiency below Threshold (Bank 1*)
P0421	Warm Up Catalyst Efficiency below Threshold (Bank 1*)
P0422	Main Catalyst Efficiency below Threshold (Bank 1*)
P0423	Heated Catalyst Efficiency below Threshold (Bank 1*)
P0424	Heated Catalyst Temperature below Threshold (Bank 1*)
P0430	Catalyst System Efficiency below Threshold (Bank 2)
P0431	Warm Up Catalyst Efficiency below Threshold (Bank 2)
P0432	Main Catalyst Efficiency below Threshold (Bank 2)
P0433	Heated Catalyst Efficiency below Threshold (Bank 2)
P0434	Heated Catalyst Temperature below Threshold (Bank 2)
P0440	Evaporative Emission Control System Problem
P0441	Evaporative Emission Control System Insufficient Purge Flow
P0442	Evaporative Emission Control System Leak Detected
P0443	Evaporative Emission Control System Purge Control Valve Circuit Problem
P0444	Evaporative Emission Control System Purge Control Valve Circuit Open
P0445	Evaporative Emission Control System Purge Control Valve Circuit Shorted
P0446	Evaporative Emission Control System Vent Control Problem
P0447	Evaporative Emission Control System Vent Control Open
P0448	Evaporative Emission Control System Vent Control Shorted
P0450	Evaporative Emission Control System Pressure Sensor Problem
P0451	Evaporative Emission Control System Pressure Sensor Range or Performance
P0452	Evaporative Emission Control System Pressure Sensor Low Input
P0453	Evaporative Emission Control System Pressure Sensor High Input

Vehicle Speed Control and Idle Control

P0500	Vehicle Speed Sensor Problem
P0501	Vehicle Speed Sensor Range or Performance
P0502	Vehicle Speed Sensor Low Input
P0505	Idle Control System Problem
P0506	Idle Control System RPM Lower Than Expected
P0507	Idle Control System RPM Higher Than Expected
P0510	Closed Throttle Position Switch Problem

Computer Output Circuit

P0600	Serial Communication Link Problem
P0605	Internal Control Module (Module Identification Defined by J1979)

Transmission

P0703	Brake Switch Input Problem
P0705	Transmission Range Sensor Circuit Problem (PRNDL Input)
P0706	Transmission Range Sensor Circuit Range or Performance
P0707	Transmission Range Sensor Circuit Low Input
P0708	Transmission Range Sensor Circuit High Input
P0710	Transmission Fluid Temperature Sensor Problem
P0711	Transmission Fluid Temperature Sensor Range or Performance
P0712	Transmission Fluid Temperature Sensor Low Input
P0713	Transmission Fluid Temperature Sensor High Input
P0715	Input or Turbine Speed Sensor Circuit Problem
P0716	Input or Turbine Speed Sensor Circuit Range or Performance
P0717	Input or Turbine Speed Sensor Circuit No Signal
P0720	Output Speed Sensor Circuit Problem
P0721	Output Speed Sensor Circuit Range or Performance
P0722	Output Speed Sensor Circuit No Signal
P0725	Engine Speed Input Circuit Problem
P0726	Engine Speed Input Circuit Range or Performance
P0727	Engine Speed Input Circuit No Signal
P0730	Incorrect Gear Ratio
P0731	Gear 1 Incorrect Ratio
P0732	Gear 2 Incorrect Ratio
P0733	Gear 3 Incorrect Ratio
P0734	Gear 4 Incorrect Ratio
P0735	Gear 5 Incorrect Ratio
P0736	Reverse Incorrect Ratio
P0740	Torque Converter Clutch System Problem
P0741	Torque Converter Clutch System Performance or Stuck Off
P0742	Torque Converter Clutch System Stuck On
P0743	Torque Converter Clutch System Electrical
P0745	Pressure Control Solenoid Problem
P0746	Pressure Control Solenoid Performance or Stuck Off
P0747	Pressure Control Solenoid Stuck On
P0748	Pressure Control Solenoid Electrical
P0750	Shift Solenoid A Problem
P0751	Shift Solenoid A Performance or Stuck Off
P0752	Shift Solenoid A Stuck On
P0753	Shift Solenoid A Electrical
P0755	Shift Solenoid B Problem
P0756	Shift Solenoid B Performance or Stuck Off
P0757	Shift Solenoid B Stuck On
P0758	Shift Solenoid B Electrical
P0760	Shift Solenoid C Problem
P0761	Shift Solenoid C Performance or Stuck Off
P0762	Shift Solenoid C Stuck On
P0763	Shift Solenoid C Electrical
P0765	Shift Solenoid D Problem
P0766	Shift Solenoid D Performance or Stuck Off
P0767	Shift Solenoid D Stuck On
P0768	Shift Solenoid D Electrical
P0770	Shift Solenoid E Problem
P0771	Shift Solenoid E Performance or Stuck Off
P0772	Shift Solenoid E Stuck On
P0773	Shift Solenoid E Electrical

OBD-II ACTIVE TESTS

The vehicle computer must run tests on the various emission-related components and turn on the malfunction indicator lamp (MIL) if faults are detected. OBD II is an *active* computer analysis system because it actually tests the operation of the oxygen sensors, exhaust gas recirculation system, and so forth whenever conditions permit. It is the purpose and function of the power train control module (PCM) to monitor these components and perform these active tests.

For example, the PCM may open the EGR valve momentarily to check its operation while the vehicle is decelerating. A change in the manifold absolute pressure (MAP) sensor signal will indicate to the computer that the exhaust gas is, in fact, being introduced into the engine. Because these tests are active and certain conditions must be present before these tests can be run, the computer uses its internal diagnostic program to keep track of all the various conditions and to schedule active tests so that they will not interfere with each other.

OBD-II Drive Cycle The vehicle must be driven under a variety of operating conditions for all active tests to be performed. A **trip** is defined as an engine-operating drive cycle that contains the necessary conditions for a particular test to be performed. For example, for the EGR test to be performed, the engine has to be at normal operating temperature and decelerating for a minimum amount of time. Some tests are performed when the engine is cold, whereas others require that the vehicle be cruising at a steady highway speed.

Types of OBD-II Codes Not all OBD-II diagnostic trouble codes are of the same importance for exhaust emissions. Each type of DTC has different requirements for it to set, and the computer will only turn on the MIL for emissions-related DTCs.

Type A Codes A type A diagnostic trouble code is emission related and will cause the MIL to be turned on at the *first trip* if the computer has detected a problem. Engine misfire or a very rich or lean air–fuel ratio, for example, would cause a type A diagnostic trouble code. These codes alert the driver to an emissions problem that may cause damage to the catalytic converter.

Type B Codes A type B code will be stored and the MIL will be turned on during the *second consecutive trip*, alerting the driver to the fact that a diagnostic test was performed and failed.

NOTE: Type A and Type B codes are emission related and will cause the lighting of the malfunction indicator lamp, usually labeled "check engine" or "service engine soon."

Type C and D Codes Type C and type D codes are for use with non-emission-related diagnostic tests. They will cause the lighting of a "service" lamp (if the vehicle is so equipped).

OBD-II Freeze-Frame To assist the service technician, OBD II requires the computer to take a "snapshot" or freeze-frame of all data at the instant an emission-related DTC is set. A scan tool is required to retrieve this data. CARB and EPA regulations require that the controller store specific freeze-frame (engine-related) data when the first emission related fault is detected. The data stored in freeze-frame can only be replaced by data from a trouble code with a higher priority such as a trouble related to a fuel system or misfire monitor fault.

NOTE: Although OBD II requires that just one freeze-frame of data be stored, the instant an emission-related DTC is set, vehicle manufacturers usually provide expanded data about the DTC beyond that required. However, retrieving enhanced data usually requires the use of the vehicle-specific scan tool.

The freeze-frame has to contain data values that occurred at the time the code was set (these values are provided in standard units of measurement). Freeze-frame data is recorded during the first trip on a two-trip fault. As a result, OBD-II systems record the data present at the time an emission-related code is recorded and the MIL activated. This data can be accessed and displayed on a scan tool. Freeze-frame data is one frame or one instant in time. Freeze-frame data is not updated (refreshed) if the same monitor test fails a second time.

Required Freeze-Frame Data Items

- Code that triggered the freeze-frame
- A/F ratio, airflow rate and calculated engine load
- Base fuel injector pulse width
- ECT, IAT, MAF, MAP, TP, and VS sensor data
- Engine speed and amount of ignition spark advance
- Open- or closed-loop status
- Short-term and long-term fuel trim values
- For misfire codes—identify the cylinder that misfired

NOTE: All freeze-frame data will be lost if the battery is disconnected, power to the PCM is removed, or the scan tool is used to erase or clear trouble codes.

Diagnosing Intermittent Malfunctions Of all the different types of conditions that you will see, the hardest to accurately diagnose and repair are intermittent malfunctions. These conditions may be temperature related (only occur when the vehicle is hot or cold), or humidity related (only occur when it is raining). Regardless of the conditions that will cause the malfunction to occur, you must diagnose and correct the condition.

When dealing with an intermittent concern, you should determine the conditions when the malfunction occurs, and then try to duplicate those conditions. If a cause is not readily apparent to you, ask the customer when the symptom occurs. Ask if there are any conditions that seem to be related to, or cause the concern.

Another consideration when working on an OBD-II-equipped vehicle is whether a concern is intermittent, or if it only occurs when a specific diagnostic test is performed by the PCM. Since OBD-II systems conduct diagnostic tests only under very precise conditions, some tests may only be run once during an ignition cycle. Additionally, if the requirements needed to perform the test are not met, the test will not run during an ignition cycle. This type of onboard diagnostics could be mistaken as "intermittent" when, in fact, the tests are only infrequent (depending on how the vehicle is driven). Examples of this type of diagnostic test are HO2S heaters, evaporative canister purge, catalyst efficiency, and EGR flow. When diagnosing intermittent concerns on an OBD-II-equipped vehicle, a logical diagnostic strategy is essential. The use of stored freeze-frame information can also be very useful when diagnosing an intermittent malfunction if a code has been stored.

SERVICE/FLASH PROGRAMMING

Designing a program that allows an engine to meet strict air quality and fuel economy standards while providing excellent performance is no small feat. However, this is only part of the challenge facing engineers assigned with the task of developing OBD-II software. The reason for this is the countless variables involved with running the diagnostic monitors. Although programmers do their best to factor in any and all operating conditions when writing this complex code, periodic revisions are often required.

Reprogramming consists of downloading new calibration files from a scan tool, personal computer, or modem into the PCM's electronically erasable programmable read-only memory (EEPROM). This can be done on or off the vehicle using the appropriate equipment. Since reprogramming is not an OBD-II requirement however, many vehicles will need a new PCM in the event software changes become necessary. Physically removing and replacing the PROM chip is no longer possible.

The following are three industry-standard methods used to reprogram the EEPROM:

- Remote programming
- Direct programming
- Off-board programming

Remote Programming Remote programming uses the scan tool to transfer data from the manufacturer's shop PC to the vehicle's PCM. This is accomplished by performing the following steps:

- Connect the scan tool to the vehicle's DLC. See Figure 63–17.
- Enter the vehicle information into the scan tool through the programming application software incorporated in the scan tool. See Figure 63–18.
- Download VIN and current EEPROM calibration using a scan tool.
- Disconnect the scan tool from the DLC and connect the tool to the shop PC.
- Download the new calibration from the PC to the scan tool. See Figure 63–19.
- Reconnect the scan tool to the vehicle's DLC and download the new calibration into the PCM.



Figure 63–17 The first step in the reprogramming procedure is to determine the current software installed using a scan tool. Not all scan tools can be used. In most cases using the factory scan tool is needed for reprogramming unless the scan tool is equipped to handle reprogramming.

CAUTION: Before programming, the vehicle's battery must be between 11 and 14 volts. Do not attempt to program while charging the battery unless using a special battery charger which does not produce excessive ripple voltage such as the Midtronics PSC-300 (30 amp) or PSC-550 (55 amp) or similar as specified by the vehicle manufacturer.

Direct Programming Direct programming does utilize a connection between the shop PC and the vehicle DLC.

Off-Board Programming Off-board programming is used if the PCM must be programmed away from the vehicle. This is preformed using the off-board programming adapter. See Figure 63–20.

J2534 REPROGRAMMING

Legislation has mandated that vehicle manufacturers meet the SAE J2534 standards for all emissions-related systems on all new vehicles starting with model year 2004. This standard enables independent service repair operators to program or reprogram emissions-related ECMs from a wide variety of vehicle manufacturers with a single tool. See Figure 63–21. A J2534 compliant pass-through system is a standardized programming and diagnostic system. It uses a personal computer (PC) plus a standard interface to a software device driver, and a hardware vehicle communication interface. The interface connects to a PC, and to a programmable ECM on a vehicle through the J1962 data link connector (DLC). This system allows programming of all vehicle manufacturer ECMs using a single set of programming hardware. Programming software made available by the vehicle manufacturer must be functional with a J2534 compliant pass-through system.

The software for a typical pass-through application consists of two major components including:

- The part delivered by the company that furnishes the hardware for J2534 enables the pass-through vehicle communication interface to communicate with the PC and provides for all Vehicle Communication Protocols as required by SAE J2534. It also provides for the software interface to work with the software applications as provided for by the vehicle manufacturers. See Figure 63–22.

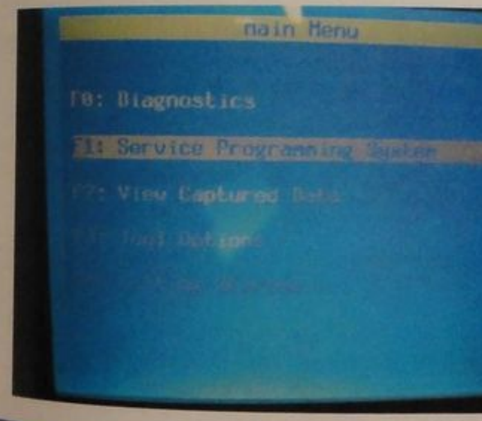


Figure 63–18 Follow the on-screen instructions.



Figure 63–19 An Internet connection is usually needed to perform updates although some vehicle manufacturers use CDs which are updated regularly at a cost to the shop.

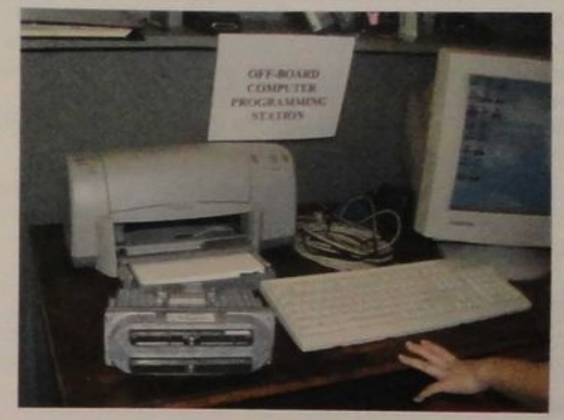


Figure 63–20 Connecting cables and a computer to perform off-board programming.

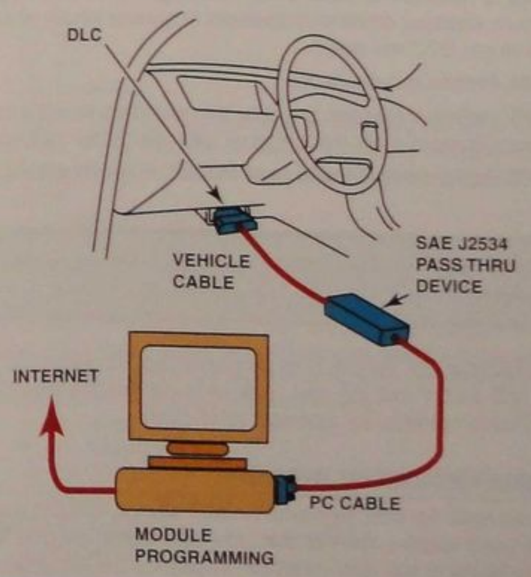


Figure 63–21 The J2534 pass-through reprogramming system does not need a scan tool to reflash the PCM on most 2004 and newer vehicles.



Figure 63–22 A typical J2534 universal reprogrammer that uses the J2534 standards.

- The second part of the pass-through enabling software is provided for by the vehicle manufacturers. This is normally a subset of the software used with their original equipment manufacturer (OEM) tools and their website will indicate how to obtain this software and under what conditions it can be used. Refer to the National Automotive Service Task Force (NASTF) website for the addresses for all vehicle manufacturers' service information and cost, *www.NASTF.org*.

Since the majority of vehicle manufacturers make this software available in downloadable form, having an Internet browser (Explorer/Netscape) and connection is a must.

MANUFACTURER'S DIAGNOSTIC ROUTINES

Each vehicle manufacturer has established their own diagnostic routines and they should be followed. Most include the following steps:

Step #1 Retrieve diagnostic trouble codes.

Step #2 Check for all technical service bulletins that could be related to the stored DTC.

Step #3 If there are multiple DTCs, the diagnostic routine may include checking different components or systems instead of when only one DTC was stored.

Step #4 Perform system checks.

Step #5 Perform a road test matching the parameters recorded in the freeze-frame to check that the repair has corrected the malfunction.

Step #6 Repeat the road test to cause the MIL to be extinguished.

NOTE: Do not clear codes (DTCs) unless instructed by the service information.

Following the vehicle manufacturer's specific diagnostic routines will ensure that the root cause is found and the repair verified. This is important for customer satisfaction.

COMPLETING SYSTEM REPAIRS

After the repair has been successfully completed, the vehicle should be driven under similar conditions that caused the original concern. Verify that the problem has been corrected. To perform this test drive, it is helpful to have a copy of the freeze-frame parameters that were present when the DTC was set. By driving under similar conditions, the PCM may perform a test of the system and automatically extinguish the MIL. This is the method preferred by most vehicle manufacturers. The DTC can be cleared using a scan tool, but then that means that monitors will have to be run and the vehicle may fail an emission inspection if driven directly to the testing station.

PROCEDURES FOR RESETTING THE PCM

The PCM can be reset or cleared of previously set DTCs and freeze-frame data in the following ways:

1. **Driving the Vehicle.** Drive the vehicle under similar conditions that were present when the fault occurred. If the conditions are similar and the PCM performed the noncontinuous monitor test and it passed three times, then the PCM will extinguish the MIL. This is the method preferred by most vehicle manufacturers, however, this method could be time consuming. If three passes cannot be achieved, the owner of the vehicle will have to be told that even though the check engine light (MIL) is on, the problem has been corrected and the MIL should go out in a few days of normal driving.
2. **Clear DTCs Using a Scan Tool.** A scan tool can be used to clear the diagnostic trouble code (DTC), which will also delete all of the freeze-frame data. The advantage of using a scan tool is that the check engine (MIL) will be out and the customer will be happy that the problem (MIL on) has been corrected. Do not use a scan tool to clear a DTC if the vehicle is going to be checked soon at a test station for state-mandated emission tests.
3. **Battery Disconnect.** Disconnecting the negative battery cable will clear the DTCs and freeze-frame on many vehicles but not all. Besides clearing the DTCs, disconnecting the battery for about 20 minutes will also erase radio station presets and other memory items in many cases. Most vehicle manufacturers do not recommend that the battery be disconnected to clear DTCs and it may not work on some vehicles.

TECH TIP ✔ **The Brake Pedal Trick**

If the vehicle manufacturer recommends that battery power be disconnected, first disconnect the negative battery cable and then depress the brake pedal. Because the brake lights are connected to battery power, depressing the brake pedal causes all of the capacitors in the electrical system and computer(s) to discharge through the brake lights.

ROAD TEST (DRIVE TRACE)

Use the freeze-frame data and test-drive the vehicle so that the vehicle is driven to match the conditions displayed on the freeze-frame. If the battery has been disconnected, then the vehicle may have to be driven under conditions that allow the PCM to conduct monitor tests. This drive pattern is called a **drive cycle.** The drive cycle is different for each vehicle manufacturer but a universal drive cycle may work in many cases. In many cases performing a universal drive cycle will reset most monitors in most vehicles.

Universal Drive Cycle

Preconditioning: Phase 1

MIL must be off.

No DTCs present.

Fuel fill between 15% and 85%.

Cold start—Preferred = 8-hour soak at 68°F to 86°F.

Alternative = ECT below 86°F.

1. With the ignition off, connect scan tool.
2. Start engine and drive between 20 and 30 mph for 22 minutes, allowing speed to vary.
3. Stop and idle for 40 seconds, gradually accelerate to 55 mph.
4. Maintain 55 mph for 4 minutes using a steady throttle input.
5. Stop and idle for 30 seconds, then accelerate to 30 mph.
6. Maintain 30 mph for 12 minutes.
7. Repeat steps 4 and 5 four times.

Using scan tool, check readiness. If insufficient readiness set, continue to universal drive trace phase II.

Important: (Do not shut off engine between phases). Phase II:

1. Vehicle at a stop and idle for 45 seconds, then accelerate to 30 mph.
2. Maintain 30 mph for 22 minutes.
3. Repeat steps 1 and 2 three times.
4. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 35 mph.
5. Maintain speed between 30 and 35 mph for 4 minutes.
6. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 30 mph.
7. Maintain 30 mph for 22 minutes.
8. Repeat steps 6 and 7 five times.
9. Using scan tool, check readiness.

SUMMARY

1. Funnel diagnostics—Visual approach to a diagnostic procedure:
   - Step 1. Verify the problem (concern)
   - Step 2. Perform a thorough visual inspection and basic tests
   - Step 3. Retrieve the diagnostic trouble codes (DTCs)
   - Step 4. Check for technical service bulletins (TSBs)
   - Step 5. Look carefully at scan tool data
   - Step 6. Narrow the problem to a system or cylinder
   - Step 7. Repair the problem and determine the root cause
   - Step 8. Verify the repair and check for any stored DTCs
2. Care should be taken to not induce high voltage or current around any computer or computer-controlled circuit or sensor.
3. A thorough visual inspection is important during the diagnosis and troubleshooting of any engine performance problem or electrical malfunction.
4. If the MIL is on, retrieve the DTC and follow the manufacturer's recommended procedure to find the root cause of the problem.
5. OBD-II vehicles use a 16-pin DLC and common DTCs.

REVIEW QUESTIONS

1. Explain the procedure to follow when diagnosing a vehicle without any stored DTCs using a scan tool.
2. Discuss what the PCM does during a drive cycle to test emission-related components.
3. Explain the difference between a type A and type B OBD-II diagnostic trouble code.
4. List three things that should be checked as part of a thorough visual inspection.
5. List the eight-step funnel diagnostic procedure.
6. Explain why a bulletin search should be performed after stored DTCs are retrieved.
7. List the three methods that can be used to reprogram a PCM.

CHAPTER QUIZ

1. Technician A says that the first step in the diagnostic process is to verify the problem (concern). Technician B says the second step is to perform a thorough visual inspection. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Which item is *not* important to know before starting the diagnosis of an engine performance problem?
   a. List of previous repairs
   b. The brand of engine oil used
   c. The type of gasoline used
   d. The temperature of the engine when the problem occurs
3. A paper test can be used to check for a possible problem with _____
   a. The ignition system (bad spark plug wire)
   b. A faulty injector on a multiport engine
   c. A burned valve
   d. All of the above
4. Which step should be performed *last* when diagnosing an engine performance problem?
   a. Checking for any stored diagnostic trouble codes
   b. Checking for any technical service bulletins (TSBs)
   c. Performing a thorough visual inspection
   d. Verify the repair
5. Technician A says that if the opposite DTC can be set, the problem is the component itself. Technician B says if the opposite DTC cannot be set, the problem is with the wiring or grounds. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. The preferred method to clear diagnostic trouble codes (DTCs) is to _____
   a. Disconnect the negative battery cable for 10 seconds
   b. Use a scan tool
   c. Remove the computer (PCM) power feed fuse
   d. Cycle the ignition key on and off 40 times
7. Which is the factory scan tool for Chrysler brand vehicles equipped with CAN?
   a. Star Scan
   b. Tech 2
   c. NGS
   d. Master Tech
8. Technician A says that reprogramming a PCM using the J2534 system requires a factory scan tool. Technician B says that reprogramming a PCM using the J2534 system required Internet access. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technician A and B
   d. Neither Technician A nor B
9. Technician A says that knowing if there are any stored diagnostic trouble codes (DTCs) may be helpful when checking for related technical service bulletins (TSBs). Technician B says that only a factory scan tool should be used to retrieve DTCs. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Which method can be used to reprogram a PCM?
    a. Remote
    b. Direct
    c. Off-board
    d. All of the above

SECTION X

Hybrid and Fuel Cell Vehicles

64 Introduction to Hybrid Vehicles
65 Hybrid Electric Vehicle Safety Procedures
66 Fuel Cells and Advanced Technologies



CHAPTER 64

Introduction to Hybrid Vehicles

OBJECTIVES: After studying Chapter 64, the reader will be able to: Describe the different types of hybrid electric vehicles. • Explain how a hybrid vehicle is able to achieve an improvement in fuel economy compared to a conventional vehicle design. • Discuss the advantages and disadvantages of the various hybrid designs. • Describe HEV components, including motors, energy sources, and motor controllers. • Discuss the operation of a typical hybrid electric vehicle.

KEY TERMS: assist hybrid • BAS • BEV • EV • full hybrid • HEV • HOV lane • hybrid • ICE • idle stop mode • medium hybrid • micro-hybrid drive • mild hybrid • motoring mode • parallel hybrid • power assist mode • quiet mode • series hybrid • series-parallel hybrid • strong hybrid • ZEV

HYBRID VEHICLE

A hybrid vehicle is one that uses two different methods to propel the vehicle. A hybrid electric vehicle, abbreviated **HEV** uses both an internal combustion engine and an electric motor to propel the vehicle. Most hybrid vehicles use a high-voltage battery pack and a combination electric motor and generator to help or assist a gasoline engine. The **internal combustion engine (ICE)** used in a hybrid vehicle can be either gasoline or diesel, although only gasoline-powered engines are currently used in hybrid vehicles. An electric motor is used to help propel the vehicle, and in some designs, is capable of propelling the vehicle alone without having to start the internal combustion engine.

Background In the early years of vehicle development, many different types of propulsion systems were used, including steam engine-powered, gasoline engine-powered, and electric motor-powered.

Early electric vehicles **(EVs)** were also called **battery electric vehicles (BEV).** These early electric vehicles used lead-acid batteries, an electric traction motor, and a mechanical controller. A traction motor is an electric motor used to rotate the drive wheels and propel vehicle. The vehicle moves as a result of the traction between the wheel and the road surface to transmit the torque needed to move the vehicle.

The controller was operated by the driver and allowed different voltages to be applied to the electric motor, depending on the needs of the driver. For an example, assume that an early electric vehicle used six 6-volt batteries. If the batteries are connected in series, the negative terminal of one battery is connected to the positive terminal of the second battery. Two 6-volt batteries connected in series result in 12 volts, but the same current as one of the batteries. If two 6-volt 500-amp hour batteries were connected in series, then the output would be 12 volts and 500-amp hours. If the batteries were connected in parallel, the current of each battery is increased, but

the voltage remains the same. If two 6-volt 500-amp hour batteries were connected in parallel, then the voltage would be six volts, but the capacity would be 1,000 amp hours.

The old electric vehicle mechanical controller was able to switch all six batteries in various combinations of series and parallel configurations to achieve lower voltage for slow speeds and higher voltages for higher speeds.

Electric vehicles did not have a long range and needed to have the batteries charged regularly, which meant that electric vehicles could only be used for short distances. In fact electric vehicles were almost more popular than steam power in 1900 when steam had 40% of the sales and electric had 38% of the sales. The gasoline-powered cars represented only 22% of the vehicles sold.

NOTE: Due to the oil embargo of 1973 and increased demand for alternative energy sources, Congress enacted Public Law 94-413, the *Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976*, which was designed to promote new technologies.

In the late 1990s, several vehicle manufacturers produced electric vehicles, using electronic controllers to meet the demands for zero emission vehicles as specified by law in California at the time. Electric vehicles were produced by Ford, Toyota, Nissan, and General Motors. Legislation was passed in California that included the following mandates within the **zero emissions vehicle (ZEV)** mandate:

As a direct result of the California zero-emission vehicle mandate originally calling for 10% ZEV, General Motors developed the Electric Vehicle 1, known as EV1, and it was leased to customers in California and Arizona. See Figures 64–1 and 64–2.

For several years, a percentage of vehicles sold in California had to be electric. However, in 2003, the requirements were changed to allow advanced technology partial zero electric vehicles (AT-PZEV) to substitute for partial credit, which relaxed the requirement for zero-emission vehicles.

DRIVING AND OWNING A HYBRID ELECTRIC VEHICLE

Driving a hybrid electric vehicle is the same as driving any other conventional vehicle. In fact, many drivers and passengers are often not aware they are driving or riding in a hybrid electric vehicle. Some unique characteristics that the driver may or may not notice include:

- After the internal combustion engine has achieved normal operating temperature and other conditions are met, the engine will stop when the vehicle slows down and stops. This condition may cause some concern to some drivers who may think that the engine has stalled and then may try to restart it.
- The brake pedal may feel different, especially at slow speeds of about 5 mph and 15 mph when slowing to a stop. It is at about these speeds that the brake system switches from regenerative braking to actually applying brake force to the mechanical brakes. A slight surge or pulsation may be felt at this time. This may or may not be felt and is often not a concern to drivers.
- The power steering works even when the engine stops because all hybrid electric vehicles use an electric power steering system.
- Some hybrid electric vehicles are able to propel the vehicle using the electric motor alone, resulting in quiet, almost eerie operation.
- If a hybrid electric vehicle is being driven aggressively and at a high rate of acceleration, there is often a feeling that the vehicle is not going to slow down when the accelerator pedal is first released. This is caused by two factors:
  - The inertia of the rotor of the electric motor attached to the crankshaft of the ICE results in the engine continuing to rotate after the throttle has been closed.
  - The slight delay that occurs when the system switches the electric motor from powering the vehicle to generating (regenerative braking). While this delay would rarely be experienced, and is not at all dangerous, for a fraction of a second it gives a feeling that the accelerator pedal did not react to a closed throttle.

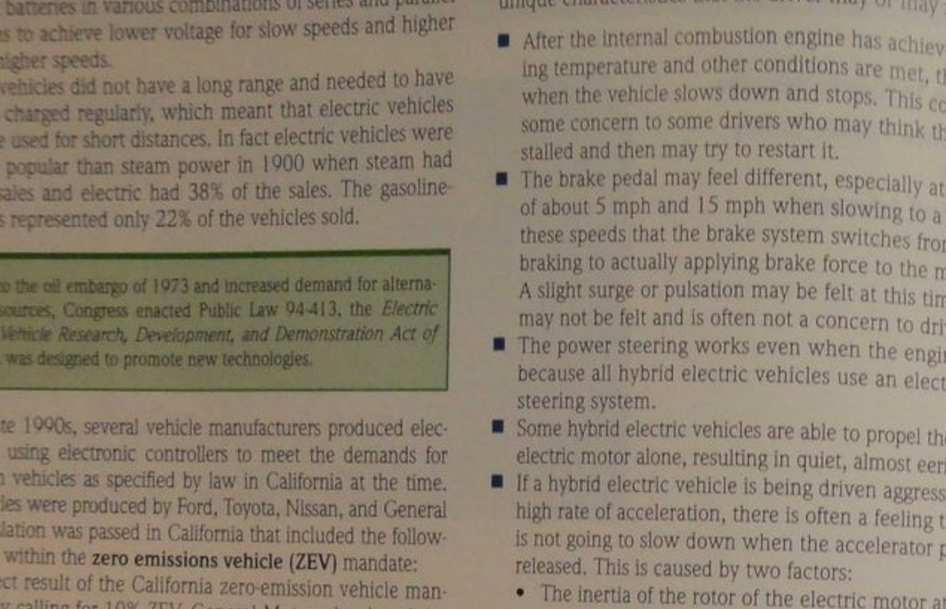


Figure 64–1 View of the components of the General Motors electric vehicle (EV-1). Many of the features of this vehicle, such as regenerative braking and DC-to-DC converters, currently used on hybrid vehicles were first put into production on this vehicle.



Figure 64–2 General Motors EV1 shown without the body.

- The fuel economy will be higher compared to a similar-type vehicle, especially if driven in city-type driving conditions where engine stop and regenerative braking really add to the efficiency of a hybrid electric vehicle. However, the range of the hybrid version may be about the same as the conventional version of the same vehicle because the hybrid version usually has a smaller fuel tank capacity.
- The hybrid version will cost and weigh more than the conventional version. The increased cost is due to the batteries, electric motor(s), and controllers used plus the additional components needed to allow operation of the heating and air conditioning systems during idle stop periods. The cost is offset in part by returning improved fuel economy. However, it may take many years of operation before the extra cost is offset by cost savings from the improved fuel economy. However, many owners purchase a hybrid electric vehicle for other reasons besides fuel savings, including a feeling that they are helping the environment and love of the high technology involved.

FREQUENTLY ASKED QUESTION ???

How Fast Does the Motor-Generator Turn the Engine When Starting?

The typical starter motor used on a conventional gasoline or diesel engine rotates the engine from 100 to 300 revolutions per minute (RPM). Because the typical engine idles at about 600 to 700 RPM, the starter motor is rotating the engine at a speed slower than it operates. This makes it very noticeable when starting because the sound is different when cranking compared to when the engine actually starts and runs.

However, when the motor-generator of a hybrid-electric vehicle rotates the engine to start it, the engine is rotated about 1000 RPMs, which is about the same speed as when it is running. As a result, engine cranking is just barely heard or felt. The engine is either running or not running, which is a truly unique sensation to those not familiar with the operation of hybrid electric vehicles (HEVs).

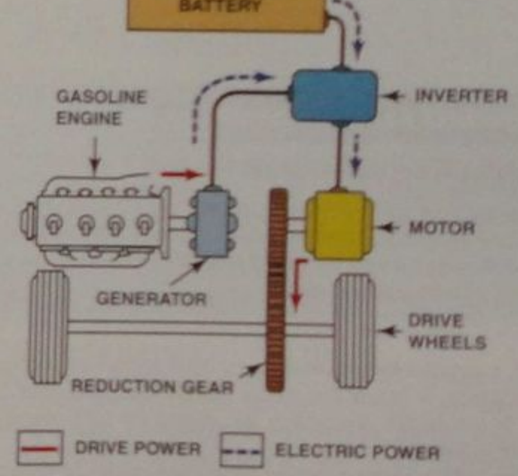


Figure 64–3 A drawing of the power flow in a typical series hybrid vehicle.

CLASSIFICATIONS OF HYBRID-ELECTRIC VEHICLES

The types of hybrid-electric vehicles include series, parallel, and series-parallel designs. In a **series-hybrid design,** sole propulsion is by a battery-powered electric motor, but the electric energy for the batteries comes from another on-board energy source, such as an internal combustion engine. In this design, the engine turns a generator and the generator can either charge the batteries or power an electric motor that drives the transmission. The internal combustion engine never powers the vehicle directly. See Figures 64–3 and 64–4.

The engine is only operated to keep the batteries charged. Therefore, the vehicle could be moving with or without the internal combustion engine running. Series-hybrid vehicles also use regeneration braking to help keep the batteries charged.

The engine is designed to just keep the batteries charged, and therefore, is designed to operate at its most efficient speed and

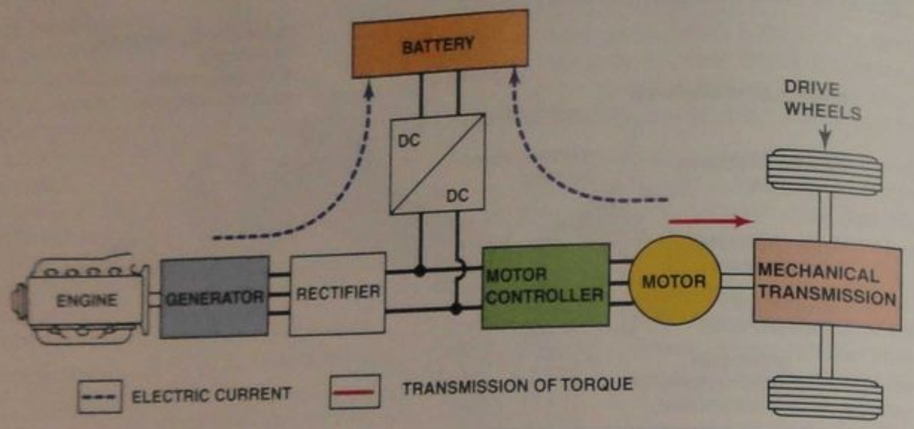


Figure 64–4 This diagram shows the components included in a typical series hybrid design. The solid-line arrow indicates the transmission of torque to the drive wheels. The dotted-line arrows indicate the transmission of electrical current.

load. An advantage of a series-hybrid design is that no transmission, clutch, or torque converter is needed on a series-hybrid design vehicle.

A disadvantage of a series-hybrid design is the added weight of the internal combustion engine to what is basically an electric vehicle. The engine is actually a heavy on-board battery charger. Also, the electric motor and battery capacity have to be large enough to power the vehicle under all operating conditions, including climbing hills.

FREQUENTLY ASKED QUESTION ???

Is a Diesel-Hybrid Electric Vehicle Possible?

Yes, using a diesel engine instead of a gasoline engine in a hybrid electric vehicle is possible. While the increased efficiency of a diesel engine would increase fuel economy, the extra cost of the diesel engine is the major reason this combination is not currently in production.

In a **parallel-hybrid design,** multiple propulsion sources can be combined, or one of the energy sources alone can drive the vehicle. In this design, the battery and engine are both connected to the transmission.

The vehicle using a parallel-hybrid design can be powered by the internal combustion engine alone, by the electric motor alone (full hybrids only), or by a combination of engine and electric motor propulsion. In most cases, the electric motor is used to assist the internal combustion engine. One of the advantages of using a parallel hybrid design is that by using an electric motor or motors to assist the internal combustion engine, the engine itself can be smaller than would normally be needed. See Figures 64–5 and 64–6.

NOTE: A parallel-hybrid design could include additional batteries to allow for plug-in capability, which could extend the distance the vehicle can travel using battery power alone.

One disadvantage of a parallel-hybrid design is that complex software is needed to seamlessly blend electric and ICE power. Another concern about the parallel-hybrid design is that it had to be engineered to provide proper heating and air-conditioning system operation when the ICE stops at idle.

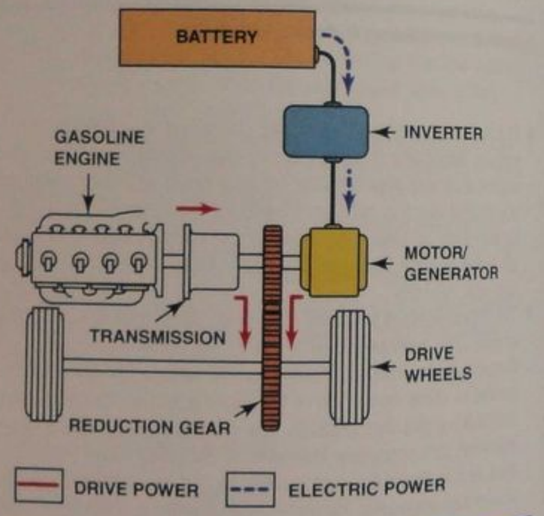


Figure 64–5 The power flow in a typical parallel hybrid vehicle.

The Toyota and Ford hybrids are classified as **series-parallel hybrids** because they can operate using electric motor power alone or with the assist of the ICE. Series-parallel hybrids combine the functions of both a series and a parallel design.

The internal combustion engine may be operating even though the vehicle is stopped if the electronic controller has detected that the batteries need to be charged. See Figure 64–7.

NOTE: The internal combustion engine may or may not start when the driver starts the vehicle depending on the temperature of the engine and other conditions. This can be confusing to some who are driving a hybrid electric vehicle for the first time and sense that the engine did not start when they tried to start the engine.

BELT ALTERNATOR STARTER SYSTEMS

The belt system, commonly called the **belt alternator starter (BAS),** is the least expensive system that can be used and still claim

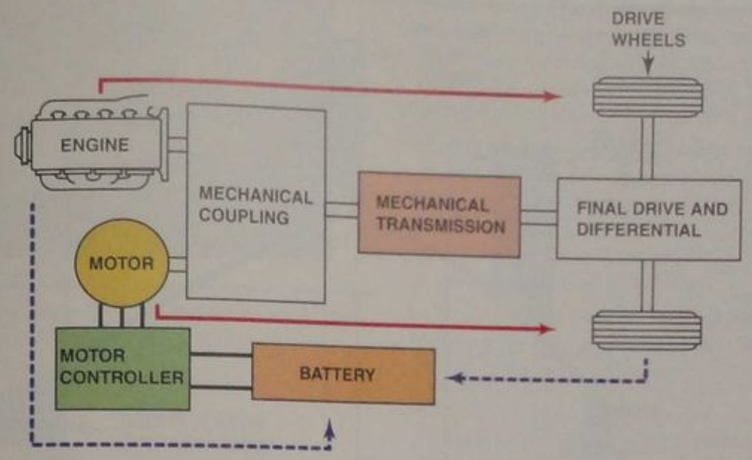


Figure 64–6 Diagram showing the components involved in a typical parallel-hybrid vehicle. The solid-line arrows indicate the transmission of torque to the drive wheels, and the dotted-line arrows indicate the flow of electrical current.

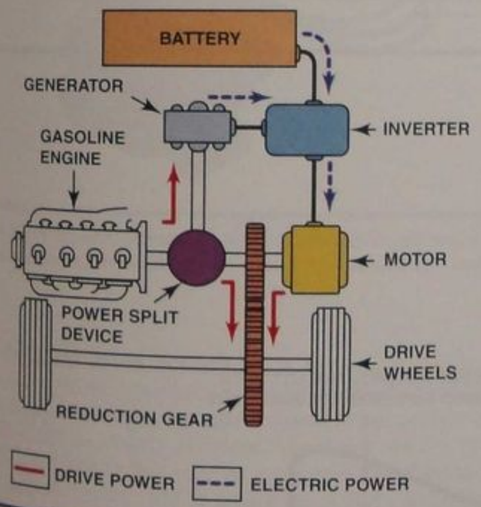


Figure 64–7 A series-parallel hybrid design allows the vehicle to operate in electric motor mode only or in combination with the internal combustion engine.

that the vehicle is a hybrid. For many buyers, cost is a major concern and the BAS system allows certain hybrid features without the cost associated with an entire redesign of the engine and power train. Consumers will be able to upgrade from conventional models to BAS hybrids at a reasonable cost and will get slightly better fuel economy.

The BAS concept is to replace the belt-driven alternator with an electric motor that serves as a generator and a motor. When the engine is running the motor, acting as a generator, it will charge a separate 36-volt battery (42-volt charging voltage). When the engine needs to be started again after being in idle stop, the BAS motor is used to crank the engine by taking electrical power from the 36-volt battery pack and applies its torque via the accessory belt, and cranks the engine instead of using the starter motor.

NOTE: A BAS system uses a conventional starter motor for starting the ICE the first time, and only uses the motor-generator to start the ICE when leaving idle stop mode.

The motor-generator is larger than a standard starter motor so more torque can be generated in the cranking mode, also referred to as the **motoring mode.** The fast rotation of the BAS allows for quicker starts of the engine, and makes the start/stop operation possible. Having the engine shut off when the vehicle is at a stop saves fuel. Of course, the stopping of the engine does create a sense that the engine has stalled, which is a common concern to drivers unfamiliar with the operation of hybrid vehicles.

A typical BAS system will achieve a 2% to 5% increase in fuel economy, mostly affecting the city mileage with little, if any, effect on the highway mileage. On extremely small vehicles, the belt alternator starter might nudge a vehicle into the mild hybrid category. The BAS system is the type used in the Saturn VUE hybrid SUV. See Figures 64–8 and 64–9.

FREQUENTLY ASKED QUESTION ???

Can Hybrids Use the HOV Lane?

In most locations the answer is yes, but it depends on the type of hybrid vehicle. The **high-occupancy vehicle (HOV)** lane in many cities is reserved for use by vehicles that are carrying more than one occupant as a way to encourage carpooling and the use of public transportation. In California, only those hybrids classified as being high-fuel-economy models and those meeting certain emission ratings qualify. Those that do qualify, such as the Toyota Prius, are issued stickers that show that they are entitled to be in the HOV lane even if there is just the driver in the vehicle. High-performance hybrids, such as the Honda Accord hybrid, do not meet the specified fuel economy rating to allow the owners to be issued HOV stickers, which are also limited as to how many in the entire state can be issued.

See Figure 64–10.

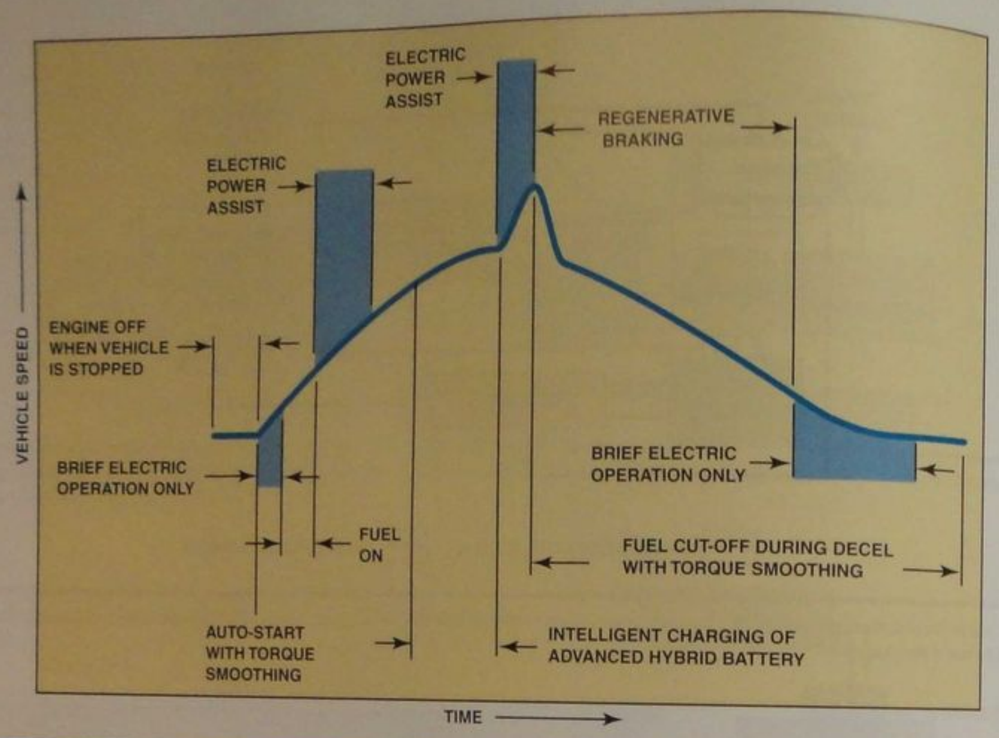


Figure 64–8 This chart shows what is occurring during various driving conditions in a BAS-type hybrid.

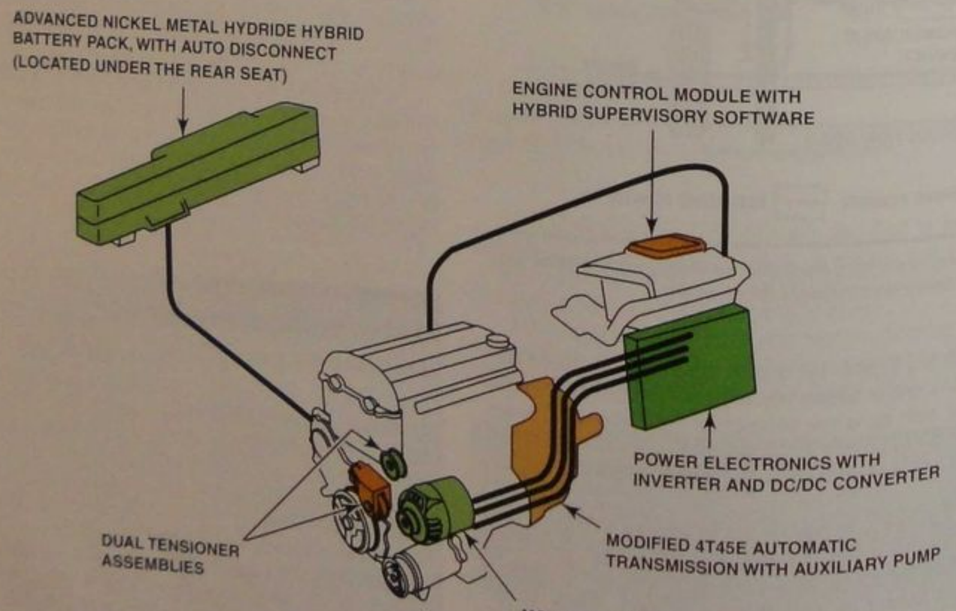


Figure 64–9 The components of a typical belt alternator-starter (BAS) system.



Figure 64–10 This sticker on a hybrid vehicle allows the driver to use the high-occupancy vehicle (HOV) lanes even if there is only one person in the vehicle as a way to increase demand for hybrid vehicles in California.

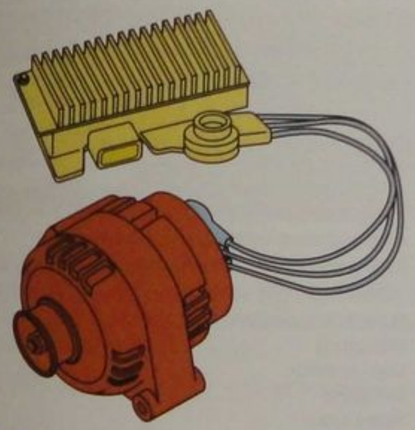


Figure 64–11 A reversible starter/alternator is used to provide idle stop function to conventional vehicles. This very limited and low cost system is called a micro-hybrid drive.

Micro-Hybrid Drive System One of the major fuel-saving features of a hybrid electric vehicle is the idle stop mode, in which the internal combustion engine is stopped, instead of idling, while in traffic.

One simple system developed by Valeo uses a reversible starter/alternator that is used as a conventional alternator when the engine is running, and as a starter to start the engine by transmitting power through the drive belt system. This type of system is often called a **micro-hybrid-drive system.** See Figure 64–11.

The only mechanical addition needed is a special belt tensioner that allows two-directional belt travel and can be fitted to almost any existing gasoline or diesel engine. The fuel and exhaust emission savings are proportional to the amount of idle time and can save up to 6% during city driving conditions.

Common Features of Most Hybrids The following are the most common features of hybrids that improve fuel economy:

Idle stop. The idle stop mode turns off the engine when the vehicle is stopped. When the brake is released, the engine immediately starts. This ensures that the vehicle is not using fuel, nor creating CO_2 emissions, when the engine is not required to propel the vehicle.

Regenerative braking. When decelerating, the braking system captures the energy and stores it in the battery or other device for later use. Regenerative braking helps keep the batteries charged.

Power assist. The electric motor provides extra power using electrical current drawn from the battery to assist the internal combustion engine during acceleration. This **power-assist mode** enables the vehicle to use a smaller, more fuel-efficient engine without giving up vehicle performance.

Engine-off drive-electric vehicle mode. The electric motor propels the vehicle at lower speeds. This mode is often called the **motoring mode.** Because the internal combustion engine is not being used during acceleration, no fuel is being used and no emissions are being released. When the hybrid is in this mode, it is essentially an electric vehicle.

LEVELS OF HYBRID VEHICLES

The term **hybrid** refers to a type of vehicle. However, there are different levels of "hybridization" among hybrids on the market. Different vehicle manufacturers use various hybrid technologies.

Mild Hybrid A **mild hybrid** will incorporate idle stop and regenerative braking but is not capable of using the electric motor to propel the vehicle on its own without help from the internal combustion engine. A mild hybrid system has the advantage of costing less, but saves less fuel compared to a full hybrid vehicle and usually uses a 42-volt electrical motor and battery package (36-volt batteries, 42-volt charging). An example of this type of hybrid is the General Motors Silverado pickup truck and the Saturn VUE. The fuel savings for a mild type of hybrid design is about 8% to 15%.

Medium Hybrid A **medium hybrid** uses 144 to 158 volt batteries that provide for engine stop/start, regenerative braking, and power assist. Like a mild hybrid, a typical medium hybrid is not capable of propelling the vehicle from a stop using battery power alone. Examples of a medium hybrid vehicle include the Honda Insight, Civic, and Accord. The fuel economy savings are about 20% to 25% for medium hybrid systems.

Full Hybrid A **full hybrid,** also called a **strong hybrid,** uses idle stop regenerative braking, and is able to propel the vehicle using the electric motor(s) alone.

Each vehicle manufacturer has made its decision on which hybrid type to implement based on its assessment of the market niche for a particular model. Examples of a full or strong hybrid include the Ford Escape SUV, Toyota Highlander, Lexus RX400h, Lexus GS450h, Toyota Prius, and Toyota Camry. The fuel economy savings are about 30% to 50% for full hybrid systems.

Efficiencies of Electric Motors and Internal Combustion Engines

- An electric motor can have efficiency (including controller) of over 90%, while a gasoline engine only has efficiency of 35% or less.
- An ICE does not have the overload capability of an electric motor. That is why the rated power of an internal combustion engine is usually much higher than required for highway cruising. Operating smoothly at idle speed produces a much lower efficiency than operating at a higher speed.
- Maximum torque of an internal combustion engine is reached at intermediate speed and the torque declines as speed increases further.
- There is a maximum fuel efficiency point in the speed range for the ICE, and this speed is optimized by many hybrid vehicle manufacturers by using a transmission that keeps the engine speed within the most efficient range.

Electric Motors Electric motors offer ideal characteristics for use in a vehicle because of the following factors:

- Constant power over all speed ranges
- Constant torque at low speeds needed for acceleration and hill-climbing capability
- Constant torque below base speed
- Constant power above base speed
- Only single gear or fixed gear is needed in the electric motor transmission

TECH TIP ✓ **Watch Out for Motoring Mode**

When a hybrid electric vehicle is operating at low speeds, it is often being propelled by the electric motor alone, sometimes called **motoring mode.** As a result, the vehicle is very quiet and is said to be operating in **quiet mode.**

During this time, the driver should be aware that the vehicle is not making any sound and should be careful when driving in congested areas. Service technicians should also be extremely careful when moving a hybrid electric vehicle around the shop due to the silence of the vehicle.

Hybrid Features by Make/Model

Make/Model	Idle Stop	Regenerative Braking	Motor Assist	Engine-Off Drive—EV Mode
Chevrolet Silverado 1500/GMC Sierra Hybrid	√	√		
Ford Escape and Mercury Mariner Hybrid	√	√	√	√
Honda Accord Civic Hybrid	√	√	√	
Honda Insight	√	√	√	
Toyota Prius	√	√	√	√
Saturn VUE	√	√	√	

FREQUENTLY ASKED QUESTION ???

What is an Assist Hybrid?

An assist hybrid-electric vehicle is a term used to describe a vehicle where the electric motor is not able to start moving the vehicle on electric power alone. This type of hybrid would include all mild hybrids (36 to 42 volts), as well as the medium hybrids that use 144- to 158-volt systems.

SUMMARY

1. Hybrids use two different power sources to propel the vehicle.
2. A mild hybrid with a lower voltage system (36–50 volts) is capable of increasing fuel economy and reducing exhaust emissions but is not capable of using the electric motor alone to propel the vehicle.
3. A medium hybrid uses a higher voltage than a mild hybrid (140–150 volts) and offers increased fuel economy over a mild hybrid design but is not capable of operating using the electric motor alone.
4. A full or strong hybrid uses a high-voltage system (250–650 volts) and is capable of operating using the electric motor(s) alone and achieves the highest fuel economy improvement of all types of hybrids.
5. Early in vehicle history, electric vehicles were more popular than either steam- or gasoline-powered vehicles.
6. Legislation passed in California in 1998, which mandated zero-emission vehicles (ZEVs), caused the vehicle manufacturers to start producing electric vehicles. When the law was changed to allow the substitution of other vehicles that produced lower emissions, but not zero, it helped promote the introduction of hybrid electric vehicles (HEVs).
7. A hybrid vehicle is defined as having two power sources to propel the vehicle.
8. Electric motors are perfect for vehicle use because they produce torque at lower speed, whereas internal combustion engines need to have an increased speed before they produce maximum power and torque.

REVIEW QUESTIONS

1. What were the major reasons for the development of electric and hybrid electric vehicles?
2. Which type of hybrid electric vehicle is the type manufactured today?
3. What are the advantages and disadvantages of mild, medium, and full hybrid vehicles?
4. Why does a BAS system cost less than the other types of hybrid vehicles?
5. What are the four modes of operation of a typical hybrid vehicle?

CHAPTER QUIZ

1. The GM EV1 was what type of vehicle?
   a. Totally electric powered
   b. A first-generation hybrid electric vehicle (HEV)
   c. A series-type HEV
   d. A parallel-type HEV
2. Which type of hybrid uses 36 to 42 volts?
   a. Mild hybrid
   b. Medium hybrid
   c. Full hybrid
   d. Strong hybrid
3. Which type of hybrid is capable of propelling the vehicle using just the electric motor?
   a. BAS type
   b. Strong (full) hybrid
   c. Medium hybrid
   d. Mild hybrid
4. About how fast does a motor-generator crank the internal combustion engine?
   a. About 1000 RPM
   b. About 2000 RPM
   c. About 150–300 RPM
   d. About 400–600 RPM
5. Which type of hybrid electric design costs the least?
   a. Strong hybrid design
   b. Series hybrid design
   c. Parallel hybrid design
   d. BAS design
6. Which type of hybrid electric vehicle has idle stop operation?
   a. Strong hybrids only
   b. Strong, mild, and medium hybrids
   c. Mild hybrids only
   d. Medium hybrids only
7. Technician A says that most hybrids require that they be plugged into an electrical outlet at night to provide the electrical power to help propel the vehicle. Technician B says that the internal combustion engine in an HEV will often stop running when the vehicle is stopped. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Technician A says that most hybrids use the series hybrid design. Technician B says that most hybrids have 42-volt batteries. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Electric motors are better than an internal combustion engine to propel a vehicle because _____.
   a. They produce high torque at low speeds
   b. They do not burn fuel and therefore do not release carbon dioxide into the environment
   c. They are quiet
   d. All of the above are correct
10. All of the following are characteristic of a hybrid electric vehicle (HEV), *except* _____.
    a. High voltages (safety issue)
    b. Lower fuel economy
    c. Lower amount of carbon dioxide released to the atmosphere
    d. Quiet

CHAPTER 65 Hybrid Electric Vehicle Safety Procedures

OBJECTIVES: After studying Chapter 65, the reader will be able to: Prepare for the ASE computerized engine controls diagnosis and repair (A8) certification test content area "E". • Safely depower a hybrid electric vehicle. • Safely perform high-voltage disconnects. • Understand the unique service issues related to HEV high-voltage systems. • Correctly use appropriate personal protective equipment (PPE). • Explain hazards while driving, moving, and hoisting a hybrid electric vehicle.

KEY TERMS: ANSI • ASTM • CAT III • DMM • floating ground • HV • HV cables • IEC • Linesman's gloves • NiMH • OSHA

HIGH-VOLTAGE SAFETY EQUIPMENT

Rubber Gloves Before working on the high-voltage system of a hybrid electric vehicle, be sure that **high-voltage (HV) linesman's gloves** are available. Be sure that the gloves are rated at least 1,000 volts and class "0" by ANSI/ASTM. The **American National Standards Institute (ANSI)** is a private, nonprofit organization that administers and coordinates the U.S. voluntary standardization and conformity assessment system. ASTM International, originally known as the **American Society for Testing and Materials (ASTM),** was formed over a century ago, to address the need for component testing in industry. The **Occupational Safety and Health Administration (OSHA)** requirements specify that HV gloves get inspected every six months by a qualified glove inspection laboratory. Use an outer leather glove to protect the HV rubber gloves. Inspect the gloves carefully before each use. High voltage and current (amperes) in combination is fatal. See Figures 65–1 and 65–2.



Figure 65–1 Rubber linesman's gloves protect the wearer from a shock hazard.

NOTE: The high-voltage insulated safety gloves must be recertified every six months to remain within OSHA guidelines.

Before using the rubber gloves, they should be tested for leaks using the following procedure:

1. Roll the glove up from the open end until the lower portion of the glove begins to balloon from the resulting air pressure. Be sure to "lean" into the sealed glove to raise the internal air pressure. If the glove leaks any air, discard the gloves. See Figure 65–3.
2. The gloves should not be used if they show any signs of wear and tear.

WARNING: HV cables and wiring are orange in color. High-voltage insulated safety gloves and a face shield must be worn when carrying out any diagnostics involving the high-voltage systems or components.



Figure 65–2 Wearing leather gloves over the linesman's gloves helps protect the rubber gloves from damage.



Figure 65–3 Checking rubber linesman's gloves for pinhole leaks.

CAT III–Rated Digital Multimeter Hybrid electric vehicles are equipped with electrical systems whose voltages can exceed 600 volts DC. A CAT III–certified **digital multimeter (DMM)** is required for making measurements on these high-voltage systems.

The **International Electrotechnical Commission (IEC)** has several categories of voltage standards for meters and meter leads. These categories are ratings for overvoltage protection and are rated CAT I, CAT II, CAT III, and CAT IV. The higher the category (CAT) rating, the greater the protection to the technician when measuring high-energy voltage.

Therefore, for best personal protection, use only meters and meter leads that are **CAT III** rated when measuring voltage on a hybrid electric vehicle.

Eye Protection Eye protection should be worn when testing for high voltage, which is considered by many experts to be anything over 60 volts. Most hybrid electric systems use voltages higher than this threshold. If the system has not been powered down or has not had the high-voltage system disabled, a shock hazard is always possible. Even when the high-voltage (HV) system has been disconnected, there is still high voltage in the HV battery box.



Figure 65–4 This Honda Accord hybrid is identified by the emblem on the rear deck lid.



Figure 65–5 A hybrid electric vehicle can often be identified by looking for orange-colored cables under the hood, as well as other markings on the engine cover.

FIRST RESPONDER PROCEDURES

Identifying a Hybrid Vehicle To confirm whether a vehicle is a hybrid, look for the word "HYBRID" on the rear of the vehicle. See Figure 65–4.

Orange cables under the hood, or orange shielding bolted to the underside of the vehicle, indicates that the vehicle is a hybrid. Except for the Honda Insight and the Toyota Prius, there is very little difference in the exterior or interior appearance of hybrids compared to those of their gasoline-powered counterparts. If a hybrid badge or label is not visible, due to damage, for example, the presence of orange cables under the hood or orange shielding under the vehicle would also identify the vehicle as a hybrid. See Figure 65–5.

Power Source The main power source of all hybrids is a conventional internal combustion engine (ICE) located under the hood. During start-up and acceleration, an electric motor provides assistance to the engine. During braking and deceleration, the motor acts as a generator, recharging both the high-voltage battery module and the 12-volt battery.

12-Volt Battery A conventional flooded-type lead-acid 12-volt battery, usually located under the hood, powers all standard



Figure 65–6 A Toyota Highlander hybrid battery pack with the cover removed.

electronics. Auxiliary 12-volt batteries that are located in the truck, such as in most Toyota hybrids, are nonspillable absorbed glass mat (AGM) designs. In most hybrids, this battery also provides power to the high-voltage battery control systems. Disconnecting or cutting the negative cables to the battery may be necessary in some emergency situations.

Fuse Box Most hybrid electric vehicles have a fuse box that is located under the hood in the engine compartment. Removing the main fuse from this box may be required in some emergency situations.

High-Voltage Battery Module The electric motor is powered by a high-voltage battery module. Because the battery module is recharged by the electric motor whenever the vehicle decelerates or by the generator during cruise conditions, the battery never needs external charging.

The high-voltage battery modules are often in plastic containers, and these cells are placed within a sturdy metal box. See Figure 65–6.

All components inside the battery box are completely insulated and isolated from the vehicle body. For maximum safety, the high-voltage battery box is positioned directly behind the seat backs or under the rear seat where it is well protected from potential damage in a collision.

Small quantities of a highly alkaline liquid electrolyte, which is corrosive to human tissue, are used in the manufacture of NiMH battery cells. However, in the finished cells, electrolyte is nonliquid and sealed in a metal case, and any leakage would be extremely rare. Moreover, the electrolyte is nonflammable, nonexplosive, and creates no hazardous fumes or vapors in normal operating conditions.

High-Voltage Cables Electrical energy flows between the high-voltage battery module and the motor through either two or three heavy-duty orange cables. In some hybrid vehicles, **high-voltage cables** also deliver current to the air-conditioning (A/C) compressor. This allows the A/C to continue running when the vehicle is in the auto idle stop mode.

The high-voltage cables are routed under the vehicle between the battery box and the engine compartment inside sturdy orange plastic protective shields. Where the cables lie close to the exhaust system, a metal thermal shield covers, but does not obscure, the orange high-voltage shield.

Airbags and Tensioners All hybrids have front airbags and front seat belt tensioners. Most hybrid vehicles also have side airbags for front-seat occupants, and many are equipped with side curtain airbags as well. These systems all use pyrotechnic devices with a deactivation time (after 12-volt power is disconnected) of up to three minutes. To reduce the risk of injury during the deactivation period, the following steps are recommended:

- Keep out of the path of an undeployed front airbag, and do not cut into the center of the steering wheel or dashboard where the front airbags are stored.
- Do not cut into the rear (C) pillar where the side curtain inflator is stored.

WARNING: Extreme heat (320–356°F [160–180°C]) can cause unintended airbag inflation. Follow recommended procedures to avoid possible injury from a deploying airbag or inflator.

ELECTRIC SHOCK POTENTIAL

Unprotected contact with any electrically charged ("hot" or "live") high-voltage component can cause serious injury or death. However, receiving an electric shock from a hybrid vehicle is highly unlikely because of the following:

1. Contact with the battery module or other components inside the battery box can occur only if the box is damaged and the contents are exposed, or the box is opened without following proper precautions.
2. Contact with the electric motor can occur only after one or more components are removed.
3. The high-voltage cables can be easily identified by their distinctive orange color, and contact with them can be avoided.
4. The system main relays (SMRs) disconnect power from the cables the moment the ignition is turned off.

There are only three situations in which the cables can potentially be "hot" in most hybrid vehicles:

1. The ignition switch is on, the engine is running, and the vehicle is accelerating. In this case, the high-voltage battery module is sending current to the motor. (This is not likely to be a concern to first responders.)
2. The ignition switch is on, the engine is running, and the vehicle is decelerating. In this case, the motor is generating electric current and sending it to the high-voltage batteries.
3. The third situation in which the cables can be hot occurs when the ignition switch is on, the engine has been turned off by the auto idle stop feature, and the air conditioner is on. In this case, the high-voltage battery module is sending current to the air-conditioner compressor.

NOTE: The only condition common to all three situations in which the cables can be "hot" is that the ignition is on. Therefore, when the ignition switch is off, electric current cannot flow into the high-voltage cables because the system main relays that control the high voltage are turned off when the ignition is off.

Locations of HV Batteries and Service Switch/Plugs

Model (Year)	HV Battery Pack Location	HV Safety Switch/Plug Location
Honda Insight 2000–2006	144-V unit under hatch floor	Under hatch carpet, remove small plate in center
Civic/Accord Hybrid 2003–2006	144-V unit (158V 06 Civic) behind back seat upright cushion	Behind back seat upright cushion, remove small oval plate in center
Toyota Prius 2001–2003	275-V unit in trunk, under carpet, lower front area	In lower front left area corner of HV battery. Plug removes toward rear of car.
Toyota Prius 2004+	201-V unit in front of spare tire	In front of spare tire, lower front left area of HV battery pack around the corner. Plug removes toward left side of car.
Toyota/Lexus SUV RX400h/Highlander 2006+	288-V unit under rear seat in three compartments	In lower rear seat left side under small rectangular trim panel. Plug removes toward left side of SUV.
Ford Escape 2005+	330-V unit under carpet, rear floor	Under rear cargo floor carpet, round orange switch on right side in plain view.
Mercury Mariner 2006+	330-V unit under carpet, rear floor	Under rear cargo floor carpet, round orange switch on right side in plain view.

VEHICLE FIRE

There are no unusual hazards if a hybrid electric vehicle is involved in a fire. It should be noted, however, that extremely high temperatures (320–356°F [160–180°C]) can cause undeployed airbags to deploy.

SUBMERGED OR PARTIALLY SUBMERGED VEHICLE

Pull the vehicle out of the water, then use one of the procedures described next for preventing electric current from flowing through the high-voltage cables.

NOTE: There is no risk of electric shock from touching the body or the bodywork whether in or out of the water.

PREVENTING CURRENT FLOW THROUGH HIGH-VOLTAGE CABLES

Before attempting to rescue occupants or move a damaged hybrid vehicle, the potential for current to flow from the electric motor or the battery module through the high-voltage cables needs to be removed. There are two recommended methods for preventing high-voltage shock hazard.

Method One

Turn the Ignition Switch Off This simple action turns off the engine and the electric motor, preventing current flow into the cables. It also turns off power to the airbags and the seat belt tensioners.

FREQUENTLY ASKED QUESTION ???

Will I Get Shocked If I Drive My Hybrid into Deep Water?

No. The computer of all hybrid electric vehicles monitors the connection between the high-voltage circuits and the body or frame of the vehicle. If water or an accident were to cause an electrical connection between the high voltage and the body of the vehicle, the high voltage is immediately turned off.

After the ignition switch is turned off, remove the key so the vehicle cannot be accidentally restarted.

NOTE: Turning the ignition key to the OFF position stops the flow of electricity in the cables.

Method Two

Remove the main fuse, and cut the negative 12-volt battery cable(s). Removing the main fuse turns off the engine and the electric motor, preventing current flow from the motor into the cables. This also cuts power to the airbags and the seat belt tensioners, as well as to the high-voltage battery controllers, preventing current from flowing into the cables from the high-voltage battery.

1. Locate the underhood fuse box, and remove the cover (see model-specific pages in the owner's manual for fuse box locations).
2. Locate the main fuse by referring to the diagram on top of, or inside, the fuse box cover. For example, on a Honda Civic hybrid, use a Phillips screwdriver and unscrew the main fuse assembly and remove it from the box. See Figure 65–7 for the location of the Toyota Highlander high-voltage plug.
3. Locate the 12-volt battery and cut the negative cables with diagonal cutters. See the 12-volt battery location chart.

NOTE: If neither method to stop the engine can be performed to prevent current flow into the high-voltage cables, use extreme care, do not cut into the cables, and do not touch damaged cables as they may be "hot."



Figure 65–7 The high-voltage disconnect (service) plug is located on the left side of the rear seat in a Toyota Highlander hybrid vehicle.

Hybrid Vehicle Auxiliary Battery Chart

Vehicle	Auxiliary Battery Type	Auxiliary Battery Location
Honda Insight Hybrid	Flooded lead acid	Underhood center near bulkhead
Honda Civic Hybrid	Flooded lead acid	Underhood driver side
Honda Accord Hybrid	Flooded lead acid	Underhood driver side
Ford Escape Hybrid	Flooded lead acid	Underhood driver side
Toyota Prius Hybrid (2001–2003)	Absorbed glass mat (AGM)	Trunk driver side
Toyota Prius Hybrid (2004–2007)	Absorbed glass mat (AGM)	Trunk passenger side
Toyota Highlander Hybrid	Flooded lead acid	Underhood passenger side
Toyota Camry Hybrid	Absorbed glass mat (AGM)	Trunk passenger side
Lexus RX 400h Hybrid	Flooded lead acid	Underhood passenger side
Lexus GS 450h Hybrid	Absorbed glass mat (AGM)	Trunk driver side
Chevrolet/GMC Hybrid Pickup Truck	Flooded lead acid	Underhood driver side

TECH TIP ✓ **Silence Is Not Golden**

Never assume the vehicle is shut off just because the engine is off. Always look for the **READY** indicator status. The vehicle is shut off when the **READY** indicator is off.

The vehicle may be powered by:

1. The electric motor only
2. The gasoline engine only
3. A combination of both the electric motor and the gasoline engine

The vehicle computer determines the mode in which the vehicle operates to improve fuel economy and reduce emissions. The driver cannot manually select the mode. See Figure 65–8.

WARNING: Power remains in the high-voltage electrical system for up to 10 minutes after the HV battery pack is shut off. Never touch, cut, or open any orange high-voltage power cable or high-voltage component without confirming that the high voltage has been completely discharged.

SRS Airbags and Seat Belt Pretensioners Two electronic frontal impact sensors are mounted in the engine compartment. Front seat belt pretensioners are mounted near the base of the B-pillar. A frontal dual-stage airbag for the driver is mounted in the steering wheel hub.



Figure 65–8 The Ford Escape Hybrid instrument panel showing the vehicle in Park and the tachometer on "EV" instead of 0 RPM. This means that the gasoline engine could start at any time depending on the state of charge of the high-voltage batteries and other factors.

TECH TIP ✓ **High Voltage Is Insulated from the Vehicle Body**

Both positive and negative high-voltage power cables are isolated from the metal chassis, so there is no possibility of shock by touching the metal chassis. This design is called a **floating ground.**

A ground fault monitor continuously monitors for high-voltage leakage to the metal chassis while the vehicle is running. If a malfunction is detected, the vehicle computer will illuminate the master warning light in the instrument cluster and the hybrid warning light in the LCD display. The HV battery pack relays will automatically open to stop electricity flow in a collision sufficient to activate the SRS airbags.

WARNING: The SRS computer is equipped with a backup source that powers the SRS airbags up to 90 seconds after disabling the vehicle. The front-seat side airbags and the curtain-shield side airbags may deploy independent of each other.

EMERGENCY RESPONSE

On arrival, emergency responders should follow their standard operating procedures for vehicle incidents.

WARNING: Never assume a hybrid vehicle is shut off simply because it is silent.

Extrication

1. Immobilize the vehicle (chock the wheels and set the parking brake).
2. Disable the vehicle.

WARNING: After disabling the vehicle, power is maintained for 90 seconds in the SRS system and 10 minutes in the high-voltage electrical system.

3. Stabilize the vehicle. Crib at four points directly under the front and rear pillars. Do not place cribbing under the high-voltage power cables, exhaust system, or fuel system.
4. Access the patients. Use normal glass removal procedures as required.

CAUTION: Responders need to be cautious when working in close proximity to undeployed airbags and seat belt pretensioners. Deployed front dual-stage airbags automatically ignite both stages within a fraction of a second.

5. Door removal/displacement. Doors can be removed by conventional rescue tools such as hand, electric, and hydraulic.
6. Roof removal. The vehicle may contain optional curtain-shield airbags. If equipped and undeployed, it is not recommend to remove or displace the roof.
7. Dash displacement. The vehicle may contain optional curtain-shield airbags. When equipped, do not remove or displace the roof during a dash displacement to avoid cutting into the airbags or inflators.
8. Rescue lift airbags. Responders should not place cribbing or rescue lift airbags under the high-voltage power cables, exhaust system, or fuel system.
9. Fire. Approach and extinguish a fire using proper vehicle firefighting practices as recommended by NFPA, IFSTA, or the National Fire Academy (NFA). Water has been proven to be a suitable extinguishing agent. Perform a fast, aggressive fire attack. Divert the runoff from entering watershed areas. Attack teams may not be able to identify the vehicle as being a hybrid until the fire has been extinguished.

NOTE: If a fire occurs in the **NiMH** HV battery pack, the incident commander will have to decide whether to pursue an offensive or defensive attack.

Offensive Fire Attack Flooding the HV battery pack, located in the cargo area, with large amounts of water at a safe distance will effectively control the HV battery pack fire by cooling the adjacent NiMH battery modules to a point below their ignition temperature. The remaining modules on fire, if not extinguished by the water, will burn themselves out.

Defensive Fire Attack If the decision has been made to fight the fire using a defensive attack, the fire attack crew should pull back a safe distance and allow the NiMH battery modules to burn out. During this defensive operation, fire crews may utilize a water stream or fog pattern to protect exposures or to control the path of smoke.

Spills Hybrid vehicles contain the same common automotive fluids used in other vehicles, with the exception of NiMH electrolyte (potassium hydroxide) used in the HV battery pack. The NiMH battery electrolyte is a caustic alkaline (pH 13.5) that is corrosive to human tissues. The electrolyte, however, is absorbed in the cell plates and will not normally spill or leak out even if a battery module is cracked. A catastrophic crash that would breach both the metal battery pack case and the plastic battery module would be a rare occurrence. Similar to using baking soda to neutralize a lead-acid battery electrolyte spill, a dilute boric acid solution or vinegar is used to neutralize a NiMH battery electrolyte spill.

Handle NiMH electrolyte spills using the following personal protective equipment (PPE):

- Splash shield or safety goggles (Fold-down helmet shields are not acceptable for acid or electrolyte spills.)
- Rubber, latex, or nitrile gloves
- Apron suitable for alkaline materials
- Rubber boots

Neutralize NiMH electrolyte using a boric acid solution or vinegar; boric acid solution is 5.5 ounces boric acid to 1 gallon of water (800 grams boric acid to 20 liters water).

Submersion Handle a hybrid vehicle that is fully or partially submerged in water by disabling the HV battery pack, SRS airbags, and gasoline fuel pump.

1. Remove vehicle from the water.
2. Drain water from the vehicle if possible.

COLLISION AND REPAIR INDUSTRY ISSUES

Jump-Starting The 12-volt auxiliary battery may be jump-started if the vehicle does not start. The 12-volt auxiliary battery is often located under the hood but can also be located in the cargo area of some HEVs. Using a jump box or jumper cable from another vehicle, make the connections to the positive and negative battery terminals. See Figure 65–9.

On the 2004+ Toyota Prius vehicles, there is a stud located under the hood that can be used to jump-start the auxiliary battery, which is located in the truck. The trunk has an electric latch and cannot be opened if the auxiliary battery is dead. See Figure 65–10.

NOTE: The high-voltage HV battery pack cannot be jump started on most HEVs. One exception is the Ford Escape/Mercury Mariner hybrids, which use a special "jump-start" button located behind the left kick panel. When this button is pushed, the auxiliary battery is used to boost the HV battery through a DC-DC converter.

MOVING AND TOWING A HYBRID

If a disabled vehicle needs to be moved a short distance (to the side of the road, for example) and the vehicle can still roll on the ground, the easiest way is to shift the transmission into neutral and manually push the vehicle. To transport a vehicle away from an



Figure 65–9 Jump-starting a 2001–2003 Toyota Prius using a 12-volt supply to boost the 12-volt auxiliary battery in the trunk.



Figure 65–10 The underhood 12-volt jump-start terminal on this 2004+ Toyota Prius has a red plastic cover with a "+" sign. The positive booster cable clamp will attach directly to the vertical metal bracket.



Figure 65–11 Use of a warning cover over the steering wheel helps others realize that work is being performed on the high-voltage system and that no one is to attempt to start or move the vehicle.

emergency location, a flatbed truck should be used if the vehicle might be repaired. If a flatbed is not available, the vehicle should be towed by wheel-lift equipment with the front wheels off the ground (FWD hybrid electric vehicles only). Do not use sling-type towing equipment. In the case of 4WD HEVs such as the Toyota Highlander, only a flatbed vehicle should be used.

Moving the Hybrid Vehicle in the Shop After an HEV has been serviced, it may be necessary to push the vehicle to another part of the shop or outside as parts are ordered. Make sure to tape any orange cable ends. Permanent magnets are used in all the drive motors and generators and it is possible that a high-voltage arc could occur as the wheels turn and produce voltage. Another way to prevent this is to use wheel dollies. A sign that says "HIGH VOLTAGE—DO NOT TOUCH" could also be added to the roof of the vehicle. Keep the keys out of the vehicle and safely stored. See Figures 65–11 and 65–12.

Removing the High-Voltage Batteries The HV battery box should always be removed as an assembly, placed on a rubber-covered work bench, and handled carefully. Every other part, especially the capacitors, should be checked for voltage reading while wearing HV rubber gloves. Always check for voltage as the components become accessible before proceeding. When removing high-voltage components, it is wise to use insulated tools. See Figure 65–13.

Storing the High-Voltage Batteries If a hybrid is to be stored for any length of time, the state of charge of the HV batteries must be maintained. If possible, start the vehicle every month and run it for at least 30 minutes to help recharge the HV batteries. This is necessary because NiMH batteries suffer from self-discharge over time. High-voltage battery chargers are either not available or are hard to find even at a dealer. If the HV battery SOC was over 60% when it was put into storage, the batteries may be stored for about a month without a problem. If, however, the SOC is less than 60%, a problem with a discharged HV battery may result.

Hoisting a Hybrid Vehicle When hoisting or using a floor jack, pay attention to the lift points. Orange cables run under the vehicle just inside the frame rails on most hybrids. See Figure 65–14.

Some Honda hybrid vehicles use an aluminum pipe painted orange that includes three HV cables for the starter/generator



Figure 65–12 A lock box is a safe location to keep the ignition keys of a hybrid electric vehicle while it is being serviced. Notice that this lock box has two separate locks so it would require two people to open, helping to insure that no harm is done by accidentally attempting to start a HEV.



Figure 65–13 Insulated tools, such as this socket set, would provide an additional margin of safety to the service technician when working around high-voltage components and systems.



Figure 65–14 The high-voltage wiring on this Honda hybrid is colored orange for easy identification.

and also three more cables for the HV air-conditioning compressor. If damage occurs to any high-voltage cables, the MIL will light up and a no-start will result if the PCM senses a fault. The cables are not repairable and are expensive. The cables can be identified by an orange outer casing, but in some cases, the orange casing is not exposed until a black plastic underbelly shield is removed first.

Paint Ovens Nickel metal hydride (NiMH) batteries may be damaged if exposed to high temperatures, such as in a paint oven. The warning labels on hybrid vehicles specify that the battery temperature should not exceed 146°F (63°C).

HV Battery Disposal The hybrid electric vehicle manufacturers are set up to ship NiMH battery packs to a recycling center. There is an 800 number located under the hood or on the HV battery pack that can be used to gain information on how to recycle these batteries.

TECH TIP ✓ **High-Voltage Battery SOC Considerations**

NiMH batteries do not store well for long lengths of time. After a repair job, or when the HV system has been powered down by a technician and powered up again, do not be surprised if a warning light(s), codes, and the MIL are illuminated. If everything was done correctly, a couple road tests may be all that is required to reset the MIL. The HV battery indicator on the dash may also read zero charge level. After a road test, the HV battery level indicator will most likely display the proper voltage level.

Always follow the proper safety procedures, and then minor service to hybrid vehicles can be done with a reasonable level of safety.

INSULATION TESTER

Whenever a hybrid electric vehicle is in an accident or has been submerged in deep water, the insulation should be tested before the high-voltage circuits are activated. An insulation tester, often called a megaohmmeter, such as the Fluke 1587, is used to test the insulation. To use an insulation tester, one meter lead is connected to one of the high-voltage cables and the other lead is connected to a good, clean body ground. There should not be any continuity. To perform an insulation test, push the test button on the tester and it performs the following:

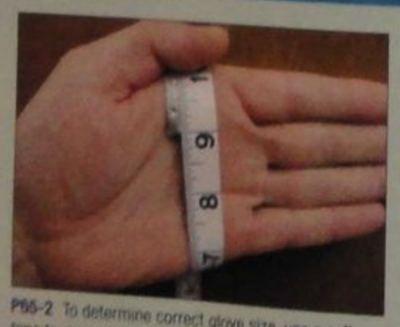
- The tester applies a test voltage on the meter leads.
- The tester then measures the voltage and the current.
- The tester then calculates the resistance and displays the reading.

The test should be repeated for each high-voltage lead on the vehicle before restoring the high-voltage circuits. Acceptable resistance readings should be over one million ohms. If the reading is less than one million ohms, then further testing should be performed to locate where the insulation is weak.

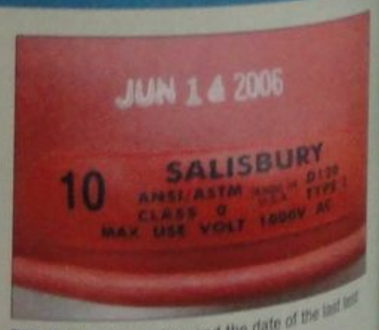
PHOTO SEQUENCE HV Glove Use



P65-1 The cuff of the rubber glove should extend at least 1/2 inch beyond the cuff of the leather protector.



P65-2 To determine correct glove size, use a soft tape to measure around the palm of the hand. A measurement of 9 inches would correspond with a glove size of 9.



P65-3 The glove rating and the date of the last test should be stamped on the glove cuff.

PHOTO SEQUENCE HV Glove Use—continued



P65-4 Start with a visual inspection of the glove fingertips, making sure that no cuts or other damage is present.



P65-5 The damage on this glove was easily detected with a simple visual inspection. Note that the rubber glove material can be damaged by petroleum products, detergents, certain hand soaps, and talcum powder.



P65-6 Manually inflate the glove to inspect for pinhole leaks. Starting at the cuff, roll up the glove and trap air at the finger end. Listen and watch carefully for deflation of the glove. If a leak is detected, the glove must be discarded.



P65-7 Petroleum on the leather protector's surfaces will damage the rubber glove underneath.



P65-8 Glove powder (glove dust) should be used to absorb moisture and reduce friction.



P65-9 Put on the gloves and tighten the straps on the back of the leather protectors.



P65-10 Technicians MUST wear HV gloves and leather protectors whenever working around the high-voltage areas of a hybrid electric vehicle.



P65-11 HV gloves and leather protectors should be placed in a canvas storage bag when not in use. Note the ventilation hole at the bottom of this bag.



P65-12 Make sure that the rubber gloves are not folded when placed in the canvas bag. Folding increases mechanical stress on the rubber and can lead to premature failure of the glove material.

SUMMARY

1. Personal protective equipment (PPE) for work on hybrid electric vehicles includes the wearing of high-voltage rubber gloves rated at 1,000 volts or more worn with leather protective gloves to help protect the rubber gloves.
2. A digital meter and meter leads that meets CAT III standards should be used when working around the high-voltage section of a hybrid electric vehicle.
3. Safety glasses and a face shield should be worn whenever working around the high-voltage circuits of a hybrid electric vehicle.
4. The high-voltage system can be shut off by disconnecting the high-voltage circuits and being sure the ignition is off. Disconnecting the 12-volt battery is additional security that the high-voltage circuits are depowered.
5. For most situations, first responder actions should be the same as if the vehicle were conventional.
6. When servicing a hybrid electric vehicle, always observe recommended safety procedures.

REVIEW QUESTIONS

1. What are the recommended items that should be used when working with the high-voltage circuits of a hybrid electric vehicle?
2. How can a hybrid electric vehicle be identified?
3. What actions are needed to disable the high-voltage (HV) circuit?

4. What precautions should first responders take to protect themselves and accident victims in the event of a collision or accident with a hybrid electric vehicle?
5. What are the precautions that service technicians should adhere to when servicing hybrid electric vehicles?

CHAPTER QUIZ

1. Rubber gloves should be worn whenever working on or near the high-voltage circuits or components of a hybrid electric vehicle. Technician A says that the rubber gloves should be rated at 1,000 volts or higher. Technician B says that leather gloves should be worn over the high-voltage rubber gloves. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. A CAT III–certified DMM should be used whenever measuring high-voltage circuits or components. The CAT III rating relates to _____.
   a. High voltage
   b. High energy
   c. High electrical resistance
   d. Both a and b
3. All of the following will shut off the high voltage to components and circuits, except _____.
   a. Opening the driver's door
   b. Turning the ignition off
   c. Disconnecting the 12-volt auxiliary battery
   d. Removing the main fuse, relay, or HV plug
4. If the engine is not running, Technician A says that the high-voltage circuits are depowered. Technician B says that all high-voltage wiring is orange in color. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Which statement is *false* about high-voltage wiring?
   a. Connects the battery pack to the electric controller
   b. Connects the controller to the motor/generator
   c. Is electrically grounded to the frame (body) of the vehicle
   d. Is controlled by a relay that opens if the ignition is off
6. The electrolyte from a NiMH battery pack can be neutralized in the remote chance that it leaks by using _____.
   a. Water
   b. Baking soda
   c. Vinegar
   d. Baking powder
7. Two technicians are discussing jump-starting a hybrid electric vehicle. Technician A says that the high-voltage (HV) batteries can be jumped on some HEV models. Technician B says that the 12-volt auxiliary battery can be jumped using a conventional jump box or jumper cable. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. What can occur if a hybrid electric vehicle is pushed in the shop?
   a. The HV battery pack can be damaged
   b. The tires will be locked unless the ignition is on
   c. Damage to the electronic controller can occur
   d. High voltage will be generated by the motor/generator
9. Nickel metal hydride (NiMH) batteries can be damaged if exposed to temperatures higher than about _____.
   a. 150°F (66°C)
   b. 175°F (79°C)
   c. 200°F (93°C)
   d. 225°F (107°C)
10. How should nickel metal hydride (NiMH) batteries be disposed of?
    a. In regular trash
    b. Call an 800 number shown under the hood of the vehicle for information
    c. Submerged in water and then disposed of in regular trash
    d. Burned at an EPA-certified plant

CHAPTER 66 Fuel Cells and Advanced Technologies

OBJECTIVES: After studying Chapter 66, the reader will be able to: Explain how a fuel cell generates electricity. • Discuss the advantages and disadvantages of fuel cells. • List the types of fuel cells. • Explain how ultracapacitors work. • Discuss alternative energy sources.

KEY TERMS: double-layer technology • electrolysis • electrolyte • energy carrier • energy density • farads • fuel cell • fuel cell hybrid vehicle (FCHV) • fuel-cell stack • fuel cell vehicle (FCV) • homogeneous charge compression ignition (HCCI) • hydraulic power assist (HPA) • inverter • low-grade heat • membrane electrode assembly (MEA) • NEDRA • plug-in hybrid electric vehicle (PHEV) • polymer electrolyte fuel cell (PEFC) • proton exchange membrane (PEM) • range • specific energy • ultracapacitor • wheel motors • wind farms

FUEL-CELL TECHNOLOGY

What Is a Fuel Cell? A **fuel cell** is an electrochemical device in which the chemical energy of hydrogen and oxygen is converted into electrical energy. The principle of the fuel cell was first discovered in 1839 by Sir William Grove, a Welsh physician. In the 1950s NASA put this principle to work in building devices for powering

space exploration vehicles. In the present day, fuel cells are being developed to power homes and vehicles while producing low or zero emissions. See Figure 66–1.

The chemical reaction in a fuel cell is the opposite of **electrolysis.** Electrolysis is the process in which electrical current is passed through water in order to break it into its components, hydrogen and oxygen. While energy is required to bring about electrolysis, this same energy can be retrieved by allowing hydrogen and oxygen to reunite in a fuel cell. It is important to note that while hydrogen can be used as a fuel, it is **not** an energy source. Instead, hydrogen is only an **energy carrier,** as energy must be expended to generate the hydrogen and store it so it can be used as a fuel.

In simple terms, a fuel cell is a hydrogen-powered battery. Hydrogen is an excellent fuel because it has a very high **specific energy** when compared to an equivalent amount of fossil fuel. One kilogram (kg) of hydrogen has three times the energy content as one kilogram of gasoline. Hydrogen is the most abundant element on earth, but it does not exist by itself in nature. This is because its natural tendency is to react with oxygen in the atmosphere to form water (H_2O). Hydrogen is also found in many other compounds, most notably hydrocarbons, such as natural gas or crude oil. In order to store hydrogen for use as a fuel, processes must be undertaken to separate it from these materials. See Figure 66–2.

Benefits of a Fuel Cell A fuel cell can be used to move a vehicle by generating electricity to power electric drive motors, as well as powering the remainder of the vehicle's electrical system. Since they are powered by hydrogen and oxygen, fuel cells by themselves do not generate carbon emissions such as CO_2. Instead, their only emissions are water vapor and heat, and this makes the fuel cell an ideal candidate for a ZEV (zero-emission vehicle).

A fuel cell is also much more energy-efficient than a typical internal combustion engine. While a vehicle powered by an internal combustion engine (ICE) is anywhere from 15% to 20% efficient, a fuel-cell vehicle can achieve efficiencies upwards of 40%. Another major benefit of fuel cells is that they have very few moving parts and have the potential to be very reliable. A number of OEMs have spent many years and millions of dollars in order to develop a low-cost, durable, and compact fuel cell that will operate satisfactorily under all driving conditions. See Figure 66–3.

A **fuel-cell vehicle (FCV)** uses the fuel cell as its only source of power, whereas a **fuel-cell hybrid vehicle (FCHV)** would also have an electrical storage device that can be used to power the vehicle. Most new designs of fuel-cell vehicles are now based on a hybrid configuration due to the significant increase in efficiency and drivability that can be achieved with this approach. See Figure 66–4.



Figure 66–1 Ford Motor Company has produced a number of demonstration fuel-cell vehicles based on the Ford Focus.

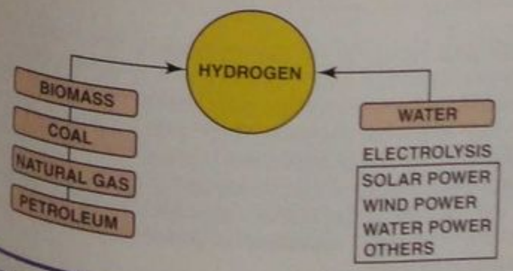


Figure 66–2 Hydrogen does not exist by itself in nature. Energy must be expended to isolate it from other, more complex materials.

Fuel-Cell Challenges While major automobile manufacturers continue to build demonstration vehicles and work on improving fuel-cell system design, no vehicle powered by a fuel cell has been placed into mass production. There are a number of reasons for this, including:

- High cost
- Lack of refueling infrastructure
- Safety perception
- Insufficient vehicle range
- Lack of durability
- Freeze starting problems
- Insufficient power density

All of these problems are being actively addressed by researchers, and significant improvements are being made. Once cost and performance levels meet that of current vehicles, fuel cells will be adopted as a mainstream technology.

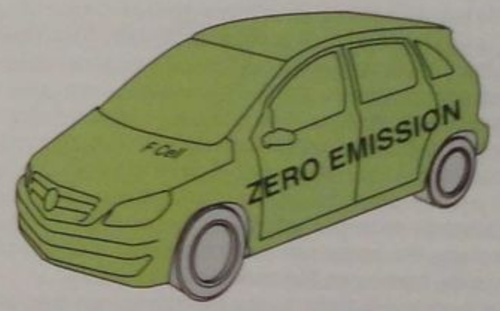


Figure 66–3 The Mercedes-Benz B-Class fuel-cell car was introduced in 2005.



Figure 66–4 The Toyota FCHV is based on the Highlander platform and uses much of Toyota's Hybrid Synergy Drive (HSD) technology in its design.

Fuel-Cell Types

	PAFC (Phosphoric Acid Fuel Cell)	PEM (Polymer Electrolyte Membrane)	MCFC (Molten Carbonate Fuel Cell)	SOFC (Solid Oxide Fuel Cell)
Electrolyte	Orthophosphoric acid	Sulfonic acid in polymer	Li and K carbonates	Yttrium-stabilized zirconia
Fuel	Natural gas, hydrogen	Natural gas, hydrogen, methanol	Natural gas, synthetic gas	Natural gas, synthetic gas
Operating Temp (F) (C)	365–410°F 185–210°C	176–212°F 80–100°C	1100–1300°F 600–700°C	1200–3300°F 650–1800°C
Electric Efficiency	40%	30–40%	43–44%	50–60%
Manufacturers	ONSI Corp	Avista, Ballard, Energy Partners, H-Power, International, Plug Power	Fuel Cell Energy, IHI, Hitachi, Siemens	Honeywell, Siemens-Westinghouse, Ceramic
Applications	Stationary power	Vehicles, portable power, small stationary power	Industrial and institutional power	Stationary power, military vehicles

Types of Fuel Cells There are a number of different types of fuel cells, and these are differentiated by the type of **electrolyte** that is used in their design. Some electrolytes operate best at room temperature, whereas others are made to operate at up to 1800°F. See the accompanying chart showing the various fuel-cell types and applications.

The fuel-cell design that is best suited for automotive applications is the **Proton Exchange Membrane (PEM)**. A PEM fuel cell must have hydrogen for it to operate, and this may be stored on the vehicle or generated as needed from another type of fuel.

PEM FUEL CELLS

Description and Operation The Proton Exchange Membrane fuel cell is also known as a **Polymer Electrolyte Fuel Cell (PEFC)**. The PEM fuel cell is known for its lightweight and compact design, as well as its ability to operate at ambient temperatures. This means that a PEM fuel cell can start quickly and produce full power without an extensive warmup period. The PEM is a simple design based on a membrane that is coated on both sides with a catalyst such as platinum or palladium. There are two electrodes, one located on each side of the membrane. These are responsible for distributing hydrogen and oxygen over the membrane surface, removing waste heat, and providing a path for electrical current flow. The part of the PEM fuel cell that contains the membrane, catalyst coatings, and electrodes is known as the **Membrane Electrode Assembly (MEA)**.

The negative electrode (anode) has hydrogen gas directed to it, while oxygen is sent to the positive electrode (cathode). Hydrogen is sent to the negative electrode as H_2 molecules, which break apart into H^+ ions (protons) in the presence of the catalyst. The electrons (e^-) from the hydrogen atoms are sent through the external circuit, generating electricity that can be utilized to perform work. These same electrons are then sent to the positive electrode where they rejoin the H^+ ions that have passed through the membrane and have reacted with oxygen in the presence of the catalyst. This creates H_2O and waste heat, which are the only emissions from a PEM fuel cell. See Figure 66–5.

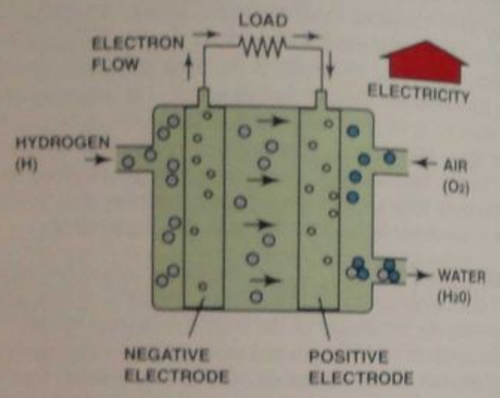


Figure 66–5 The polymer electrolyte membrane only allows H^+ ions (protons) to pass through it. This means that electrons must follow the external circuit and pass through the load to perform work.

NOTE: It is important to remember that a fuel cell generates direct current (DC) electricity as electrons only flow in one direction (from the anode to the cathode).

Fuel-Cell Stacks A single fuel cell by itself is not particularly useful, as it will generate less than 1 volt of electrical potential. It is more common for hundreds of fuel cells to be built together in a **fuel-cell stack**. In this arrangement, the fuel cells are connected in series so that total voltage of the stack is the sum of the individual cell voltages. The fuel cells are placed end-to-end in the stack, much like slices in a loaf of bread. Automotive fuel-cell stacks contain upwards of 400 cells in their construction. See Figure 66–6.

TECH TIP ✓ **CO Poisons the PEM Fuel-Cell Catalyst**

Purity of the fuel gas is critical with PEM fuel cells. If more than 10 parts per million (ppm) of carbon monoxide is present in the hydrogen stream being fed to the PEM anode, the catalyst will be gradually poisoned and the fuel cell will eventually be disabled. This means that the purity must be "five nines" (99.999% pure). This is a major concern in vehicles where hydrogen is generated by reforming hydrocarbons such as gasoline, because it is difficult to remove all CO from the hydrogen during the reforming process. In these applications, some means of hydrogen purification must be used to prevent CO poisoning of the catalyst.

The total voltage of the fuel-cell stack is determined by the number of individual cells incorporated into the assembly. The current-producing ability of the stack, however, is dependent on the surface area of the electrodes. Since output of the fuel-cell stack is related to both voltage and current (voltage × current = power), increasing the number of cells or increasing the surface area of the cells will increase power output. Some fuel-cell vehicles will use more than one stack, depending on power output requirements and space limitations.

Direct Methanol Fuel Cells High-pressure cylinders are one method of storing hydrogen onboard a vehicle for use in a fuel cell.



Figure 66–6 A fuel-cell stack is made up of hundreds of individual cells connected in series.

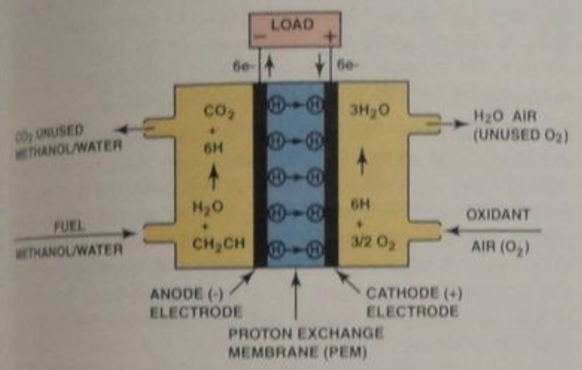


Figure 66–7 A direct methanol fuel cell uses a methanol/water solution for fuel instead of hydrogen gas.

This is a simple and lightweight storage method, but often does not provide sufficient vehicle driving range. Another approach has been to fuel a modified PEM fuel cell with liquid methanol instead of hydrogen gas. See Figure 66–7.

Methanol is most often produced from natural gas and has a chemical symbol of CH_3OH. It has a higher **energy density** than gaseous hydrogen because it exists in a liquid state at normal temperatures, and is easier to handle since no compressors or other high-pressure equipment is needed. This means that a fuel-cell vehicle can be refueled with a liquid instead of high-pressure gas, which makes the refueling process simpler and produces a greater vehicle driving range. See Figure 66–8.

FREQUENTLY ASKED QUESTION ???

What Is the Role of the Humidifier in a PEM Fuel Cell?

The polymer electrolyte membrane assembly in a PEM fuel cell acts as conductor of positive ions and as a gas separator. However, it can only perform these functions effectively if it is kept moist. A fuel-cell vehicle uses an air compressor to supply air to the positive electrodes of each cell, and this air is sometimes sent through a humidifier first to increase its moisture content. The humid air then comes in contact with the membrane assembly and keeps the electrolyte damp and functioning correctly.

Unfortunately, direct methanol fuel cells suffer from a number of problems, not the least of which is the corrosive nature of



Figure 66–8 A direct methanol fuel cell can be refueled similar to a gasoline-powered vehicle.

methanol itself. This means that methanol cannot be stored in existing tanks and thus requires a separate infrastructure for handling and storage. Another problem is "fuel crossover," in which methanol makes its way across the membrane assembly and diminishes performance of the cell. Direct methanol fuel cells also require much greater amounts of catalyst in their construction, which leads to higher costs. These challenges are leading researchers to look for alternative electrolyte materials and catalysts to lower cost and improve cell performance.

NOTE: Direct methanol fuel cells are not likely to see service in automotive applications. However, they are well suited for low-power applications, such as cell phones or laptop computers.

FUEL-CELL VEHICLE SYSTEMS

Humidifiers Water management inside a PEM fuel cell is critical. Too much water can prevent oxygen from making contact with the positive electrode; too little water can allow the electrolyte to dry out and lower its conductivity. The amount of water and where it resides in the fuel cell is also critical in determining at how low a temperature the fuel cell will start, because water freezing in the fuel cell can prevent it from starting. The role of the humidifier is to achieve a balance where it is providing sufficient moisture to the fuel cell by recycling water that is evaporating at the cathode. The humidifier is located in the air line leading to the cathode of the fuel-cell stack. See Figure 66–9.

Some newer PEM designs manage the water in the cells in such a way that there is no need to pre-humidify the incoming reactant gases. This eliminates the need for the humidifier assembly and makes the system simpler overall.

FREQUENTLY ASKED QUESTION ???

When Is Methanol Considered to Be a "Carbon-Neutral" Fuel?

Most of the methanol in the world is produced by reforming natural gas. Natural gas is a hydrocarbon, but does not increase the carbon content of our atmosphere as long as it remains in reservoirs below the earth's surface. However, natural gas that is used as a fuel causes extra carbon to be released into the atmosphere, which is said to contribute to global warming. Natural gas is not a carbon-neutral fuel, and neither is methanol that is made from natural gas.

Fortunately, it is possible to generate methanol from biomass and wood waste. Methanol made from renewable resources is carbon neutral, because no extra carbon is being released into the earth's atmosphere than what was originally absorbed by the plants used to make the methanol.

Fuel-Cell Cooling Systems Heat is generated by the fuel cell during normal operation. Excess heat can lead to a breakdown of the polymer electrolyte membrane, so a liquid cooling system must be utilized to remove waste heat from the fuel-cell stack. One of the major challenges for engineers in this regard is the fact that the heat generated by the fuel cell is classified as **low-grade heat.** This means that there is only a small difference between the temperature of the coolant and that of the ambient air. Heat transfers very slowly under these conditions, so heat exchangers with a much larger surface area must be utilized. See Figure 66–10.

In some cases, heat exchangers may be placed in other areas of the vehicle when available space at the front of the engine compartment is insufficient. In the case of the Toyota FCHV, an auxiliary heat exchanger is located underneath the vehicle to increase the cooling system heat-rejection capacity. See Figure 66–11.

An electric water pump and a fan drive motor are used to enable operation of the fuel cell's cooling system. These and other support devices use electrical power that is generated by the fuel cell, and therefore tend to decrease the overall efficiency of the vehicle.

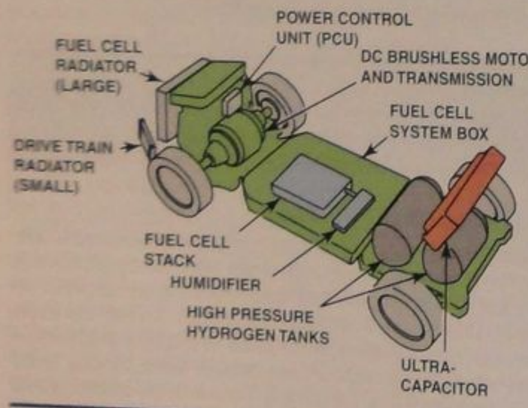


Figure 66–9 Power train layout in a Honda FCX fuel-cell vehicle. Note the use of a humidifier behind the fuel-cell stack to maintain moisture levels in the membrane electrode assemblies.

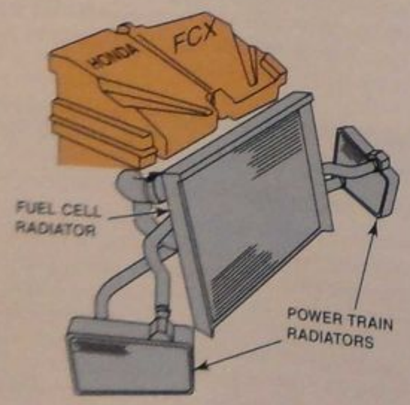


Figure 66–10 The Honda FCX uses one large radiator for cooling the fuel cell, and two smaller ones on either side for cooling drive train components.

Air Supply Pumps Air must be supplied to the fuel-cell stack at the proper pressure and flow rate to enable proper performance under all driving conditions. This function is performed by an onboard air supply pump that compresses atmospheric air and supplies it to the fuel cell's positive electrode (cathode). This pump is often driven by a high-voltage electric drive motor.

Fuel-Cell Hybrid Vehicles Hybridization tends to increase efficiency in vehicles with conventional drive trains, as energy that was once lost during braking and otherwise normal operation is instead stored for later use in a high-voltage battery or **ultracapacitor.** This same advantage can be gained by applying the hybrid design concept to fuel-cell vehicles. Whereas the fuel cell is the only power source in a fuel-cell vehicle, the fuel-cell hybrid vehicle (FCHV) relies on both the fuel cell and an electrical storage device for motive power. Drivability is also enhanced with this design, as the electrical storage device is able to supply energy immediately to the drive motors and overcome any "throttle lag" on the part of the fuel cell.

Secondary Batteries All hybrid vehicle designs require a means of storing electrical energy that is generated during regenerative braking and other applications. In most FCHV designs, a high-voltage nickel-metal hydride (NiMH) battery pack is used as a secondary battery. This is most often located near the back of the vehicle, either under or behind the rear passenger seat. See Figure 66–12. The secondary battery is built similar to a fuel-cell stack, because it is made up of many low-voltage cells connected in series to build a high-voltage battery.

Figure 66–11 Space is limited at the front of the Toyota FCHV engine compartment, so an auxiliary heat exchanger is located under the vehicle to help cool the fuel-cell stack.

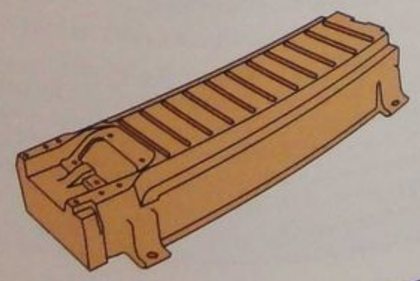


Figure 66–12 The secondary battery in a fuel-cell hybrid vehicle is made up of many individual cells connected in series, much like a fuel-cell stack.

Ultracapacitors An alternative to storing electrical energy in batteries is to use ultracapacitors. A capacitor is best known as an electrical device that will block DC current, but allow AC to pass. However, a capacitor can also be used to store electrical energy, and it is able to do this without a chemical reaction. Instead, a capacitor stores electrical energy using the principle of electrostatic attraction between positive and negative charges.

Ultracapacitors are built very different from conventional capacitors. Ultracapacitor cells are based on **double-layer technology,** in which two activated-carbon electrodes are immersed in an organic electrolyte. The electrodes have a very large surface area and are separated by a membrane that allows ions to migrate but prevents the electrodes from touching. See Figure 66–13. Charging and discharging occurs as ions move within the electrolyte but no chemical reaction takes place. Ultracapacitors can charge and discharge quickly and efficiently, making them especially suited for electric assist applications in fuel-cell hybrid vehicles.

Ultracapacitors that are used in fuel-cell hybrid vehicles are made up of multiple cylindrical cells connected in parallel. See Figure 66–14. This results in the total capacitance being the sum of the values of each individual cell. For example, ten 1.0-**farad** capacitors connected in parallel will have a total capacitance of 10.0 farads. Greater capacitance means greater electrical storage ability, and this contributes to greater assist for the electric motors in a fuel-cell hybrid vehicle.

Ultracapacitors have excellent cycle life, meaning that they can be fully charged and discharged many times without degrading their performance. They are also able to operate over a wide temperature range and are not affected by low temperatures to the same degree as many battery technologies. The one major downside of ultracapacitors is a lack of specific energy, which means that they are bested suited for sudden bursts of energy as opposed to prolonged discharge cycles. Research is being conducted to improve this and other aspects of ultracapacitor performance.

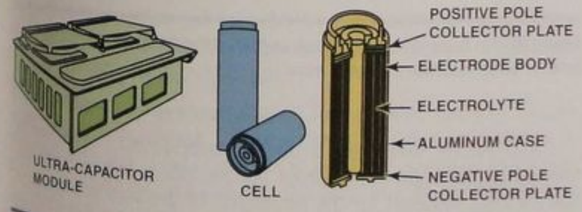


Figure 66–13 The Honda ultracapacitor module and construction of the individual cells.

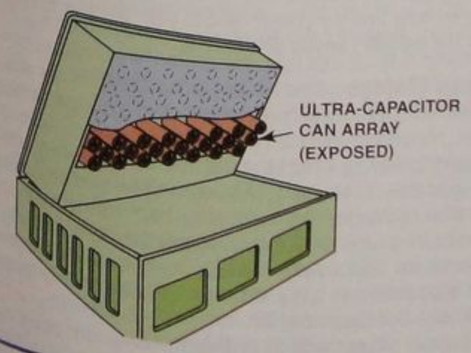


Figure 66–14 An ultracapacitor can be used in place of a high-voltage battery in a hybrid electric vehicle. This example is from the Honda FCX fuel-cell hybrid vehicle.

Fuel-Cell Traction Motors Much of the technology behind the electric drive motors being used in fuel-cell vehicles was developed during the early days of the California ZEV mandate. This was a period when battery-powered electric vehicles were being built by the major vehicle manufacturers in an effort to meet a legislated quota in the state of California. The ZEV mandate rules were eventually relaxed to allow other types of vehicles to be substituted for credit, but the technology that had been developed for pure electric vehicles was now put to work in these other vehicle designs.

The electric traction motors used in fuel-cell hybrid vehicles are very similar to those being used in current hybrid electric vehicles. The typical drive motor is based on an AC synchronous design, which is sometimes referred to as a DC brushless motor. This design is very reliable as it does not use a commutator or brushes, but instead has a three-phase stator and a permanent magnet rotor. See Figure 66–15. An electronic controller (inverter) is used to generate the three-phase high-voltage AC current required by the motor. While the motor itself is very simple, the electronics required to power and control it are complex.

Some fuel-cell hybrid vehicles use a single electric drive motor and a transaxle to direct power to the vehicle's wheels. It is also possible to use **wheel motors** to drive individual wheels. While this approach adds a significant amount of unsprung weight to the chassis, it allows for greater control of the torque being applied to each individual wheel. See Figure 66–16.

Transaxles Aside from the hydrogen fueling system, fuel-cell hybrid vehicles are effectively pure electric vehicles in that their drive train is electrically driven. Electric motors work very well for automotive applications because they produce high torque at low RPMs and are able to maintain a consistent power output throughout their entire RPM range. This is in contrast to vehicles powered by internal combustion engines, which produce very little torque at low RPMs and have a narrow range where significant horsepower is produced.

ICE-powered vehicles require complex transmissions with multiple speed ranges in order to accelerate the vehicle quickly and maximize the efficiency of the ICE. Fuel-cell hybrid vehicles use electric drive motors that require only a simple reduction in their final drive and a differential to send power to the drive wheels. No gear shifting is required and mechanisms such as torque converters and clutches are done away with completely.



Figure 66–15 Drive motors in fuel-cell hybrid vehicles often use stator assemblies similar to ones found in Toyota hybrid electric vehicles. The rotor turns inside the stator and has permanent magnets on its outer circumference.

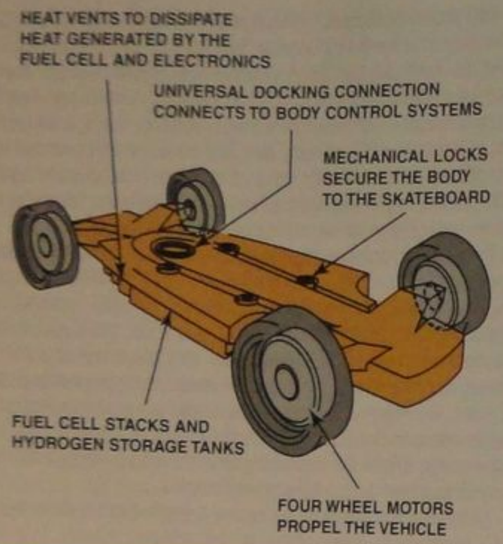


Figure 66–16 The General Motors "Skateboard" concept uses a fuel-cell propulsion system with wheel motors at all four corners.

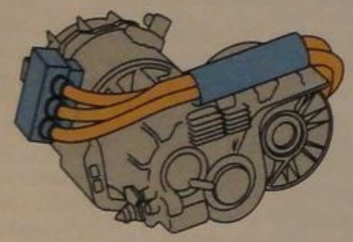


Figure 66–17 The electric drive motor and transaxle assembly from a Toyota FCHV. Note the three orange cables, indicating that this motor is powered by high-voltage three-phase alternating current.

A reverse gear is not required either, as the electric drive motor is simply powered in the opposite direction. The transaxles used in fuel-cell hybrid vehicles are extremely simple with few moving parts, making them extremely durable, quiet, and reliable. See Figure 66–17.

Power Control Units The drive train of a fuel-cell hybrid vehicle is controlled by a power control unit (PCU), which controls fuel-cell output and directs the flow of electricity between the various components. One of the functions of the PCU is to act as an **inverter,** which changes direct current from the fuel-cell stack into three-phase alternating current for use in the vehicle drive motor(s). See Figure 66–18.

Power to and from the secondary battery is directed through the power control unit, which is also responsible for maintaining the battery pack's state of charge and for controlling and directing the output of the fuel-cell stack. See Figure 66–19.

During regenerative braking, the electric drive motor acts as a generator and converts kinetic (moving) energy of the vehicle into electricity for recharging the high-voltage battery pack. The PCU must take the three-phase power from the motor (generator) and convert (or *rectify*) this into DC voltage to be sent to the battery. DC power from the fuel cell will also be processed through the PCU for recharging the battery pack.

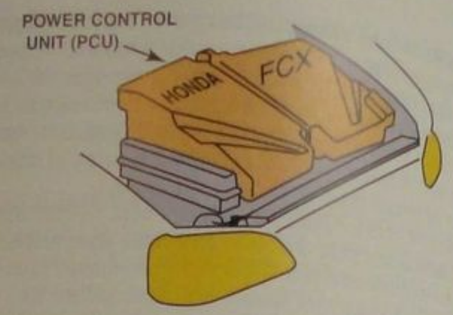


Figure 66–18 The power control unit (PCU) on a Honda FCX fuel-cell hybrid vehicle is located under the hood.

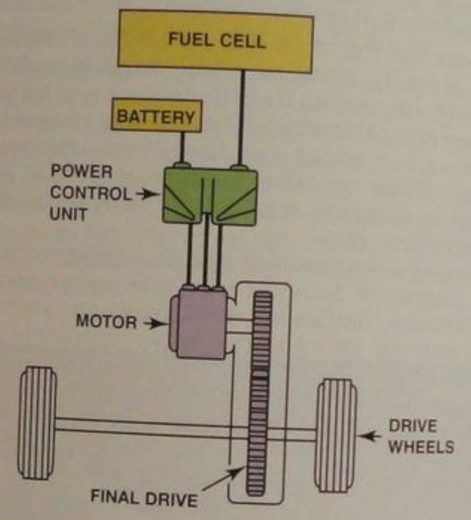


Figure 66–19 Toyota's FCHV uses a power control unit that directs electrical energy flow between the fuel cell, battery, and drive motor.

A DC-to-DC converter is used in hybrid-electric vehicles for converting the high voltage from the secondary battery pack into the 12 volts required for the remainder of the vehicle's electrical system. Depending on the vehicle, there may also be 42 volts required to operate accessories such as the electric-assist power steering. In fuel-cell hybrid vehicles, the DC-to-DC converter function may be built into the power control unit, giving it full responsibility for the vehicle's power distribution.

Hydrogen Storage One of the pivotal design issues with fuel-cell hybrid vehicles is how to store sufficient hydrogen onboard to allow for reasonable vehicle range. Modern drivers have grown accustomed to having a minimum of 300 miles between refueling stops, a goal that is extremely difficult to achieve when fueling the vehicle with hydrogen. Hydrogen has a very high energy content on a pound-for-pound basis, but its energy density is less than that of conventional liquid fuels. This is because gaseous hydrogen, even at high pressure, has a very low physical density (mass per unit volume). See Figure 66–20.

A number of methods of hydrogen storage are being considered for use in fuel-cell hybrid vehicles. These include high-pressure compressed gas, liquefied hydrogen, and solid storage in metal hydrides. Efficient hydrogen storage is one of the technical



Figure 66–20 This GM fuel-cell vehicle uses compressed hydrogen in three high-pressure storage tanks.

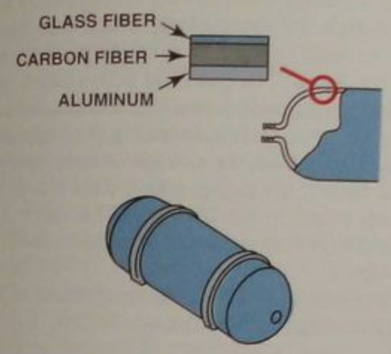


Figure 66–21 The Toyota FCHV uses high-pressure storage tanks that are rated at 350 bar. This is the equivalent of 5,000 pounds per square inch.

issues that must be solved in order for fuel cells to be adopted for vehicle applications. Much research is being conducted to solve the issue of onboard hydrogen storage.

High-Pressure Compressed Gas Most current fuel-cell hybrid vehicles use compressed hydrogen that is stored in tanks as a high-pressure gas. This approach is the least complex of all the storage possibilities, but also has the least energy density. Multiple small storage tanks are often used rather than one large one in order to fit them into unused areas of the vehicle. One drawback with this approach is that only cylinders can be used to store gases at the required pressures. This creates a good deal of unused space around the outside of the cylinders and leads to further reductions in hydrogen storage capacity. It is common for a pressure of 5000 PSI (350 bar) to be used, but technology is available to store hydrogen at up to 10000 PSI (700 bar). See Figure 66–21.

The tanks used for compressed hydrogen storage are typically made with an aluminum liner wrapped in several layers of carbon fiber and an external coating of fiberglass. In order to refuel the compressed hydrogen storage tanks, a special high-pressure fitting is installed in place of the filler neck used for conventional vehicles. See Figure 66–22. There is also a special electrical connector that is used to enable communication between the vehicle and the filling station during the refueling process. See Figure 66–23.

The filling station utilizes a special coupler to connect to the vehicle's high-pressure refueling fitting. The coupler is placed on



Figure 66–22 The high-pressure fitting used to refuel a fuel-cell hybrid vehicle.



Figure 66–23 Note that high-pressure hydrogen storage tanks must be replaced in 2020.

the vehicle fitting, and a lever on the coupler is rotated to seal and lock it into place.

Liquid Hydrogen Hydrogen can be liquefied in an effort to increase its energy density, but this requires that it be stored in cryogenic tanks at −423°F (−253°C). This increases vehicle range, but impacts overall efficiency, as a great deal of energy is required to liquefy the hydrogen and a certain amount of the liquid hydrogen will "boil off" while in storage.

One liter of liquid hydrogen only has one-fourth the energy content of 1 liter of gasoline. See Figures 66–24 and 66–25.

Solid Storage of Hydrogen One method discovered to store hydrogen in solid form is as a metal hydride, similar to how a nickel-metal hydride (NiMH) battery works.

A demonstration vehicle features a lightweight fiber-wrapped storage tank under the body that stores 3 kg (about 6.6 pounds) of hydrogen as a metal hydride at low pressure. The vehicle can travel almost 200 miles with this amount of fuel. One kilogram of hydrogen is equal to 1 gallon of gasoline. Three gallons of water will generate 1 kilogram of hydrogen.

A metal hydride is formed when gaseous hydrogen molecules disassociate into individual hydrogen atoms and bond with the metal atoms in the storage tank. This process uses powdered metallic alloys capable of rapidly absorbing hydrogen to make this occur.

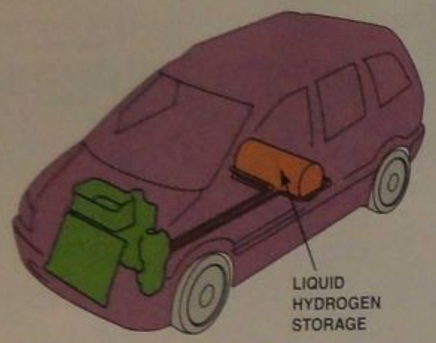


Figure 66–24 GM's Hydrogen3 has a range of 249 miles when using liquid hydrogen.

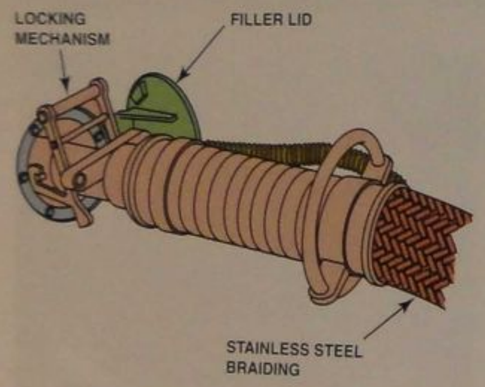


Figure 66–25 Refueling a vehicle with liquid hydrogen.

TECH TIP ✓ **Hydrogen Fuel = No Carbon**

Most fuels contain hydrocarbons or molecules that contain both hydrogen and carbon. During combustion, the first element that is burned is the hydrogen. If combustion is complete, then all of the carbon is converted to carbon dioxide gas and exits the engine in the exhaust. However, if combustion is not complete, carbon monoxide is formed, plus leaving some unburned carbon to accumulate in the combustion chamber. See Figure 66–26.



Figure 66–26 Carbon deposits, such as these, are created by incomplete combustion of a hydrocarbon fuel.

HYDRAULIC HYBRID STORAGE SYSTEM

Ford Motor Co. is experimenting with a system it calls **Hydraulic Power Assist (HPA).** This system converts kinetic energy to hydraulic pressure, and then uses that pressure to help accelerate the vehicle. It is currently being tested on a four-wheel-drive (4WD) Lincoln Navigator with a 4.0-L V-8 engine in place of the standard 5.4-L engine.

A variable-displacement hydraulic pump/motor is mounted on the transfer case and connected to the output shaft that powers the front drive shaft. The HPA system works with or without 4WD engaged. A valve block mounted on the pump contains solenoid valves to control the flow of hydraulic fluid. A 14-gallon, high-pressure accumulator is mounted behind the rear axle, with a low-pressure accumulator right behind it to store hydraulic fluid. The master cylinder has a "deadband," meaning the first few fractions of an inch of travel do not pressurize the brake system. When the driver depresses the brake pedal, a pedal movement sensor signals the control unit, which then operates solenoid valves to send hydraulic fluid from the low-pressure reservoir to the pump. The pumping action slows the vehicle, similar to engine compression braking, and the fluid is pumped into the high-pressure reservoir. Releasing the brake and pressing on the accelerator signals the control unit to send that high-pressure fluid back to the pump, which then acts as a hydraulic motor and adds torque to the drive line. The system can be used to launch the vehicle from a stop and/or add torque for accelerating from any speed.

While the concept is simple, the system itself is very complicated. Additional components include:

- Pulse suppressors
- Filters
- An electric circulator pump for cooling the main pump/motor

Potential problems with this system include leakage problems with seals and valves, getting air out of the hydraulic fluid system, and noise. In prototype stages the system demands different driving techniques. Still, this system was built to prove the concept, and the engineers believe that these problems can be solved and that a control system can be developed that will make HPA transparent to the driver. A 23% improvement in fuel economy and improvements in emissions reduction were achieved using a dynamometer set for a 7,000-pound vehicle. While the HPA system could be developed for any type of vehicle with any type of drive train, it does add weight and complexity, which would add to the cost.

HCCI

Homogeneous Charge Compression Ignition (HCCI) is a combustion process. HCCI is the combustion of a very lean gasoline air–fuel mixture without the use of a spark ignition. It is a low-temperature, chemically controlled (flameless) combustion process. See Figure 66–27.

HCCI combustion is difficult to control and extremely sensitive to changes in temperature, pressure, and fuel type. While the challenges of HCCI are difficult, the advantages include having a gasoline engine being able to deliver 80% of diesel efficiency (a 20% increase in fuel economy) for 50% of the cost. A diesel engine using HCCI can deliver gasoline-like emissions. Spark and injection timing are no longer a factor as they are in a conventional port-fuel injection system.

While much research and development needs to be performed using this combustion process, it has been shown to give excellent

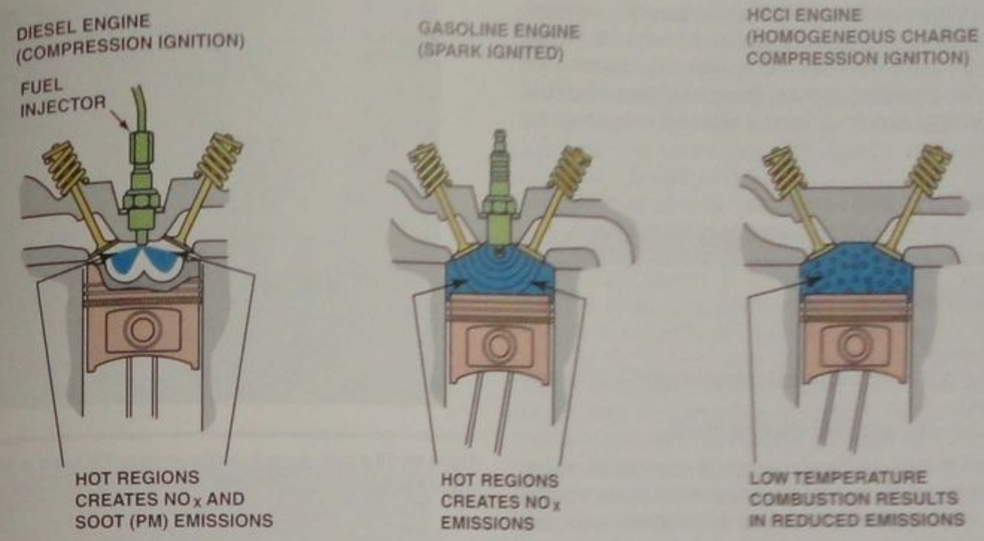


Figure 66–27 Both diesel and conventional gasoline engines create exhaust emissions due to high peak temperatures created in the combustion chamber. The lower combustion temperatures during HCCI operation result in high efficiency with reduced emissions.

performance from idle to mid-load, and from ambient to warm operating temperatures as well as cold-start and run capability. Because an engine only operates in HCCI mode at light throttle settings, such as during cruise conditions at highway speeds, engineers need to improve the transition in and out of the HCCI mode. Work is also being done on piston and combustion chamber shape to reduce combustion noise and vibration that is created during operation in the HCCI operating mode.

Ongoing research is focusing on improving fuel economy under real-world operating conditions as well as controlling costs.

PLUG-IN HYBRID ELECTRIC VEHICLES

A **plug-in hybrid electric vehicle (PHEV)** is a hybrid electric vehicle that is designed to be plugged into an electrical outlet at night to charge the batteries. By charging the batteries in the vehicle, it can operate using electric power alone (stealth mode) for a longer time, thereby reducing the use of the internal combustion engine (ICE). The less the ICE is operating, the less fuel is consumed and the lower the emissions. At the present time, plug-in hybrids are not offered by any major manufacturer but many conventional HEVs are being converted to plug-in hybrids by adding additional batteries.

If a production plug-in hybrid is built, it should be able to get about twice the fuel economy of a conventional hybrid. The extra weight of the batteries will be offset, somewhat, by the reduced weight of a smaller ICE. At highway speeds, fuel efficiency is affected primarily by aerodynamics, and therefore the added weight of the extra batteries is equal to one or two additional passengers and thus would only slightly reduce fuel economy. Recharging will normally take place at night during cheaper off-peak hours. Counting fuel and service, the total lifetime cost of ownership will be lower than a conventional gasoline-powered vehicle.

There are emissions related to the production of the electricity, which are called *well-to-wheel emissions.* These emissions, including greenhouse gases, are far lower than those of gasoline, even for the national power grid, which is 50% coal. Vehicles charging off-peak will use power from plants that cannot be turned off at night and often use cleaner sources such as natural gas and hydroelectric power. Plug-in hybrids could be recharged using rooftop photovoltaic systems, which would create zero emissions.

THE FUTURE FOR ELECTRIC VEHICLES

The future of electric vehicles depends on many factors, including:

1. The legislative and environmental incentives to overcome the cost and research efforts to bring a usable electric vehicle to the market.
2. The cost of alternative energy. If the cost of fossil fuels increases to the point that the average consumer cannot afford to drive a conventional vehicle, then electric vehicles (EVs) may be a saleable alternative.
3. Advancement in battery technology that would allow the use of lighter-weight and higher-energy batteries.

Cold-Weather Concerns Past models of electric vehicles such as the General Motors electric vehicle (EV1) were restricted to locations such as Arizona and southern California that had a warm climate, because cold weather is a major disadvantage to the use of electric vehicles for the following reasons:

- Cold temperatures reduce battery efficiency.
- Additional electrical power from the batteries is needed to heat the batteries themselves to be able to achieve reasonable performance.
- Passenger compartment heating is a concern for an electric vehicle because it would require the use of resistance units or other technology that would reduce the range of the vehicle.

Hot-Weather Concerns Batteries do not function well at high temperatures, and therefore some type of battery cooling must be added to the vehicle to allow for maximum battery performance. This would then result in a reduction of vehicle range

due to the use of battery power needed just to keep the batteries working properly. Besides battery concerns, the batteries would also have to supply the power needed to keep the interior cool as well as all of the other accessories. These combined electrical loads represent a huge battery drain and reduce the range of the vehicle.

Recharging Methods and Concerns How far an electric vehicle can travel on a full battery charge is called its **range.** The range of an electric vehicle depends on many factors, including:

- Battery energy storage capacity
- Vehicle weight
- Outside temperature
- Terrain (driving in hilly or mountainous areas requires more energy from the battery)
- Use of air conditioning and other electrical devices

Because electric vehicles have a relatively short range, charging stations must be made available in areas where these vehicles are driven. For example, when the state of California mandated the sale of zero-emission vehicles (ZEV), charging stations were set up in many areas, usually in parking lots of businesses and schools. See Figure 66–28. The parking spaces near the charging stations were designated for electric vehicles only and could be used for free to recharge electric vehicles. If electric vehicles are going to become widely used, charging stations will have to be established to allow the necessary recharging for trips to work and back home.

Charging Methods When the state of California set up electric vehicle charging stations, both a conductive- and inductive-type charger was made available at each station.

Conductive Charging Conductive charging uses an electrical plug that makes physical contact with terminals in the vehicle. The charger can be powered by 110-V AC, or most commonly 220-V AC. See Figure 66–29. This type of charger connection is used on some Ford and Honda electric vehicles.

Inductive Charging Inductive charging is achieved by inserting a paddlelike probe into a charging receptacle (opening) in the vehicle. The charger is powered by 220-volt AC and does not make physical contact with the vehicle. See Figure 66–30.



Figure 66–28 A typical electric vehicle charging station on the campus of a college in Southern California.



Figure 66–29 A conductive-type charging connector. This type of battery charging connector is sometimes called an AVCON connector, named for the manufacturer.



Figure 66–30 An inductive-type electric vehicle battery charger connector. This type of connector fits into a charging slot in the vehicle, but does not make electrical contact.

FREQUENTLY ASKED QUESTION ???

What Is NEDRA?

NEDRA is the **National Electric Drag Racing Association** that holds drag races for electric-powered vehicles throughout the United States. The association does the following:

1. Coordinates a standard rule set for electric vehicle drag racing, to balance the needs and interests of all those involved in the sport.
2. Sanctions electric vehicle drag racing events, to:
   - Make the events as safe as possible.
   - Record and maintain official records.
   - Maintain consistency on a national scale.
   - Coordinate and schedule electric vehicle drag racing events.
3. Promotes electric vehicle drag racing to:
   - Educate the public and increase people's awareness of electric vehicles while eliminating any misconceptions.
   - Encourage participation in electric vehicle drag racing.
   - Have fun in a safe and silent drag racing environment.

See Figure 66–31.



(a)



(b)

Figure 66–31 (a) The motor in a compact electric drag car. This 8-inch-diameter motor is controlled by an electronic controller that limits the voltage to 170 volts to prevent commutator flash-over yet provides up to 2,000 amperes. This results in an amazing 340,000 watts or 455 hp. (b) The batteries used for the compact drag car include twenty 12-volt absorbed glass mat (AGM) batteries connected in series to provide 240 volts.

An inductive charger paddle contains a coil of wire and the AC current from the charger flows through the winding, which creates a moving magnetic field around the paddle. Inside the charging receptacle of the vehicle is another coil of wire. The alternating magnetic field induces an AC voltage in the coil winding.

The electronics in the vehicle then changes the induced AC current into DC current to charge the batteries. Inductive-type chargers are used with the General Motors EV-1, as well as Nissan and Toyota electric vehicles.

WIND POWER

Wind power is used to help supplement electric power generation in many parts of the country. Because AC electricity cannot be stored, this energy source is best used to reduce the use of natural gas and coal to help reduce CO_2 emissions. Wind power is most economical if the windmills are located where the wind blows consistently above 8 miles per hour (13 km/h). Locations include the eastern slope of mountain ranges, such as the Rocky Mountains, or on high ground in many states. Often, wind power is used as supplemental power in the evenings when it is most needed, and is allowed to stop rotating in daylight hours when the power is not needed. Windmills are usually grouped together to form **wind farms,** where the product is electrical energy. Energy from wind farms can be used to charge plug-in hybrid vehicles, as well as for domestic lighting and power needs. See Figures 66–32 and 66–33.

HYDROELECTRIC POWER

Hydroelectric power is limited to locations where there are dammed rivers and hydroelectric plants. However, electricity can and is transmitted long distances—so that electricity generated at the Hoover Dam can be used in California and other remote locations. Electrical power from hydroelectric sources can be used to charge plug-in hybrid electric vehicles, thereby reducing emissions that would normally be created by burning coal or natural gas to create electricity. However, hydroelectric plants are limited as to the amount of power they can produce, and constructing new plants is extremely expensive. See Figure 66–34.

SUMMARY

1. The chemical reaction inside a fuel cell is the opposite of electrolysis in that electricity is created when hydrogen and oxygen are allowed to combine in the fuel cell.
2. A fuel cell produces electricity and releases heat and water as the only by-products.
3. The major disadvantages of fuel cells include:
   - High cost
   - Lack of hydrogen refueling stations
   - Short range
   - Freezing-temperature starting problems
4. Types of fuel cells include PEM (the most commonly used), PAFC, MCFC, and SOFC.
5. Ultracapacitors are an alternative to batteries for the storage of electrical energy.
6. A gasoline-powered engine can be more efficient if it uses a homogeneous charge compression ignition (HCCI) combustion process.
7. Plug-in hybrid electric vehicles could expand the range of hybrid vehicles by operating on battery power alone.
8. Wind power and hydroelectric power are being used to recharge plug-in hybrids and provide electrical power for all uses, without harmful emissions.

REVIEW QUESTIONS

1. How does a fuel cell work?
2. What are the advantages and disadvantages of fuel cells?
3. What are the uses of the various types of fuel cells?
4. How does an ultracapacitor work?
5. What are the advantages and disadvantages of using hydrogen?
6. What alternative power sources could be used for vehicles?

CHAPTER QUIZ

1. A fuel cell produces electricity from _____ and _____.
   a. Gasoline/oxygen
   b. Nitrogen/hydrogen
   c. Hydrogen/oxygen
   d. Water/oxygen

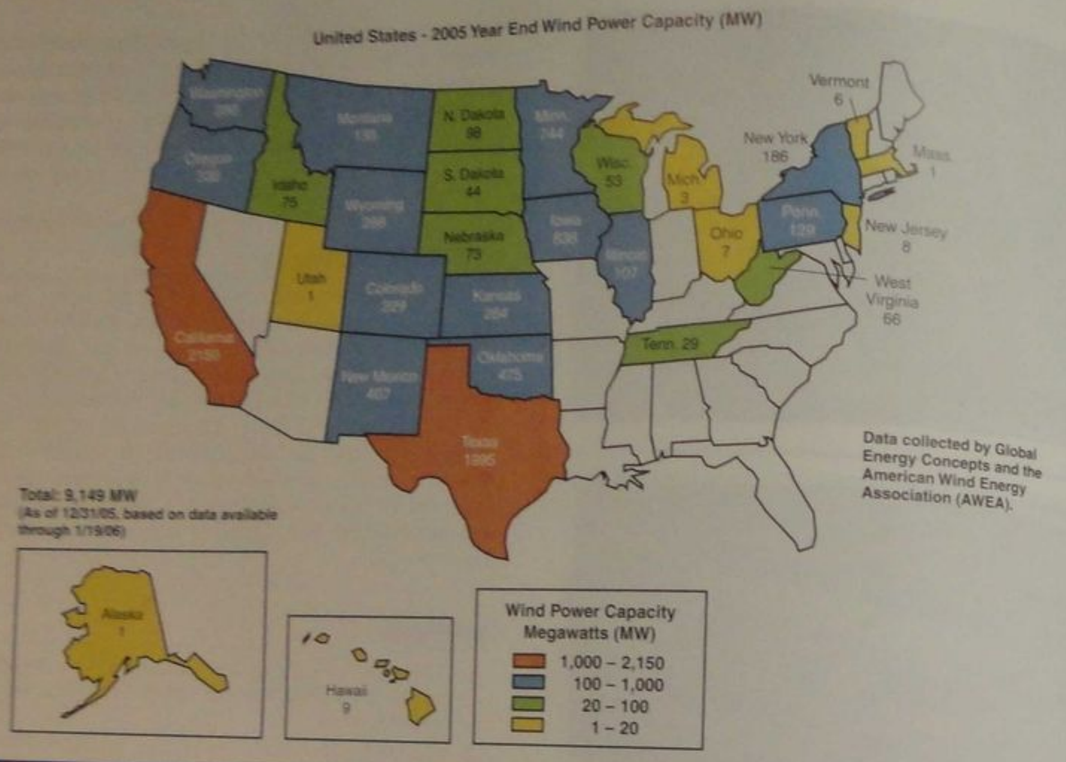


Figure 66–32 *Wind power capacity by area. (Courtesy of U.S. Department of Energy)*



Figure 66–33 *A typical wind generator that is used to generate electricity.*



Figure 66–34 The Hoover Dam in Nevada/Arizona is used to create electricity for use in the southwest United States.

2. What are the by-products (emissions) from a fuel cell?
   a. Water
   b. CO_2
   c. CO
   d. Nonmethane hydrocarbon
3. Which type of fuel cell is the most likely to be used to power vehicles?
   a. PAFC
   b. PEM
   c. MCFC
   d. SOFC
4. Which liquid fuel could be used to directly power a fuel cell?
   a. Methanol
   b. Ethanol
   c. Biodiesel
   d. Unleaded gasoline
5. Which is *not* a function of an ultracapacitor?
   a. Can pass AC current
   b. Can be charged with DC current
   c. Discharges DC current
   d. Can pass DC current

6. Hydrogen is commonly stored at what pressure?
   a. 100,000 PSI
   b. 50,000 PSI
   c. 5,000 PSI
   d. 1,000 PSI
7. Hydrogen storage tanks are usually constructed from _____.
   a. Steel
   b. Aluminum
   c. Carbon fiber
   d. Both b and c
8. HCCI is a process that eliminates what parts or components in a gasoline engine?
   a. Fuel tank
   b. Battery
   c. Fuel injectors
   d. Ignition system
9. A plug-in hybrid is different from a conventional hybrid electric vehicle because it has _____.
   a. A built-in battery charger
   b. Li Ox batteries
   c. More batteries
   d. Bigger motor/generator
10. Which energy source(s) is (are) currently being used to help reduce the use of fossil fuels?
    a. Hydrogen
    b. Wind power
    c. Hydroelectric power
    d. Both b and c

SECTION XI Brakes

67 Brake System Components and Performance Standards
68 Braking System Principles
69 Brake Hydraulic Systems
70 Hydraulic Valves and Switches
71 Brake Fluid and Lines
72 Brake Bleeding Methods and Procedures
73 Wheel Bearings and Service
74 Drum Brake Parts and Operation
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76 Disc Brake Parts and Operation
77 Disc Brake Diagnosis and Service
78 Parking Brake Operation, Diagnosis, and Service
79 Machining Brake Drums and Rotors
80 Power Brake Unit Operation, Diagnosis, and Service
81 ABS Components and Operation
82 ABS Diagnosis and Service



CHAPTER 67

Braking System Components and Performance Standards

OBJECTIVES: **After studying Chapter 67, the reader will be able to:** Prepare for ASE Brakes (A5) certification test. • List the parts and terms for disc and drum brakes. • Describe brake design requirements. • List the six brake system categories. • Discuss federal braking and stopping standards.

KEY TERMS: adjustable pedals • antilock braking system (ABS) • apply system • base brakes • boost system • brake balance control system • brake pedal • brake warning lights • Department of Transportation (DOT) • disc brakes • drum brakes • electric adjustable pedals (EAP) • Federal Motor Vehicle Safety Standards (FMVSS) • foundation brakes • gross vehicle weight rating (GVWR) • hydraulic system • lightly loaded vehicle weight (LLVW) • parking brake • red brake warning lamp • service brakes • snub • wheel brakes

Brakes are by far the most important mechanism on any vehicle because the safety and lives of those riding in the vehicle depend on proper operation of the braking system. It has been estimated that the brakes on the average vehicle are applied 50,000 times a year!

HOW BRAKES STOP VEHICLES

Brakes are an energy-absorbing mechanism that converts vehicle movement into heat while stopping the rotation of the wheels. All braking systems are designed to reduce the speed and stop a

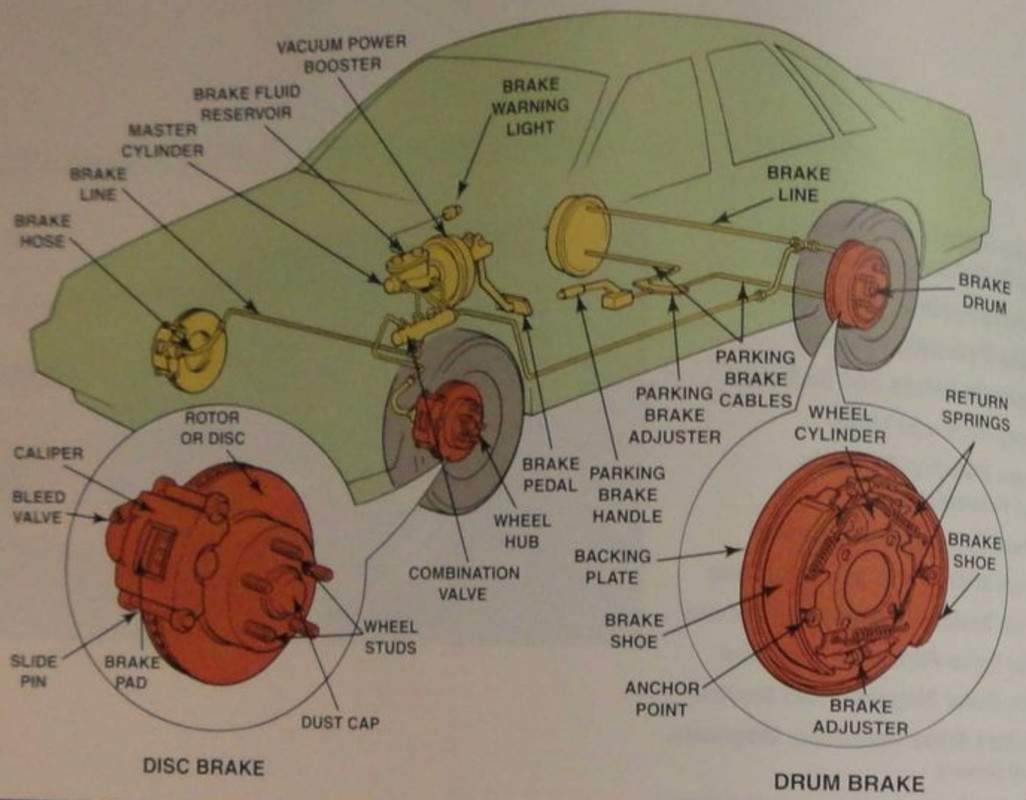


Figure 67–1 Typical vehicle brake system showing all typical components.

moving vehicle and to keep it from moving if the vehicle is stationary. **Service brakes** are the main driver-operated brakes of the vehicle. See Figure 67–1.

Service brakes are also called **base brakes** or **foundation brakes.**

Most vehicles built since the late 1920s use a brake on each wheel. To stop a wheel, the driver exerts a force on a brake pedal. The force on the brake pedal pressurizes brake fluid in a master cylinder. This hydraulic force (liquid under pressure) is transferred through steel lines and flexible brake lines to a wheel cylinder or caliper at each wheel. Hydraulic pressure to each wheel cylinder or caliper is used to force friction materials against the brake drum or rotor. The friction between the stationary friction material and the rotating drum or rotor (disc) causes the rotating part to slow and eventually stop. Since the wheels are attached to the drums or rotors, the wheels of the vehicles also stop.

The heavier the vehicle and the higher the speed, the more heat the brakes have to be able to absorb. Long, steep hills can cause the brakes to overheat, reducing the friction necessary to slow and stop a vehicle. See Figures 67–2 and 67–3.

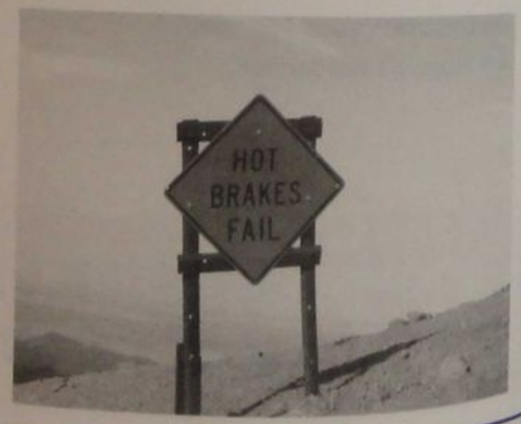


Figure 67–2 Brakes change the energy of the moving vehicle into heat. Too much heat and brakes fail, as indicated on this sign coming down from Pike's Peak in Colorado at 14,000 ft (4,300 m).

DRUM BRAKES

Drum brakes are used on the rear of many rear-wheel-drive, front-wheel-drive, and four-wheel-drive vehicles. When drum brakes are applied, brake shoes are moved outward against a rotating brake drum. The wheel studs for the wheels are attached to the drum. When the drum slows and stops, the wheels also slow and stop.

Drum brakes are economical to manufacture, service, and repair. Parts for drum brakes are generally readily available and reasonably priced. On some vehicles, an additional drum brake is used as a parking brake on vehicles equipped with rear disc brakes. See Figures 67–4 and 67–5.

DISC BRAKES

Disc brakes are used on the front of most vehicles built since the early 1970s and on the rear wheels of many vehicles. A disc brake operates by squeezing brake pads on both sides of a rotor or disc that is attached to the wheel. See Figure 67–6.



Figure 67–3 When driving down long, steep grades, select a lower transmission gear to allow the engine compression to help maintain vehicle speed.

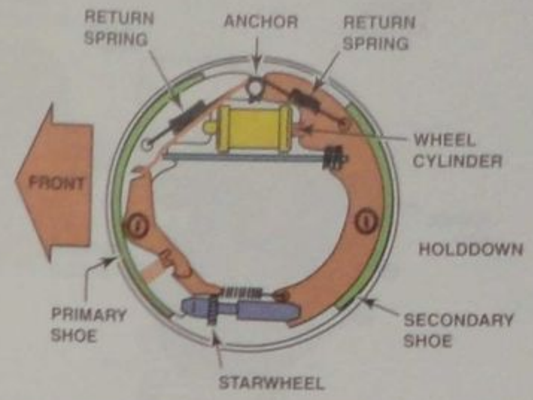


Figure 67–4 Typical drum brake assembly.

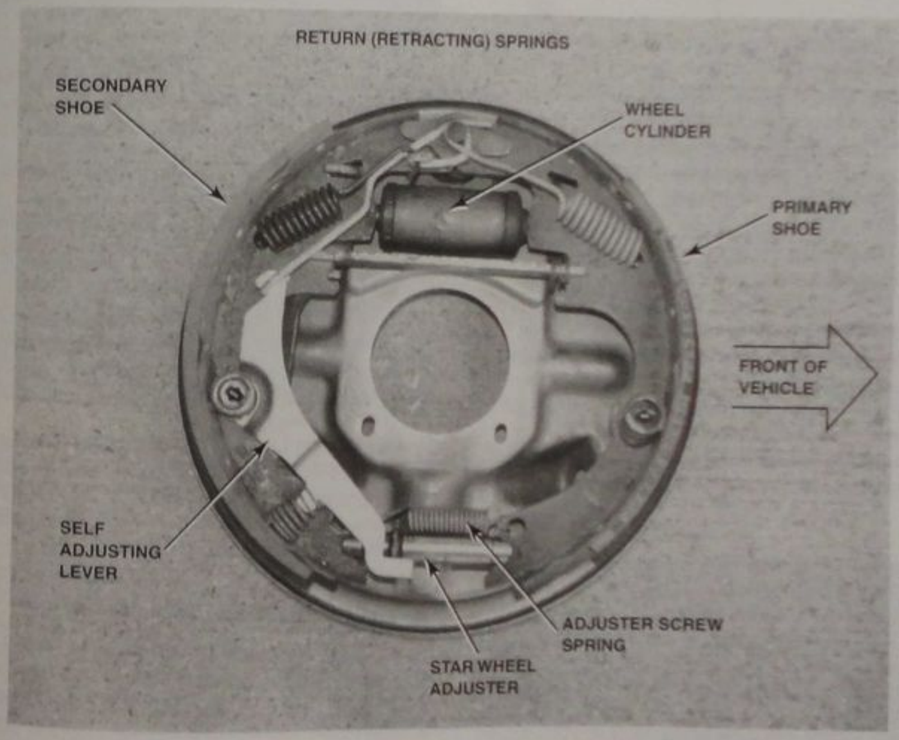


Figure 67–5 Drum brake assembly as used on the right rear wheel.

Type of Brake	Rotating Part	Friction Part
Drum brakes	Brake drum	Brake shoes
Disc brakes	Rotor or disc	Brake pads

Due to the friction between the road surface and the tires, the vehicle stops. To summarize, the events necessary to stop a vehicle include the following:

1. The driver presses on the brake pedal.
2. The brake pedal force is transferred hydraulically to a wheel cylinder or caliper at each wheel.
3. Hydraulic pressure inside the wheel cylinder or caliper presses friction materials (brake shoes or pads) against rotating brake drums or rotors.
4. The friction slows and stops the drum or rotor. Since the drum or rotor is bolted to the wheel of the vehicle, the wheel also stops.
5. When the wheels of the vehicle slow and stop, the tires must have friction (traction) with the road surface to stop the vehicle.

BRAKE DESIGN REQUIREMENTS

All braking forces must provide for the following:

1. Equal forces must be applied to both the left and right sides of the vehicle to assure straight stops.

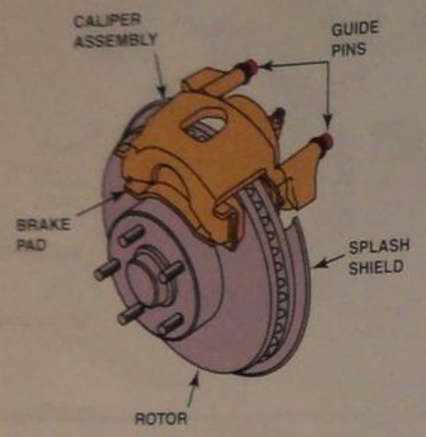


Figure 67–6 Typical disc brake assembly.

2. Hydraulic systems must be properly engineered and serviced to provide for changes as vehicle weight shifts forward during braking. Hydraulic valves must be incorporated into the hydraulic system to permit the maximum possible braking forces but still prevent undesirable wheel lockup. Antilock braking systems (ABS) are specifically designed to prevent wheel lockup under all driving conditions, including wet or icy road conditions.
3. The hydraulic system must use a fluid that will not evaporate or freeze. The fluid has to withstand extreme temperatures without boiling and must not damage rubber or metal parts of the braking system.
4. The friction material (braking lining or brake pads) must be designed to provide adequate friction between the stationary axles and the rotating drum or rotor. The friction material should be environmentally safe. Nonasbestos lining is generally considered to be safe for the environment and the technician.
5. The design of the braking system should secure the brake lining solidly to prevent the movement of the friction material during braking.

NOTE: It is this movement of the friction material that causes brake noise (squeal). Various movement dampers are used by the vehicle manufacturers to help control any movement that does occur. It is important that every technician restore the operation of all aspects of the braking system whenever they are serviced, even the noise dampers.

6. Most braking systems incorporate a power assist unit that reduces the driver's effort but does not reduce stopping distance. The most commonly used brake booster is vacuum operated. The vacuum from the intake manifold is the most commonly used source of vacuum for power brake boosters. Therefore, the engine itself must be functioning correctly for proper operation of the power vacuum booster.

BRAKE SYSTEM CATEGORIES

Brake system components can be classified and placed into six subsystem categories, depending on their function. See Figure 67–7.

Apply System. The driver starts the operation of the braking system by pressing on the **brake pedal** or applying the **parking brake.** The apply system includes all the levers, pedals, or linkage needed to activate a braking force.

Boost System. The boost system is used on most vehicles to increase the brake pedal force.

Hydraulic System. The brake pedal force is transferred to the hydraulic system, where the force is directed through pipes and hoses to the wheel brakes.

Wheel Brakes. Hydraulic pressure from the hydraulic system moves a piston, in either a disc or drum brake system, that uses friction to press material against a rotating drum or rotor. The resulting friction slows the rotation of the wheels.

Brake Balance Control System. Mechanical, electrical, and hydraulic components are used to ensure that brakes are applied quickly and with balanced pressure for safe operation. Components in this category include metering valves, proportioning valves, and antilock braking system components.

FREQUENTLY ASKED QUESTION ???

How Do Adjustable Pedals Work?

Adjustable pedals, also called **electric adjustable pedals (EAP),** place the brake pedal and the accelerator pedal on movable brackets that are motor operated. A typical adjustable pedal system includes the following components:

1. **Adjustable pedal position switch,** which allows the driver to position the pedals.
2. **Adjustable pedal assembly,** which includes the motor, threaded adjustment rods and a pedal position sensor. See Figure 67–8 on page 816.

The position of the pedals, as well as the position of the seat system, is usually included as part of the memory seat function and can be set for two or more drivers.

Brake Warning Lights. The **red brake warning lamp** lights whenever a hydraulic system failure occurs. The amber ABS warning lamp or dim red brake light indicates an ABS self-test and/or a possible problem in the ABS system. See Figures 67–9 and 67–10 on page 816.

ANTILOCK BRAKE SYSTEM OPERATION

The purpose of an **antilock braking system (ABS)** is to prevent the wheels from locking during braking, especially on low-friction surfaces such as wet, icy, or snowy roads. Remember, it is the friction between the tire tread and the road that does the actual stopping of the vehicle. Therefore, ABS does not mean that a vehicle can stop quickly on all road surfaces. ABS uses sensors at the wheels to measure the wheel speed. If a wheel is rotating slower than the others, indicating possible lockup (for example, on an icy spot), the ABS computer will control the brake fluid pressure to that wheel for a fraction of a second. *A locked wheel has less traction to the road surface than a rotating wheel.*

The ABS computer can reapply the pressure from the master cylinder to the wheel a fraction of a second later. Therefore, if a wheel starts to lockup, the purpose of the ABS system is to pulse the brakes on and off to maintain directional stability with maximum braking force. Many ABS units will cause the brake pedal to pulse if the unit is working in the ABS mode. The pulsating brake pedal is a cause for concern for some drivers. However, the pulsing brake pedal informs the driver that the ABS is being activated.

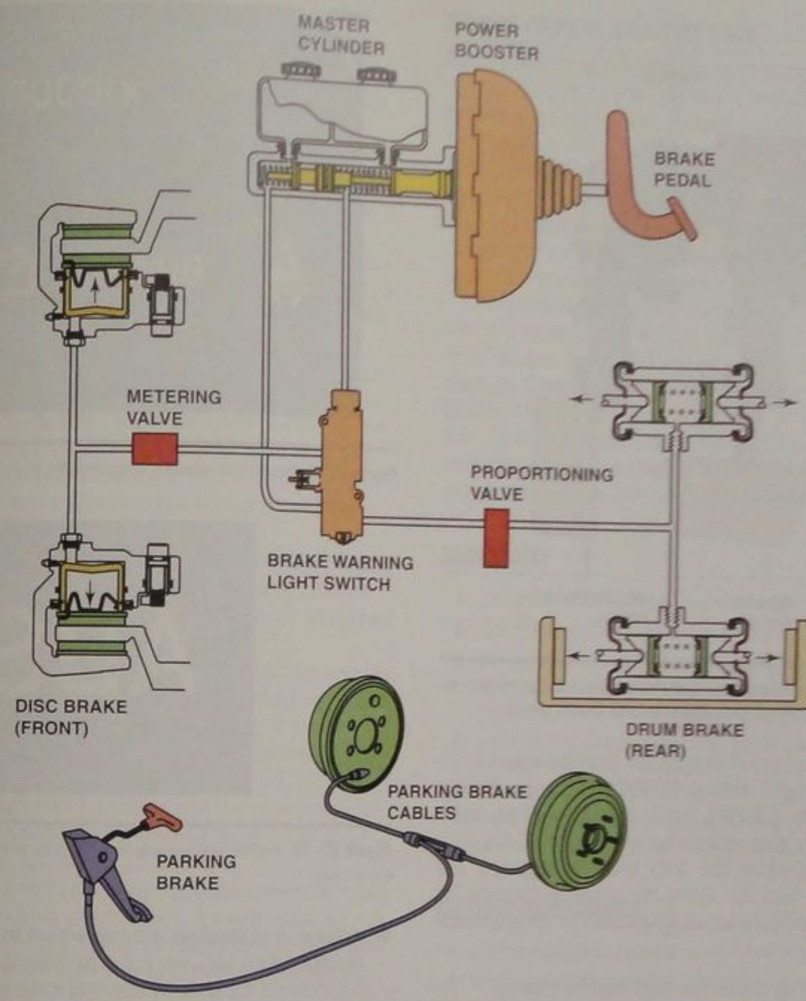


Figure 67–7 Typical brake system components.

Some ABS units use an isolator valve in the ABS unit to prevent brake pedal pulsations during ABS operation. With these types of systems, it is often difficult for the driver to know if and when the ABS unit is working to control a locking wheel. See Figure 67–11 for an overview of a typical ABS on a rear-wheel-drive vehicle.

Another symptom of normal ABS unit operation is the activation of the hydraulic pressure pump used by many ABS units. In some ABS units, the hydraulic pump is run every time the vehicle is started and moved. Other types of units operate randomly or whenever the pressure in the system calls for the pump to operate.

FEDERAL BRAKE STANDARDS

The statutes pertaining to automotive brake systems are part of the **Federal Motor Vehicle Safety Standards (FMVSS)** established by the United States **Department of Transportation (DOT).** Several standards apply to specific components within the brake system. The overall service and parking brake systems are dealt with in Standard 135.

FMVSS 135 was first mandated on September 1, 2000, for passenger vehicles, and September 1, 2002, for multipurpose vehicles, trucks, and buses with a gross vehicle weight rating (GVWR) of 7,716 pounds (3,500 kilograms). Its purpose is to "ensure safe braking performance under normal and emergency conditions." FMVSS 135 applies "to passenger vehicles, multipurpose passenger vehicles, trucks, and buses."

FMVSS 135 deals with brake system safety by establishing specific brake performance requirements. It does not dictate the *design* of the system, although some requirements may make older technologies impractical or obsolete. Only four parts of the brake system are specifically regulated:

- Fluid reservoir and labeling
- Dashboard warning lights
- A method of automatic adjustment
- A mechanically engaging, friction-type parking brake system

The majority of FMVSS 135 consists of a comprehensive test procedure designed to reveal any weakness in a vehicle's braking system. The test is used by manufacturers to certify the braking performance of all new vehicles available for public purchase.

FMVSS 135 Brake Test The overall FMVSS 135 brake test procedure consists of up to 24 steps, depending on the vehicle's configuration and braking system. The actual performance tests

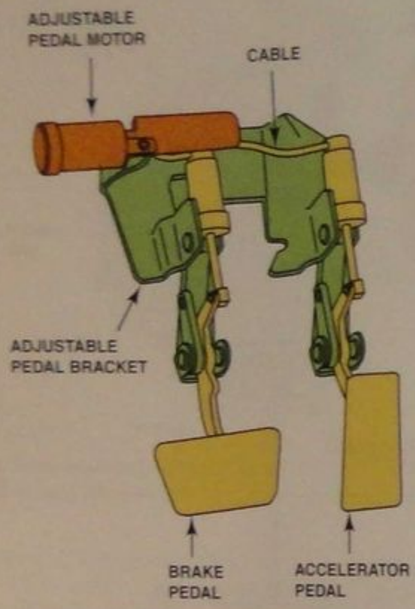


Figure 67–8 A typical adjustable pedal assembly. Both the accelerator and the brake pedal can be moved forward and rearward by using the adjustable pedal position switch.

are made with the vehicle loaded to both the manufacturer's specified **gross vehicle weight rating (GVWR)** and the **lightly loaded vehicle weight (LLVW)**, with certain applied brake forces. There are precise instructions for every step of the test, including the number of times the tests must be repeated, the sequence of the testing, and the allowable stopping distance for the particular type of vehicle. Some highlights of the testing procedure include:

- **Burnish procedure.** The brakes are burnished by making 200 stops from 50 mph (80 km/h) at a fixed rate of deceleration with a controlled cool-down period after each stop. This procedure conditions the friction material. Afterward, the brakes are adjusted manually according to the vehicle manufacturer's recommendations.

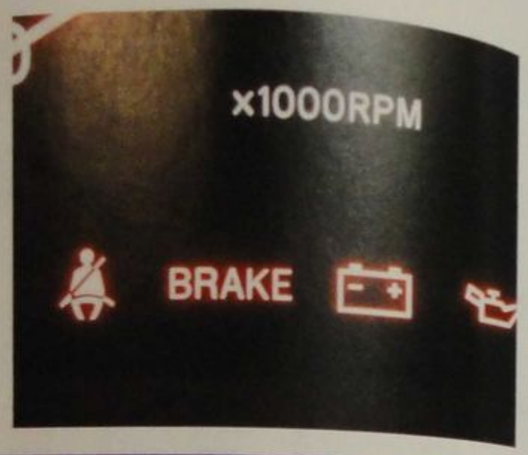


Figure 67–9 The red brake warning lamp alerts the driver to a possible brake system fault.



Figure 67–10 The ABS dash warning lamp alerts the driver to a possible antilock brake system fault.

- **Adhesion utilization (torque wheel method).** For vehicles not equipped with ABS, this test is performed at LLVW and GVWR to determine if the brake system will make adequate use of the road surface in stopping the vehicle.
- **Cold effectiveness.** This test is performed at both GVWR and LLVW, to determine if the vehicle will have sufficient stopping power when the brake lining materials are not preheated by previous stops.

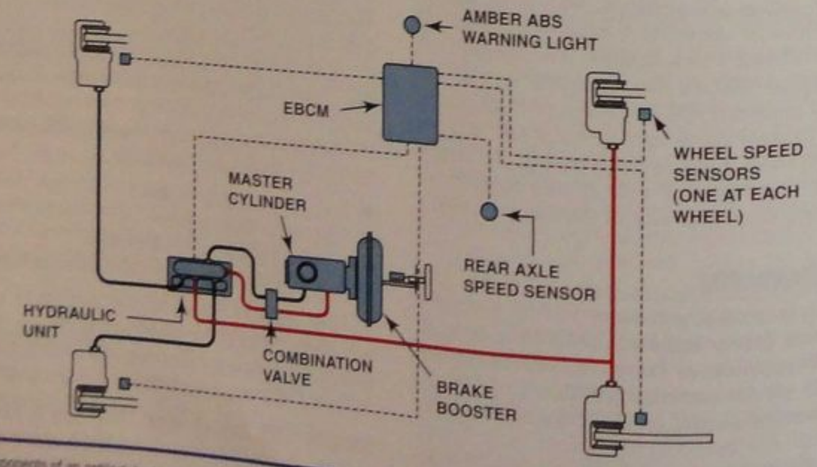


Figure 67–11 Typical components of an antilock braking system (ABS) used on a rear-wheel-drive vehicle.

- **High speed effectiveness.** This test is performed only on vehicles capable of exceeding 78 mph (125 km/h) to determine if the brake system will provide adequate stopping power for all loading conditions. The allowable stopping distance is calculated from the maximum speed the vehicle can attain.
- **Stops with the engine off.** This test is for vehicles equipped with brake power assist units. The vehicle, loaded to GVWR, must stop within 230 ft (70 m), from a speed of 62 mph (100 km/h). This test must be repeated six times.
- **Antilock functional failure.** This test ensures that service brakes will function correctly in the event of an antilock functional failure, and the brake system warning indicator is activated when an ABS electrical function failure occurs.
- **Variable brake proportioning system.** This test is performed on vehicles equipped with either a mechanical or an electrical variable proportioning system. It ensures that, in the event of a failure, the vehicle can still come to a stop in an acceptable distance. In addition, if the vehicle uses an electrically operated variable brake proportioning system, the brake warning system must immediately alert the driver of any electrical functional failure.
- **Hydraulic circuit failure.** This test is performed to ensure that the driver will be alerted via the brake warning system indicator that a failure has occurred, and that the vehicle can still be stopped in an acceptable distance.
- **Brake power assist unit inoperative.** This test makes sure the service brake can stop the vehicle in an acceptable distance with the brake power assist unit in an inoperative state. It is performed on vehicles with brake power assist units turned off or inoperative.
- **Parking brake.** The parking brake alone will hold the vehicle stationary in either the forward or reverse direction on a 20% grade for a period of at least 5 minutes.
- **Heating snubs.** This procedure heats the brake system by making a series of 15 stops from a high speed. A **snub** is a controlled brake application. The vehicle is loaded to GVWR, with rapid acceleration between each stop to minimize cooling the brakes.
- **Hot performance.** After the brake system has been heated by a series of heating snubs, the hot performance test is immediately performed. The vehicle is loaded to GVWR and two stops are made. The stopping distance must be within acceptable limits as specified in the test. This test ensures that the brake system on the vehicle will not fade following a series of high speed stops at GVWR.

Although these tests may seem extreme, remember that they are only a minimum standard of performance. Any brake repair work should also leave the brake system capable of meeting FMVSS 135.

FREQUENTLY ASKED QUESTION ???

Do the FMVSS 135 Standards Apply to Replacement Brake Part Performance?

No. The Federal Motor Vehicle Safety Standard 135 applies to new vehicles. Replacement parts used during a brake repair or replacement may or may not permit the vehicle to achieve the same standards as when new.

To help ensure like-new braking performance, the service technician should always use quality brake parts from a known manufacturer.

BRAKE REPAIR AND THE LAW

Once an automobile leaves the factory, the responsibility for maintaining the designed-in level of braking performance falls on the owner of the vehicle. Owners look to trained automotive technicians to service their brake systems. Many states have laws that regulate brake work to help ensure safe repairs. These laws vary from one area to another, but they may require special licensing for brake technicians, or special business practices when selling brake work. In some cases, the laws provide the consumer with specific warranties and the right to outside arbitration in cases of defective or substandard repairs.

Regardless of whether there are specific laws governing brake repair, a technician is always liable for damage or injuries resulting from repairs performed in an unprofessional or unworkmanlike manner. Considering the lives and property that depend on good brakes, there is only one acceptable goal when making brake system repairs: to restore the system and its component parts so they perform to original specifications. In other words, *the purpose of any repair is to restore like-new performance.*

SUMMARY

1. Drum brakes are used on the rear of most vehicles.
2. Disc brakes are used on the front of most vehicles.
3. The six brake subsystems include: apply system, boost system, hydraulic system, wheel brakes, **brake balance control system** (which includes ABS), and **brake warning lights**.
4. An antilock braking system (ABS) pulses the hydraulic force to the wheels to prevent the tires from locking up. A locked tire has lower friction than a rolling tire.
5. The federal brake standards covered in FMVSS 135 regulate specific brake performance requirements, but not the actual design of the braking system.

REVIEW QUESTIONS

1. List the differences between drum brakes and disc brakes.
2. List the six brake subsystem categories.
3. Explain how ABS units prevent wheel lockup.
4. List ten of the brake tests performed under the Federal Motor Vehicle Safety Standard (FMVSS) 135.

CHAPTER QUIZ

1. Disc brakes use replaceable friction material called _____.
   a. Linings
   b. Pads
   c. Core
   d. Web
2. Drum brakes use replaceable friction material called _____.
   a. Linings
   b. Pads
   c. Core
   d. Web
3. Technician A says that a power-assisted brake reduces stopping distances compared with a nonpower-assisted brake system. Technician B says that the power-assisted brake system reduces the force that the driver must exert on the brake pedal. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. A locked wheel _____ to the road surface than a rolling wheel.
   a. Has less traction
   b. Has greater traction

5. Technician A says that all vehicles equipped with ABS will experience a pulsating brake pedal even during normal braking. Technician B says that some ABS units only control the rear wheel brakes. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

6. The FMVSS 135 standards determine _____.
   a. The design of the braking system
   b. The performance of the braking system
   c. The materials used in the braking system
   d. All of the above

7. An owner of a vehicle equipped with ABS brakes complained that whenever he tried to stop on icy or slippery roads, the brake pedal would pulse up and down rapidly. Technician A says that this is normal for many ABS units. Technician B says that the ABS unit is malfunctioning. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. A brake snub is _____.
   a. An event that results in an ABS stop
   b. A brake event that causes the tires to slide on the pavement
   c. A controlled brake application
   d. A parking brake test procedure

9. All of the following are specified by FMVSS 135 *except:*
   a. Brake burnish procedure
   b. Variable brake proportioning system
   c. Brake noise levels
   d. Cold effectiveness

10. What is the purpose of any brake repair?
    a. Reduce noise during braking
    b. Replace pads and linings
    c. Restore proper brake pedal height
    d. Restore like-new performance

CHAPTER **68**

Braking System Principles

OBJECTIVES: After studying Chapter 68, the reader will be able to: Prepare for ASE Brakes (A5) certification test. • Explain kinetic energy and why it is so important to brake design. • Discuss mechanical advantage and how it relates to the braking system. • Explain the coefficient of friction. • Describe how brakes can fade due to excessive heat.

KEY TERMS: brake fade • coefficient of friction • energy • friction • fulcrum • gas fade • inertia • kinetic energy • kinetic friction • leverage • lining fade • mechanical advantage • mechanical fade • pedal ratio • static friction • weight bias • weight transfer • work

ENERGY PRINCIPLES

Energy is the ability to do work. There are many forms of energy, but chemical, mechanical, and electrical energy are the most familiar kinds involved in the operation of an automobile. See Figure 68–1.

For example, when the ignition key is turned to the "Start" position, chemical energy in the battery is converted into electrical energy to operate the starter motor. The starter motor then converts the electrical energy into mechanical energy that is used to crank the engine.

In the example above, energy is being used to perform work. **Work** is the transfer of energy from one physical system to another—especially the transfer of energy to an object through the application of force. This is precisely what occurs when a vehicle's brakes are applied: The *force* of the actuating system *transfers* the energy of the vehicle's motion to the brake drums or rotors where friction converts it into heat energy and stops the vehicle.

KINETIC ENERGY

Kinetic energy is a fundamental form of mechanical energy. It is the energy of mass in motion. Every moving object possesses kinetic energy, and the amount of that energy is determined by the object's mass and speed. The greater the mass of an object and the faster it moves, the more kinetic energy it possesses. Even at low speeds, a moving vehicle has enough kinetic energy to cause serious injury and damage. The job of the brake system is to dispose of that energy in a safe and controlled manner.

Engineers calculate kinetic energy using the following formula:

$$\frac{mv^2}{29.9} = E_k$$

where:

m = mass or weight of the vehicle in pounds (lb)
v = velocity of the vehicle in miles per hour
E_k = kinetic energy in foot-pounds (ft-lb)

Another way to express this equation is as follows.

$$\frac{\text{weight} \times \text{speed}^2}{29.9} = \text{kinetic energy}$$

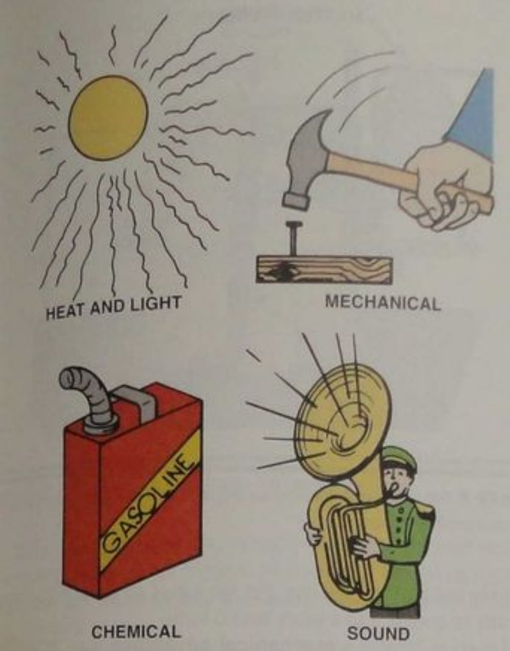


Figure 68–1 Energy, which is the ability to perform work, exists in many forms.

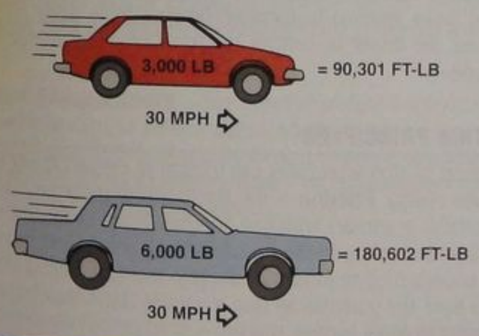


Figure 68–2 Kinetic energy increases in direct proportion to the weight of the vehicle.

If a 3,000-lb vehicle traveling at 30 mph is compared with a 6,000-lb vehicle also traveling at 30 mph as shown in Figure 68–2, the equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{6{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 18{,}602 \text{ ft-lb}$$

The results show that when the weight of a vehicle is doubled from 3,000 to 6,000 lb, its kinetic energy is also doubled from 90,301 ft-lb to 180,602 ft-lb. In mathematical terms, kinetic energy increases *proportionally* as weight increases. In other words, if the weight of a moving object doubles, its kinetic energy also doubles. If the weight quadruples, the kinetic energy becomes four times as great.

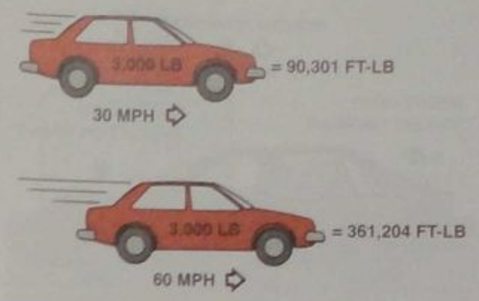


Figure 68–3 Kinetic energy increases as the square of any increase in vehicle speed.

If a 3,000-lb vehicle traveling at 30 mph is compared with the same vehicle traveling at 60 mph (Figure 68–3), the equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{3{,}000 \text{ lb} \times 60^2 \text{ mph}}{29.9} = 361{,}204 \text{ ft-lb}$$

The results show that the vehicle traveling at 30 mph has over 90,000 ft-lb of kinetic energy, but at 60 mph the figure increases to over 350,000 ft-lb. In fact, at twice the speed, the vehicle has exactly four times as much kinetic energy. If the speed were doubled again to 120 mph, the amount of kinetic energy would grow to almost 1,500,000 ft-lb! In mathematical terms, kinetic energy increases as the *square of its speed.* In other words, if the speed of a moving object doubles (2), the kinetic energy becomes four times as great ($2^2 = 4$). And if the speed quadruples (4), say from 15 to 60 mph, the kinetic energy becomes 16 times as great ($4^2 = 16$). This is the reason speed has such an impact on kinetic energy.

Kinetic Energy and Brake Design The relationships between weight, speed, and kinetic energy have significant practical consequences for the brake system engineer. If vehicle A weighs twice as much as vehicle B, it needs a brake system that is twice as powerful. But if vehicle C has twice the speed potential of vehicle D, it needs brakes that are, not twice, but four times more powerful.

INERTIA

Although brake engineers take both weight and speed capability into account when designing a brake system, these are not the only factors involved. Another physical property, inertia, also affects the braking process and the selection of brake components. **Inertia** is defined by Isaac Newton's first law of motion, which states that a body at rest tends to remain at rest, and a body in motion tends to remain in motion in a straight line unless acted upon by an outside force.

Weight Transfer and Bias Inertia, in the form of **weight transfer,** plays a major part in a vehicle's braking performance. Newton's first law of motion dictates that a moving vehicle will remain in motion unless acted upon by an outside force. The vehicle brakes provide that outside force, but when the brakes are applied at the wheel friction assemblies, only the wheels and tires begin to slow immediately. The rest of the vehicle, all of the weight carried by the suspension, attempts to remain in forward motion. The

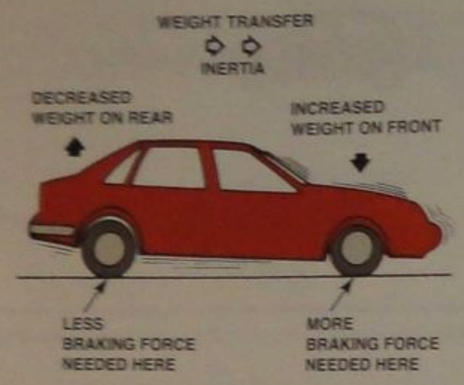


Figure 68–4 Inertia creates weight transfer that requires the front brakes to provide most of the braking power.

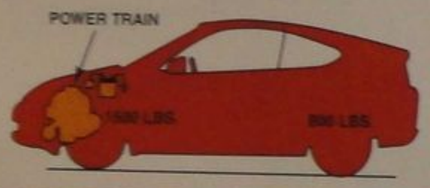


Figure 68–5 Front-wheel-drive vehicles have much of their weight over the front wheels.

result is that the front suspension compresses, the rear suspension extends, and the weight is transferred toward the front of the vehicle. See Figure 68–4.

The total weight of the vehicle does not change, only the amount supported by each axle.

To compound the problem of weigh transfer, most vehicles also have a forward **weight bias,** which means that even when stopped, more than 50% of their weight is supported by the front wheels. Front-wheel-drive (FWD) vehicles, in particular, have a forward weight bias. This occurs because the engine, transmission, and most other heavy parts are located toward the front of the vehicle. See Figure 68–5.

Whenever the brakes are applied, weight transfer and weight bias greatly increase the load on the front wheels, while the load on the rear wheels is substantially reduced. This requires the front brakes to provide 60% to 80% of the total braking force. To deal with the extra load, the front brakes are much more powerful than the rear brakes. They are able to convert more kinetic energy into heat energy.

TECH TIP ✓ **Brakes Cannot Overcome the Laws of Physics**

Vehicles cannot stop on a dime. The energy required to slow or stop a vehicle must be absorbed by the braking system. All drivers should be aware of this fact and drive at a reasonable speed for the road and traffic conditions.

MECHANICAL PRINCIPLES

The primary mechanical principle used to increase application force in every brake system is **leverage.** In the science of mechanics, a lever is a simple machine that consists of a rigid object, typically a metal bar that pivots about a fixed point called a **fulcrum.** There

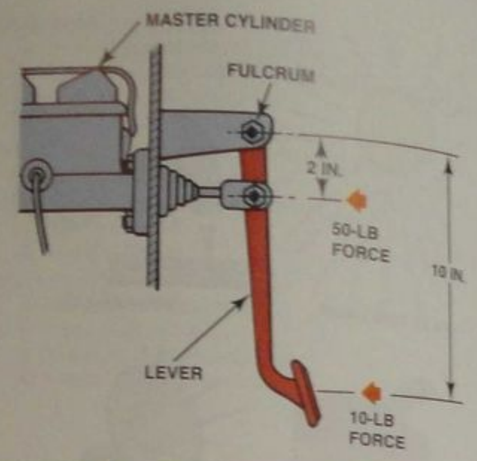


Figure 68–6 This brake pedal assembly is a second-class lever design that provides a 5 to 1 mechanical advantage.

are three basic types of levers, but the job of all three is to change a quantity of energy into a more useful form.

Leverage creates a **mechanical advantage** that, at the brake pedal, is called the **pedal ratio.** For example, a pedal ratio of 5 to 1 is common for manual brakes, which means that a force of 10 lb at the brake pedal will result in a force of 50 lb at the pedal pushrod. In practice, leverage is used at many points in both the service and parking brake systems to increase braking force while making it easier for the driver to control the amount of force applied. See Figure 68–6.

FRICTION PRINCIPLES

The wheel friction assemblies use friction to convert kinetic energy into heat energy. **Friction** is the resistance to movement between two surfaces in contact with one another. Brake performance is improved by increasing friction (at least to a point), and brakes that apply enough friction to use all the grip the tires have to offer will always have the potential to stop a vehicle faster than brakes with less ability to apply friction.

Coefficient of Friction The amount of friction between two objects or surfaces is commonly expressed as a value called the **coefficient of friction** and is represented by the Greek letter mu (μ). The coefficient of friction, also referred to as the friction coefficient, is determined by dividing tensile force by weight force. The tensile force is the pulling force required to slide one of the surfaces across the other. The weight force is the force pushing down on the object being pulled. The equation for calculating the coefficient of friction is as follows.

$$\frac{F_t}{G} = \mu$$

where:

F_t = tensile force in pounds
G = weight force in pounds
μ = coefficient of friction

Another way to express the equation is as follows.

$$\frac{\text{Tensile force}}{\text{Weight force}} = \text{Coefficient of friction}$$

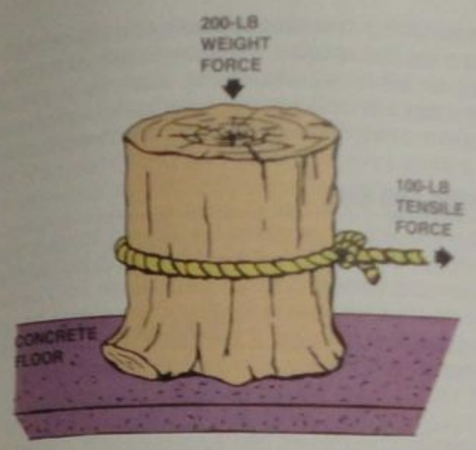


Figure 68–7 The coefficient of friction (μ) in this example is 0.5.

This equation can be used to show the effect different variables have on the coefficient of friction. At any given weight (application) force there are three factors that affect the friction coefficient of vehicle brakes:

- Surface finish
- Friction material
- Heat

For reasons that will be explained later, the friction coefficient of the wheel friction assemblies of vehicle brake systems is always less than one.

Surface Finish Effects The effect of surface finish on the friction coefficient can be seen in Figure 68–7.

In this case, 100 lb of tensile force is required to pull a 200-lb block of wood across a concrete floor. The equation for computing the coefficient of friction is as follows:

$$\frac{100 \text{ lb}}{200 \text{ lb}} = 0.5$$

The friction coefficient in this instance is 0.5. Now take the same example, except assume that the block of wood has been sanded smooth, which improves its surface finish and reduces the force required to move it to only 50 lb. In this case the equation reads as follows:

$$\frac{50 \text{ lb}}{200 \text{ lb}} = 0.25$$

The friction coefficient drops by half, and it would decrease even further if the surface finish of the floor were changed from rough concrete to smooth marble.

It is obvious that the *surface finish* of two connecting surfaces has a major effect on their coefficient of friction.

Friction Material Effects Taking the example above one step further, consider the effect if a 200-lb block of ice, a totally different type of material, is substituted for the wood block. In this case, it requires only a 10-lb force to pull the block across the concrete. See Figure 68–8.

The equation reads as follows:

$$\frac{10 \text{ lb}}{200 \text{ lb}} = 0.05$$

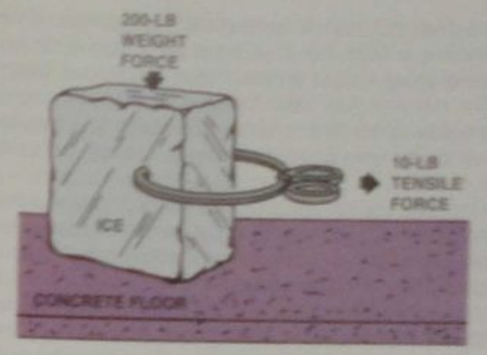


Figure 68–8 The types of friction materials affect the friction coefficient, which is only 0.05 in this example.

The coefficient of friction in this example decreases dramatically to only 0.05, and once again, even further reductions would be seen if the floor surface were changed to polished marble or some other similar smooth surface.

It is obvious that the type of materials being rubbed together have a very significant effect on the coefficient of friction. The choice of materials for brake drums and rotors is limited. Iron and steel are used most often because they are relatively inexpensive and can stand up under the extreme friction brake drums and rotors must endure.

The brake lining material, however, can be replaced relatively quickly and inexpensively, and therefore does not need to have as long a service life. Brake shoe and pad friction materials play a major part in determining coefficient of friction. There are several fundamentally different materials to choose from, and each has its own unique friction coefficient and performance characteristics.

Friction Contact Area For sliding surfaces, such as those in wheel friction assemblies, the amount of contact area has no effect on the amount of friction generated. This fact is related to the earlier statement that brake friction materials always have a friction coefficient of less than 1.0. To have a friction coefficient of 1.0 or more, material must be *transferred* between the two friction surfaces. The amount of contact area does not affect the coefficient of friction, but it does have significant effects on lining life and the dissipation of heat that can lead to brake fade.

Tires are an example where contact area makes a difference. All other things being equal, a wide tire with a large contact area on the road has a higher coefficient of friction than a narrow tire with less contact area. This occurs because the tire and road do not have a sliding relationship. A tire conforms to and engages the road surface, and during a hard stop, a portion of the braking force comes from shearing or tearing away the tire tread rubber. The rubber's tensile strength, its internal resistance to being pulled apart, adds to the braking efforts of friction. A racing tire making a hard stop on dry pavement, for example, has a friction coefficient of 1.0 or better. The transfer of material between the two surfaces can be seen as skid marks on the pavement.

Static and Kinetic Friction There are actually two measurements of the coefficient of friction, the **static friction** coefficient and the **kinetic friction** coefficient. The static value is the coefficient of friction with the two friction surfaces at rest. The kinetic value is the coefficient of friction while the two surfaces are sliding against one another.

The coefficient of static friction is always higher than that of kinetic friction, which explains why it is harder to start an object

moving than to *keep* it moving. In the example shown in Figure 68–9, it takes 100 lb of tensile force to start the wooden block sliding, but once in motion, it takes only 50 lb to keep it sliding. The relatively high static friction is harder to overcome than the somewhat lower kinetic friction. The static and kinetic friction coefficients for several combinations of materials are shown in Figure 68–10.

The difference between static and kinetic friction explains why parking brakes, although much less powerful than service brakes, are still able to hold a vehicle in position on a hill. The job of the parking brakes is relatively easy because the stationary vehicle has no kinetic energy, and the brake lining and drum or disc are not moving when they are applied. To start the vehicle moving, enough force would have to be applied to overcome the relatively high static friction of the parking brakes. The service brakes, however, have a much more difficult job. The moving vehicle has a great deal of kinetic energy, and the fact that the brake friction surfaces are in relative motion means that kinetic friction makes them less efficient.

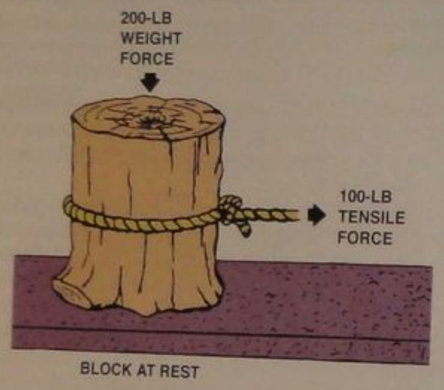


Figure 68–9 The static friction coefficient of an object at rest is higher than its kinetic friction coefficient once in motion.

CONTACTING SURFACES	COEFFICIENT OF FRICTION	
	STATIC	KINETIC
STEEL ON STEEL (DRY)	0.6	0.4
STEEL ON STEEL (GREASY)	0.1	0.05
TEFLON ON STEEL	0.04	0.04
BRASS ON STEEL (DRY)	0.5	0.4
BRAKE LINING ON CAST IRON	0.4	0.3
RUBBER TIRES ON SMOOTH PAVEMENT (DRY)	0.9	0.8
METAL ON ICE	—	0.02

Figure 68–10 Every combination of materials has different static and kinetic friction coefficients.

FRICTION AND HEAT

The function of the brake system is to convert kinetic energy into heat energy through friction. But just how much heat is created by this conversion process? Although there are too many variables to obtain the exact temperature increase of any specific component, the *average* temperature rise of the brakes during a single stop can be computed as follows:

$$\frac{K_c}{77.8\ W_b} = T_r$$

where:

K_c = kinetic energy change in ft-lb
W_b = weight of all the rotors and drums in pounds
T_r = temperature rise in Fahrenheit degrees

Another way to express this equation is as follows:

$$\frac{\text{Energy change}}{77.8 \times \text{drum/rotor weight}} = \text{Temperature rise}$$

To see how this works, consider a 3,000-lb vehicle with a combined brake drum and rotor weight of 20 lb that is brought to a complete stop from 30 mph. See Figure 68–11.

In the first section of this chapter we calculated that this vehicle has 90,301 ft-lb of kinetic energy, and since the vehicle is coming to a full stop, the change in kinetic energy during the stop will equal the entire 90,301 ft-lb. Based on this information, the equation for computing the rise in brake temperature reads as follows:

$$\frac{90{,}301 \text{ ft-lb}}{77.8 \times 20 \text{ lb}} = 58°F\ (32°C)$$

The total brake temperature increase in this case is 58°F (32°C). This increase is relatively small, but the weight and speed of the vehicle are also rather low. It is the *change* in kinetic energy that determines the amount of temperature increase, and kinetic energy increases proportionately with increases in weight, and as the square of any increase in speed. If the weight of the vehicle is doubled to 6,000 lb, the change in kinetic energy required to bring it to a full stop will be 180,602 ft-lb.

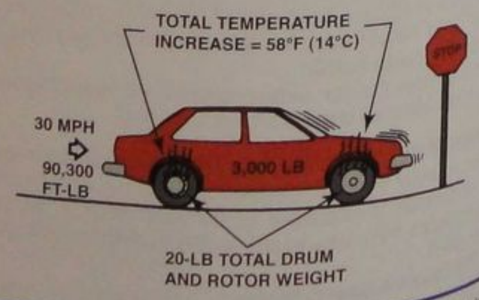


Figure 68–11 Brake temperature increase is determined mostly by vehicle weight, drum and rotor weight, and the change in kinetic energy.

The temperature increase computed with this equation is the average of all the friction generating components. Some of the heat is absorbed by the brake drums and rotors, some goes into the shoes and pads, and some is conducted into the wheel cylinders, calipers, and brake fluid. In addition, the front brakes provide 60% to 80% of the total braking force and they receive a similar percentage of the average temperature increase. The increase at each axle is divided evenly between the two wheel friction assemblies unless there is unequal traction from one side to the other, or there is a problem within the brake system itself.

HEAT-CAUSED BRAKE FADE

The temperature of a brake drum or rotor may rise more than 100°F (55°C) in only seconds during a hard stop, but it could take 30 seconds or more for the rotor to cool to the temperature that existed before the stop. If repeated hard stops are performed, the brake system components can overheat and lose effectiveness, or possibly fail altogether. This loss of braking power is called **brake fade.**

The point at which brakes overheat and fade is determined by a number of factors including the brake design, its cooling ability, and the type of friction material being used. There are three primary types of brake fade caused by heat:

- Mechanical fade
- Lining fade
- Gas fade

Mechanical fade occurs when a brake drum overheats and expands away from the brake lining. See Figure 68–12.

To maintain braking power, the brake shoes must move farther outward, which requires additional brake pedal travel. When the drum expands to a point where there is not enough pedal travel to keep the lining in contact with the drum, brake fade occurs. Sometimes, partial braking power can be restored by rapidly pumping the brake pedal to move the brake shoes farther outward and back into contact with the drums. Mechanical fade in drum brakes is reduced by using larger or heavier drums that can absorb more heat before they expand too far. Cooling fins are also added to the drums or make them partially of aluminum to help speed heat transfer to the passing air. Mechanical fade is not a problem with disc brakes because as a brake rotor heats up it expands *toward* the brake pads rather than away from them.

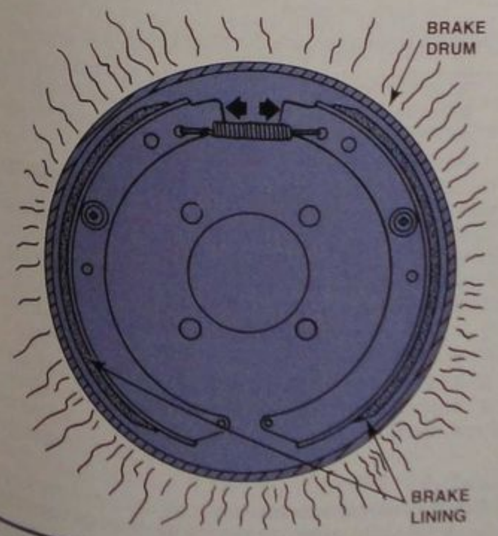


Figure 68–12 Mechanical fade occurs when the brake drums become so hot they expand away from the brake lining.

Lining fade affects both drum and disc brakes, and occurs when the friction material overheats to the point where its coefficient of friction drops off. See Figure 68–13.

When lining fade occurs on drum brakes, partial braking power can sometimes be restored by increasing pressure on the brake pedal, although this may only make matters worse since the extra pressure increases the amount of heat and fade. With disc brakes, lining fade is possible, but less of a problem because of disc brakes' superior ability to dissipate heat. The rotor friction surfaces are exposed to the passing air, and most rotors have internal ventilation passages that further aid in cooling.

Gas fade is a relatively rare type of brake fade that occurs under very hard braking when a thin layer of hot gases and dust particles builds up between the brake drum or rotor and linings. The gas layer acts as a lubricant and reduces friction. See Figure 68–14.

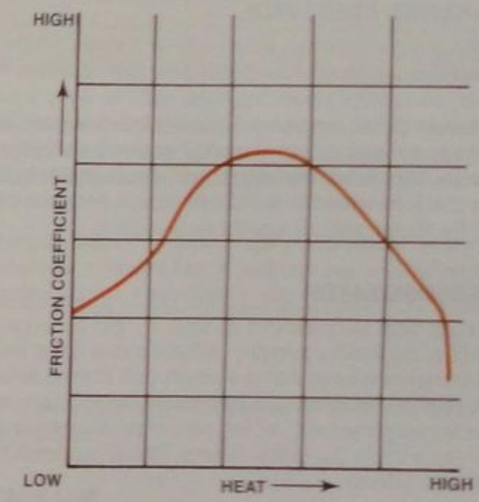


Figure 68–13 Some heat increases the coefficient of friction, but too much heat can cause it to drop off sharply.

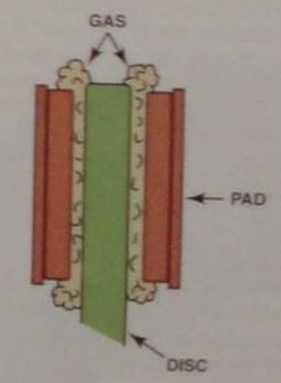


Figure 68–14 One cause of brake fade occurs when the phenolic resin, a part of the friction material, gets so hot that it vaporizes. The vaporized gas from the disc brake pads gets between the rotor (disc) and the friction pad. Because the friction pad is no longer in contact with the rotor, no additional braking force is possible.

As with lining fade, greater application force at the brake pedal is required to maintain a constant level of stopping power. Gas fade becomes more of a problem as the size of the brake lining increases because gases and particles have a harder time escaping from under a drum brake shoe than a disc brake pad. Some high-performance brake shoes and pads have slotted linings to provide paths for gas and particles to escape.

In most cases brake fade is a temporary condition. The brakes will return to normal once they have all been allowed to cool. This is true in all except extreme situations where the heat has been so great it has damaged the friction material or melted rubber seals within the hydraulic system.

NOTE: The possibility of brake fade caused by heat can be reduced if the transmission gear selector is placed in a lower gear when descending a steep or long hill to reduce the amount of braking needed to maintain a safe road speed. Engine braking will help keep the vehicle speed under control.

WATER-CAUSED BRAKE FADE

If a vehicle is driven through deep water or during a severe rainstorm, water can get between the brake drum and the linings. When this occurs, no stopping power is possible until the water is pushed out and normal friction is restored. While water fade is most likely to occur with drum brakes, it can also occur on disc brakes. After driving through deep water, the wise driver should lightly apply the brakes to check the operation and to help remove any water trapped between the friction material and the rotor or drum.

DECELERATION RATES

Deceleration rates are measured in units of "feet per second per second" (No, this is not a misprint). What it means is that the vehicle will change in velocity during a certain time interval divided by the time interval. Deceleration is abbreviated "ft/sec^2" (pronounced "feet per second per second" or "feet per second squared") or meters per sec^2 (m/sec^2) in the metric system. Typical deceleration rates include the following:

- Comfortable deceleration is about 8.5 ft/sec^2 (3 m/sec^2).
- Loose items in the vehicle will "fly" above 11 ft/sec^2 (3.5 m/sec^2).
- Maximum deceleration rates for most vehicles and light trucks range from 16 to 32 ft/sec^2 (5 to 10 m/sec^2).

An average deceleration rate of 15 ft/sec^2 (3 m/sec^2) can stop a vehicle traveling at 55 mph (88 km/h) in about 200 ft (61 m) in less than 4 seconds. During a standard brake system test, a vehicle is braked at this rate 15 times. Temperatures at the front brake pads can reach 1300°F (700°C) or higher, sometimes reaching as high as 1800°F (980°C). Brake fluid and rubber components may reach 300°F (150°C) or higher.

SUMMARY

1. Energy is the ability to do work. A vehicle in motion represents kinetic energy, which must be absorbed by the braking system during a stop.
2. The front brakes must provide a higher percentage of the braking force due to weight bias and weight transfer.
3. The brake pedal uses mechanical advantage to increase the force applied by the driver to the master cylinder.
4. Coefficient of friction represents the amount of friction between two surfaces.
5. Friction creates heat during a stop and the braking system must be able to absorb this heat.
6. Brake fade results when the heat generated by the brakes causes changes in the friction materials that reduce the braking force or by water that can get between the brake drum and the linings.
7. Deceleration rates are expressed in feet per second per second or ft/sec^2 or m/sec^2.

REVIEW QUESTIONS

1. What is kinetic energy?
2. How is mechanical advantage used in the braking system?
3. What is the coefficient of friction?
4. Why do brakes fade due to excessive heat or water?

CHAPTER QUIZ

1. All of the following are correct statements about braking *except*:
   a. Kinetic energy must be absorbed by the braking system.
   b. Kinetic energy of a vehicle doubles when the speed doubles.
   c. The heavier the vehicle, the greater the kinetic energy when moving.
   d. If the vehicle weight is doubled, the kinetic energy of a moving vehicle is doubled.
2. Technician A says that the front brakes do most of the braking because the front brakes are larger. Technician B says that due to weight transfer, most of the braking force needs to be done by the front brakes. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. The brake pedal assembly uses a mechanical lever to _____.
   a. Increase the driver's force on the brake pedal applied to the master cylinder
   b. Increase the distance the brake pedal needs to be depressed by the driver
   c. Decrease the driver's force on the brake pedal applied to the master cylinder
   d. Allow for clearance between the brake pedal and the floor when the brakes are applied
4. The friction between two surfaces is affected by all *except* _____.
   a. Speed difference between the two surfaces
   b. Surface finish
   c. Frictional material
   d. Heat
5. Technician A says that the thicker or heavier the disc brake rotor, the more heat can be absorbed. Technician B says that the faster the vehicle is traveling when the brakes are applied, the greater the amount of heat created in the brake system. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. All of the following are types of brake fade *except* _____.
   a. Mechanical fade
   b. Lining fade
   c. Gas fade
   d. Rotor fade
7. Brake fade caused by water can occur _____.
   a. Only if the vehicle is driven in water above the centerline of the axle
   b. Whenever it rains and the roads are wet or damp
   c. Due to moisture in the air on a humid day
   d. Whenever driving through water puddles or during a severe rainstorm
8. What can the driver do to reduce the possibility of brake fade caused by heat?
   a. Ride the brakes to keep the shoes and pads against the drum or rotor
   b. Pump the brake pedal while descending a steep hill
   c. Select a lower transmission gear
   d. Shift the transmission into neutral and allow the vehicle to coast down long or steep hills
9. Maximum deceleration rates for a typical passenger car or light truck is _____.
   a. 1 to 3 ft/sec
   b. 5 to 10 ft/sec
   c. 16 to 32 ft/sec^2
   d. 200 to 250 ft/sec^2
10. Disc brake pads can reach temperatures as high as _____.
    a. 300°F (150°C)
    b. 1000°F (540°C)
    c. 1300°F (700°C)
    d. 1800°F (980°C)

CHAPTER 69

Brake Hydraulic Systems

OBJECTIVES: After studying Chapter 69, the reader will be able to: Prepare for ASE Brakes (A5) certification test content area "A" (Hydraulic System Diagnosis and Repair). • State Pascal's Law. • Describe the function, purpose, and operation of the master cylinder. • Explain how hydraulic force can be used to supply high pressures to each individual wheel brake. • Describe the process of troubleshooting master cylinders and related brake hydraulic components. • Explain how a quick take-up master cylinder works.

KEY TERMS: bore master cylinder • breather port • bypass port • bypassing • compensating port • diagonal split master cylinder • dual split master cylinder • fast-fill master cylinder • filler port • hydraulic system • master cylinder • Pascal's Law • pedal free play • pedal height • pedal reserve distance • piston assemblies • quick take-up master cylinder • replenishing port • self-apply • step-bore master cylinder • vent port

HYDRAULIC PRINCIPLES

In addition to the mechanical advantage provided by leverage, all vehicles use hydraulic pressure to help increase brake application force.

All braking systems require that a driver's force is transmitted to the drum or rotor attached to each wheel. See Figure 69–1.

The force that can be exerted on the brake pedal varies due to the strength and size of the driver. Engineers design braking systems to require less than 150 lb of force (68 kg) from the driver, yet provide the force necessary to stop a heavy vehicle from high speed.

NONCOMPRESSIBILITY OF LIQUIDS

Hydraulic systems use liquids to transmit motion. For all practical purposes, a liquid cannot be compressed. No matter how much pressure or force is placed on a quantity of liquid, its volume will remain the same. This fact enables liquids in a closed system to transmit motion. See Figure 69–2.

If piston A is moved a distance of 1 in., the liquid will be displaced ahead of it and piston B will move 1 in. as well.

Liquids cannot be compressed, but any air trapped in the system can be compressed. The simple hydraulic system has been contaminated with air. See Figure 69–3.

Even though piston A is moved a distance of 1 in., piston B will not move if the load on it is greater than the pressure of the air in the system. For example, if the load on piston B is 50 pounds per square inch (PSI), the movement of piston A must compress the air in the system to that same pressure before piston B will begin to move. A brake hydraulic system must be air free or there will be serious problems.

PASCAL'S LAW

The hydraulic principles that permit a brake system to function were discovered by a French physicist, Blaise Pascal (1632–1662). **Pascal's Law** states that "when force is applied to a liquid confined in a container or an enclosure, the pressure is transmitted equal and

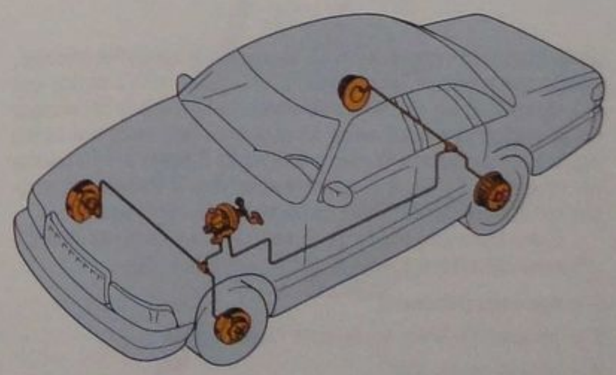


Figure 69–1 Hydraulic brake lines transfer the brake effort to each brake assembly attached to all four wheels.

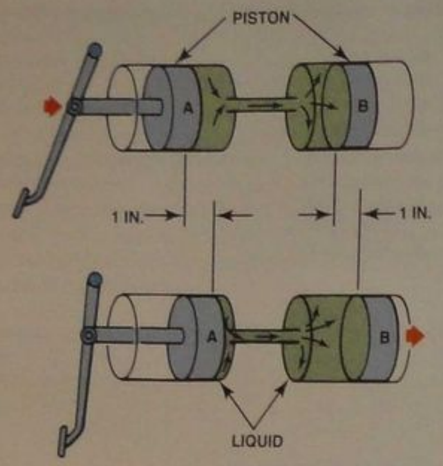


Figure 69–2 Because liquids cannot be compressed, they are able to transmit motion in a closed system.

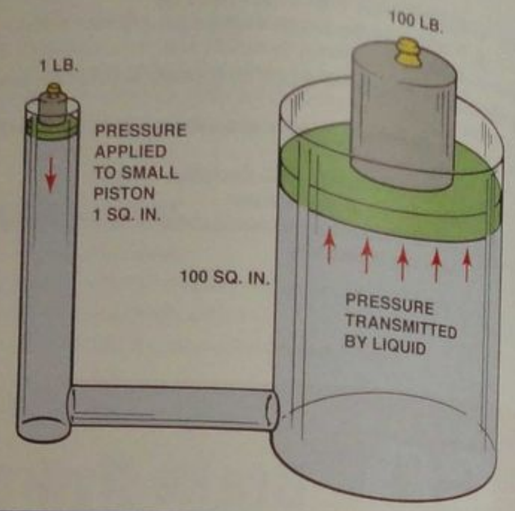


Figure 69–4 A one-pound force exerted on a small piston in a sealed system transfers the pressure to each square inch throughout the system. In this example, the 1-lb force is able to lift a 100-lb weight because it is supported by a piston that is 100 times larger in area than the small piston.

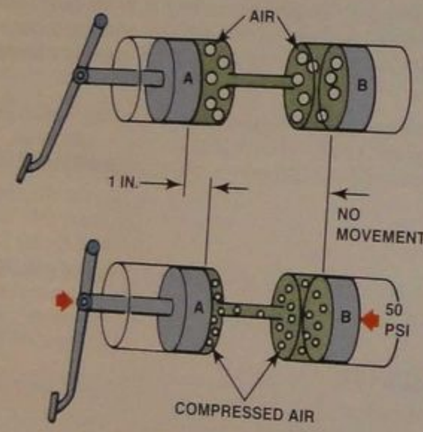


Figure 69–3 Hydraulic system must be free of air to operate properly.

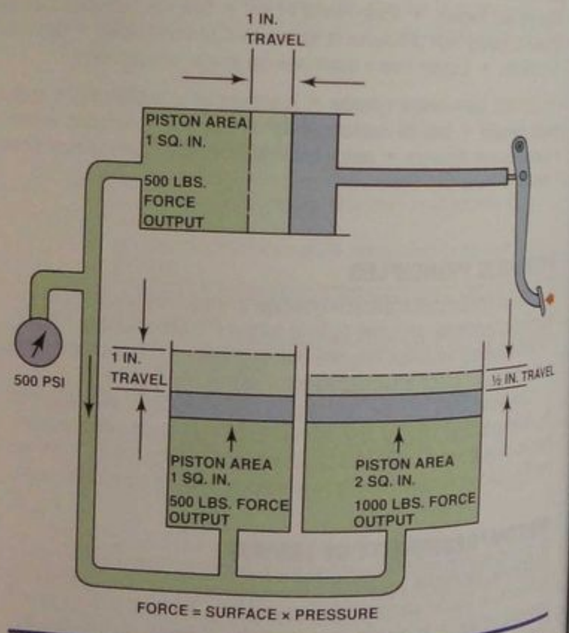


Figure 69–5 The amount of force on the piston is the result of pressure multiplied by the surface area.

undiminished in every direction." To help understand this principle, assume that a force of 10 lb is exerted on a piston with a surface area of 1 square inch (sq. in.). Since this *force* measured in lb or Newtons (N) is applied to a piston with an area measured in square inches (sq. in.), the *pressure* is the force divided by the area or "10 pounds per square inch" (PSI). It is this "pressure" that is transmitted, without loss, throughout the entire hydraulic system. See Figure 69–4.

If you know two out of the three factors, you can calculate the other one by using this formula:

F = force (lb) (Newtons)
P = pressure in lb per sq. in. (kilo Pascals [kPa])
A = area in sq. in. (cm^2)
F = P × A (force is equal to the pressure multiplied by the area)
P = F ÷ A (pressure is equal to the force divided by the area)
A = F ÷ P (area is equal to the force divided by the pressure)

A practical example involves a master cylinder with a piston area of 1 sq. in., and one wheel cylinder with an area of 1 sq. in., and one wheel cylinder with a piston area of 2 sq. in. See Figure 69–5.

The real "magic" of a hydraulic brake system is the fact that different forces can be created at different wheel cylinders. More force is necessary for front brakes than for rear brakes because, as the brakes are applied, the weight of the vehicle moves forward.

Larger (area) pistons are used in wheel cylinders (calipers, if disc brakes) on the front wheels to increase the force used to apply the front brakes.

Not only can hydraulics act as a "force machine" (by varying piston size), but the hydraulic system also can be varied to change piston stroke distances.

On a typical vehicle, a driver-input force of 150 lb (660 Newtons) is boosted both mechanically (through the brake pedal linkage) and by the power booster to a fluid pressure of about 1700 PSI (11,700 kPa).

NOTE: During a typical brake application, only about *1 teaspoon (5 ml or cc) of brake fluid* actually is moved from the master cylinder and into the hydraulic system to cause the pressure buildup to occur.

With a drum brake, the wheel cylinder expands and pushes the brake shoes against a brake drum. *The distance the shoes move is only about 0.005–0.012 in. (5 to 12 thousandths of an inch) (0.015–0.30 mm).* See Figure 69–6.

With a disc brake, brake fluid pressure pushes on the piston in the caliper a small amount and causes a clamping of the disc brake pads against both sides of a rotor (disc). See Figure 69–7.

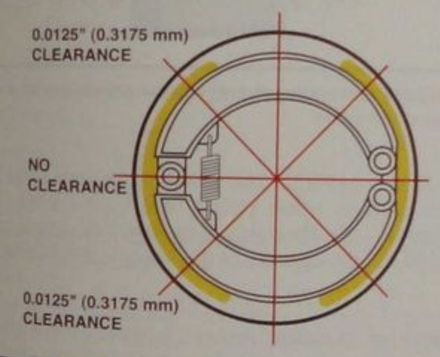


Figure 69–6 Drum brake illustrating the typical clearance between the brake shoes (friction material) and the rotating brake drum represented as the outermost black circle.

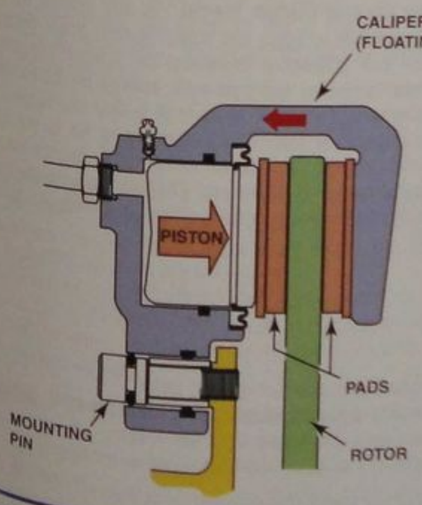


Figure 69–7 The brake pad (friction material) is pressed on both sides of the rotating rotor by the hydraulic pressure of the caliper.

The typical distance the pads move is only about 0.001–0.003 in. (1- to 3-thousandths of an inch) (0.025–0.076 mm).

Hydraulic Pressure and Piston Size If a mechanical force of 100 lb is exerted by the brake pedal pushrod onto a master cylinder piston with 1 sq. in. of surface area, the equation reads as follows:

$$\frac{100\ \text{lb}}{1\ \text{sq. in.}} = 100\ \text{PSI}$$

The result in this case is 100 PSI of brake system hydraulic pressure. See Figure 69–8.

However, if the same 100-lb force is applied to a master cylinder piston with twice the area (2 sq. in.), the equation will read as follows:

$$\frac{100\ \text{lb}}{2\ \text{sq. in.}} = 50\ \text{PSI}$$

Doubling the area of the master cylinder piston cuts the hydraulic system pressure in half. Conversely, if the same 100-lb force is applied to a master cylinder piston with only half the area (0.5 or 1/2 sq. in.), the equation will show that the system pressure is doubled:

$$\frac{100\ \text{lb}}{0.5\ \text{sq. in.}} = 200\ \text{PSI}$$

Application Force and Piston Size While the size of the master cylinder piston affects the hydraulic pressure of the entire brake system, weight shift and bias require that the heavily loaded front brakes receive much higher application force than the lightly loaded rear brakes. These differences in force are obtained by using different-sized pistons in the wheel cylinders and brake calipers. Pascal's Law states that a pressurized liquid in a confined space acts with equal pressure on equal areas and as long as the pistons in a hydraulic system have the same area, 100 PSI from

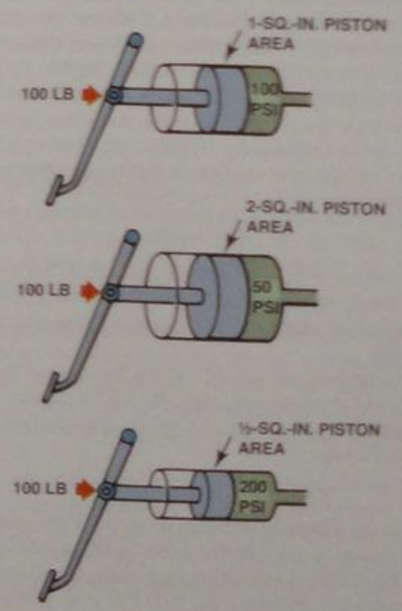


Figure 69–8 Mechanical force and the master cylinder piston area determine the hydraulic pressure in the brake system.

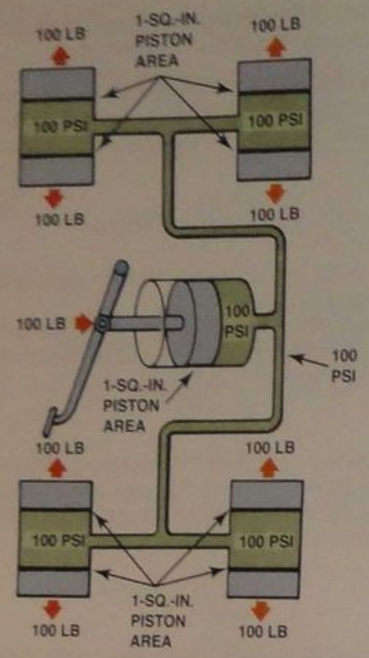


Figure 69–9 Hydraulic pressure is the same throughout a closed system and acts with equal force on equal areas.

the master cylinder will result in 100 PSI of friction assembly application force. See Figure 69–9.

However, when equal pressure acts on *unequal* areas, as with different-sized pistons, the brake application force will differ as well.

The mechanical *force* (F) at the brake pedal pushrod is applied to the master cylinder piston *area* and converted into brake system hydraulic *pressure* (P). Brake calipers and wheel cylinders perform exactly the opposite. Hydraulic *pressure* applied to the wheel cylinder or brake caliper piston *area* (A) is converted back into mechanical *force* that is used to apply the wheel friction assemblies. Because the variables are identical, the same equation can be rewritten to explain how changes in piston size affect brake application force:

$$P \times A = F$$

It is piston surface *area*, not diameter, that affects force.

In the simple brake system, the pedal and linkage apply a 100-lb force on a master cylinder piston with an area of 1 sq. in. See Figure 69–10.

This results in a pressure of 100 PSI throughout the hydraulic system. At the front wheels, the 100 PSI is applied to a brake caliper piston that has an area of 4 sq. in. The equation for this example is as follows:

$$100 \text{ PSI} \times 4 \text{ sq. in.} = 400 \text{ lb}$$

In this case the difference in piston areas (1 sq. in. compared with 4 sq. in.) results in the 100-PSI brake pedal pushrod force being increased for 400 lb of application force at the wheel friction assembly. The hydraulic pressure is still 100 PSI at all points within the system and the increase in application pressure is solely the result of 100 PSI acting on a 4-sq.-in. piston. The 400 lb is a mechanical force, not hydraulic pressure.

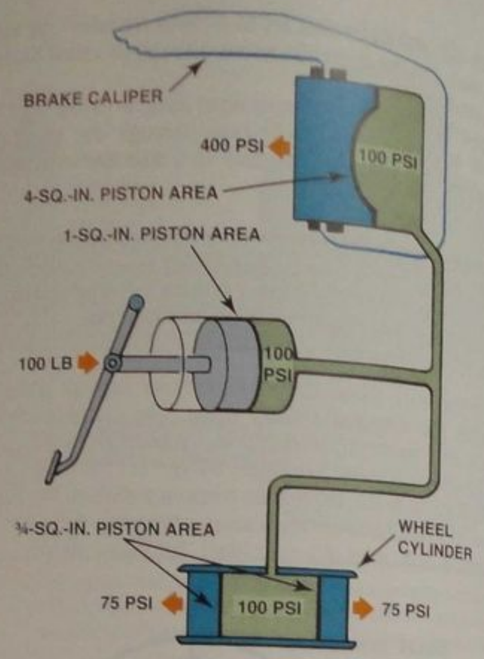


Figure 69–10 Differences in brake caliper and wheel cylinder piston area have a major effect on brake application force.

The drum brakes at the rear wheels of the same brake system use wheel cylinders whose pistons have three-quarters (3/4 or 0.75) of an inch of surface area. If the hydraulic system pressure remains 100 PSI, the equation for this example is as follows:

$$100 \text{ PSI} \times 0.75 \text{ sq. in.} = 75 \text{ lb}$$

Just as larger pistons increase application force, this example shows that smaller pistons decrease it. The system hydraulic pressure remains 100 PSI at all points, but the smaller piston is unable to transmit all of the available pressure. As a result, the mechanical application force is reduced to only 75 lb.

Piston Size versus Piston Travel In disc brakes, the mechanical force available to apply the brakes is four times greater because of the size difference between the master cylinder and caliper pistons. Some of the hydraulic energy is converted into *increased* mechanical force. The tradeoff is that the larger caliper piston with the greater force will not move as far as the smaller master cylinder piston. The amount of hydraulic energy converted into mechanical motion is *decreased*. The relative movement of pistons within the brake system can be calculated with the following equation:

$$\frac{A_1}{A_2} \times S = M$$

where:

A_1 = the area of the master cylinder piston
A_2 = the area of the wheel cylinder or caliper piston
S = the master cylinder piston stroke length
M = the wheel cylinder or caliper piston movement

Another way to express this equation is as follows:

$$\frac{\text{Area}_1}{\text{Area}_2} \times \text{Stroke} = \text{Movement}$$

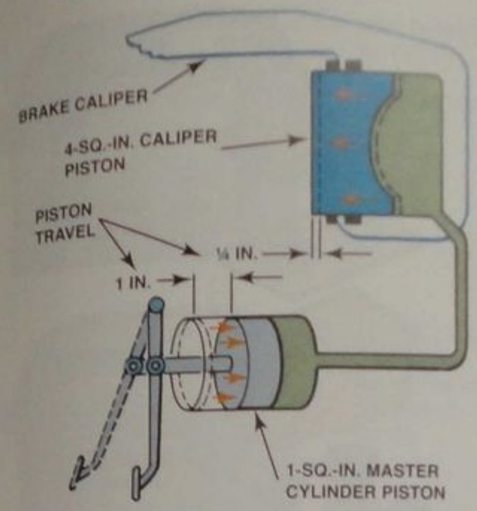


Figure 69–11 The increase in application force created by the large brake caliper piston is offset by a decrease in piston travel.

In the case of the disc brake example above, the equation would read as follows:

$$\frac{1 \text{ sq. in.}}{4 \text{ sq. in.}} \times 1 \text{ in.} = 1/4 \text{ in.}$$

The results show that, in this example, if the master cylinder piston stroke is 1 in., the caliper piston will move only 1/4 inch. See Figure 69–11.

If the caliper piston area were reduced to only 2 sq. in., the application force would increase to only 200 lb, but the caliper piston would travel 1/2 inch for a 1 in. master cylinder stroke.

The equation for computing the difference in piston movement works for wheel cylinders as well. In the drum brake example above, the amount of force transmitted by the wheel cylinder is less than the 100 PSI that exists within the hydraulic system. If energy cannot be destroyed, the extra 25 PSI of pressure must be converted into another form. The equation for this problem reveals where the energy goes:

$$\frac{1 \text{ sq. in.}}{0.75 \text{ sq. in.}} \times 1 \text{ in.} = 1.333 \text{ in.}$$

The answer shows that if the master cylinder again travels 1 in., the wheel cylinder piston will travel 1.333 in. With a dual-piston wheel cylinder like that shown in Figure 69–12, the total travel is divided between the two pistons.

If the wheel cylinder piston area were reduced to only 0.5 or 1/2 inch, the application force would be further reduced to only 50 lb, but the wheel cylinder piston would travel 2 in. for a 1-in. master cylinder stroke.

Hydraulic Principles and Brake Design When a brake system is designed, the hydraulic relationships discussed above play a major part in determining the sizes of the many pistons within the system. The piston sizes selected must move enough fluid to operate the wheel cylinder and brake caliper pistons through a wide range of travel, while at the same time they must create enough application force to lock the wheel friction assemblies.

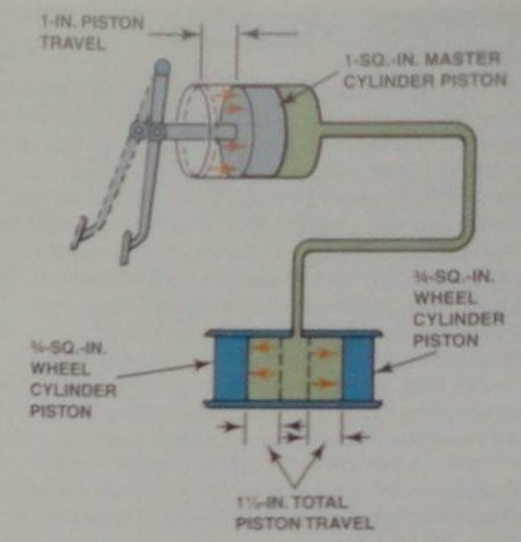


Figure 69–12 The decrease in application force created by a small wheel cylinder piston is offset by an increase in piston travel.

The piston sizes chosen should also provide the driver with good brake pedal "feel" so the brakes are easy to apply in a controlled manner.

For example, a very small master cylinder piston can provide a lot of hydraulic pressure with light pedal effort, but it will not move enough fluid to operate brake calipers with large pistons. In addition, a small piston will give the brake pedal a very "touchy" feel that makes modulation difficult and leads to premature brake lockup. A large piston, however, provides less pressure and requires higher pedal effort, but it provides plenty of fluid volume and results in a less-sensitive pedal feel that makes the brakes easier to control. Most vehicles with disc brakes have large master cylinder pistons to move the required volume of fluid, and a power booster to reduce the required brake pedal force.

MASTER CYLINDERS

The **master cylinder** is the heart of the entire braking system. No braking occurs until the driver depresses the brake pedal. The brake pedal linkage is used to apply the force of the driver's foot into a closed hydraulic system.

Master Cylinder Reservoirs Most vehicles built since the early 1980s are equipped with see-through master cylinder reservoirs, which permit owners and service technicians to check the brake fluid level without having to remove the top of the reservoir. Some countries have laws that require this type of reservoir. See Figure 69–13.

The reservoir capacity is great enough to allow for the brakes to become completely worn out and still have enough reserve for safe operation. The typical capacity of the entire braking system is usually 2 to 3 pints (1 to 1.5 liters). Vehicles equipped with four-wheel disc brakes usually hold 4 pints (2 liters) or more.

Master Cylinder Reservoir Diaphragm The entire brake system is filled with brake fluid up to the "full" level of the master cylinder reservoir.

REAL WORLD FIX **Is Bigger Better?**

A vehicle owner wanted better braking performance from his off-road race vehicle. Thinking that a larger master cylinder would help, a technician replaced the original 1-in.-bore-diameter master cylinder with a larger master cylinder with a 1 1/8-in.-bore-diameter master cylinder.

After bleeding the system, the technician was anxious to test-drive the "new" brake system. During the test-drive the technician noticed that the brake pedal "grabbed" much higher than with the original master cylinder. This delighted the technician. The owner of the vehicle was also delighted until he tried to stop from highway speed. *The driver had to use both feet to stop!*

The technician realized, after the complaint, that the larger master cylinder was able to move more brake fluid, but with *less* pressure to the wheel cylinders. The new master cylinder gave the impression of better brakes because the fluid was moved into the wheel cylinders (and calipers) quickly, and the pads and shoes contacted the rotor and drums sooner because of the greater volume of brake fluid moved by the larger pistons in the master cylinder.

To calculate the difference in pressure between the original (stock) master cylinder and the larger replacement, the technician used Pascal's Law with the following results:

Original Master Cylinder (1 in. bore)	Replacement Master Cylinder (1 1/8 in. bore)
$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$	$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$
$\text{PSI} = \frac{450\text{ lb}}{\text{Area}}$ (typical)	$\text{PSI} = \frac{450\text{ lb}}{\text{Area}}$ (typical)
$\text{Area} = \pi r^2 = 3.14 \times .5^2$ (1/2 of 1 in.)	$\text{Area} = \pi r^2 = 3.14 \times .5625^2$ (1/2 of 1 1/8 in.)
Area = 3.14 × .25	Area = 3.14 × .316
Area = .785 sq. in.	Area = .992 sq. in.
$\text{Pressure} = \frac{450}{.785} = 573\text{ PSI}$	$\text{Pressure} = \frac{450}{.992} = 454\text{ PSI}$

The difference in pressure is 119 PSI less with the larger master cylinder (573 – 454 = 119).

The stopping power of the brakes was reduced because the larger diameter master cylinder piston produced lower pressure (the same force was spread over a larger area and this means that the pressure [PSI] is less).

All master cylinders are sized correctly from the factory for the correct braking effort, pressure, pedal travel, and stopping ability. *A technician should never change the sizing of any hydraulic brake component on any vehicle!*

CAUTION: The master cylinder should never be filled higher than the recommended full mark to allow for brake fluid expansion that occurs normally when the brake fluid gets hot due to the heat generated by the brakes.

The reservoir is vented to the atmosphere so the fluid can expand and contract without difficulty as would be the case if the reservoir were sealed.

Being open to the atmosphere, however, allows the possibility of moisture-laden air coming in contact with the brake fluid! This moisture in the air is readily and rapidly absorbed into the brake fluid because brake fluid has an affinity (attraction) to moisture (water).

Master cylinders use a rubber diaphragm or floating disc to help seal outside air from direct contact with brake fluid and still

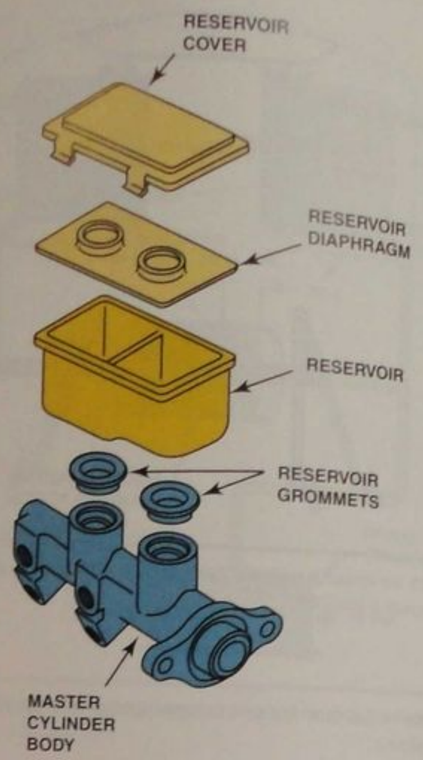


Figure 69–13 Typical master cylinder showing the reservoir and associated parts. The reservoir diaphragm lays directly on top of the brake fluid, which helps keep air from the surface of the brake fluid because brake fluid easily absorbs moisture from the air.

allow the brake fluid to expand and contract as the fluid heats up and cools down during normal brake system operation. This rubber diaphragm is vented between the steel cap and diaphragm. As the brake fluid level drops due to normal disc brake pad wear, the rubber diaphragm also lowers to remain like a second skin on top of the brake fluid.

Whenever adding brake fluid, push the rubber diaphragm back up into the cover. Normal atmospheric pressure will allow the diaphragm to return to its normal position on top of the brake fluid. Whenever servicing a brake system, be sure to check that the vent hole is clear on the cover to allow air to get between the cover and the diaphragm. See Figure 69–14.

TECH TIP **Don't Fill the Master Cylinder Without Seeing Me!**

The boss explained to the beginning technician that there are two reasons why the customer should be told not to fill the master cylinder reservoir when the brake fluid is down to the "minimum" mark, as shown in Figure 69–15.

1. If the master cylinder reservoir is low, there may be a leak that should be repaired.
2. As the brakes wear, the disc brake piston moves outward to maintain the same distance between friction materials and the rotor. Therefore, as the disc brake pads wear, the brake fluid level goes down to compensate.

If the customer notices that the brake fluid is low in the master cylinder reservoir, the vehicle should be serviced—either for new brakes or to repair a leak.

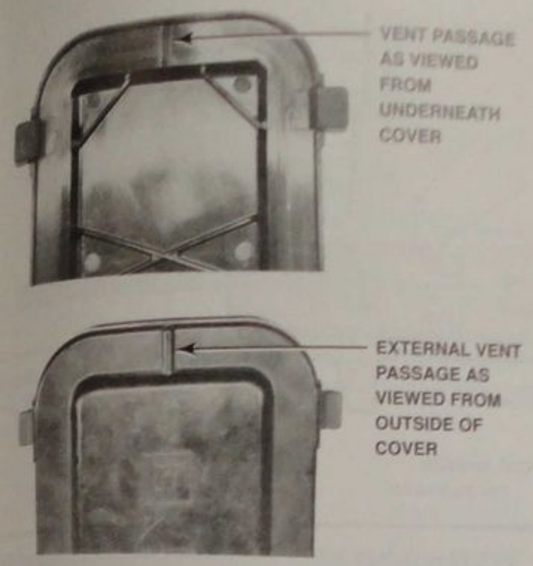


Figure 69–14 All master cylinders should have a vent hole on the outside cover that allows air between the cover and the rubber diaphragm.



Figure 69–15 Master cylinder with brake fluid level at the "MAX" (maximum) line.

MASTER CYLINDER OPERATION

The master cylinder is the heart of any hydraulic braking system. Brake pedal movement and force are transferred to the brake fluid and directed to wheel cylinders or calipers. See Figure 69–16.

The master cylinder is also separated into two pressure-building chambers (or circuits) to provide braking force to one-half of the brake in the event of a leak or damage to one circuit. See Figure 69–17.

Both pressure-building sections of the master cylinder contain two holes from the reservoir. The Society of Automotive Engineers' (SAE) term for the forward (tapered) hole is the **vent port,** and the rearward straight drilled hole is called the **replenishing port.** See Figure 69–18.

Various vehicle and brake component manufacturers call these ports by various names. For example, the vent port is the high-pressure port. This tapered forward hole is also called the **compensating port.**

The replenishing port is the low-pressure rearward, larger diameter hole. The inlet port is also called the **bypass port, filler port,** or **breather port.**

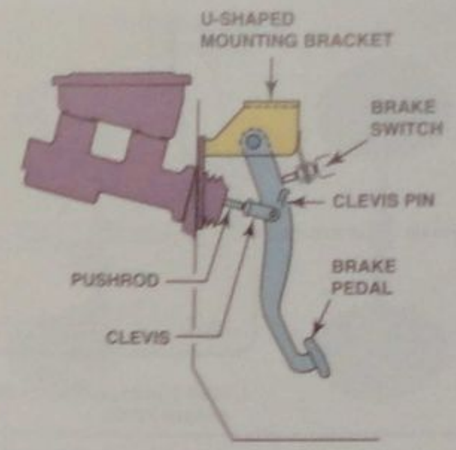


Figure 69–16 The typical brake pedal is supported by a mount and attached to the pushrod by a U-shaped bracket. The pin used to retain the clevis to the brake pedal is usually called a clevis pin.

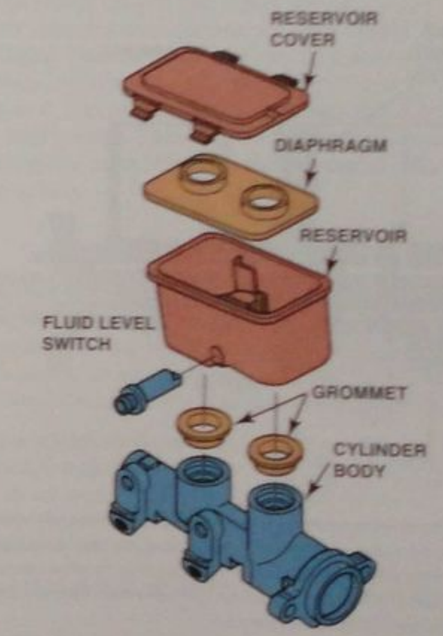
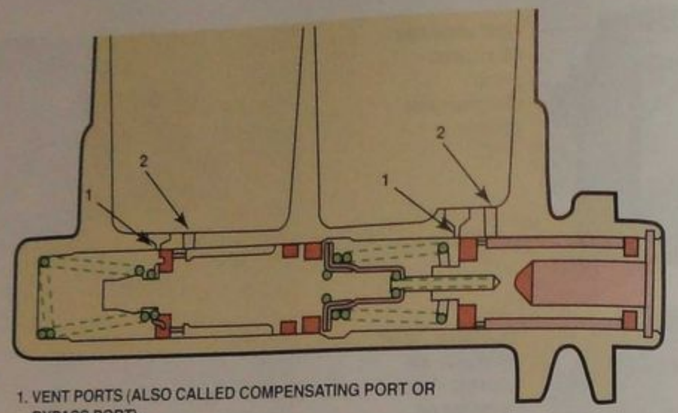


Figure 69–17 The composite master cylinder is made from two different materials—aluminum for the body and plastic materials for the reservoir and reservoir cover. This type of reservoir feeds both primary and secondary chambers, and therefore uses a fluid level switch that activates the red dash warning lamp if the brake fluid level drops.

The function of the master cylinder can be explained from the at-rest, applied, and released positions.

At-Rest Position The primary sealing cups are between the compensating port hole and the inlet port hole. In this position, the brake fluid is free to expand and move from the calipers, wheel cylinders, and brake lines up into the reservoir through the vent port (compensation port) if the temperature rises and the fluid expands. If the fluid was trapped, the pressure of the brake fluid would increase with temperature, causing the brakes to **self-apply.** See Figure 69–19.



1. VENT PORTS (ALSO CALLED COMPENSATING PORT OR BYPASS PORT)

2. REPLENISHING PORTS (ALSO CALLED INLET PORT, BYPASS PORT, FILLER PORT, OR BREATHER PORT)

Figure 69–18 Note the various names for the vent port (front port) and the replenishing port (rear port). Names vary by vehicle and brake component manufacturer. The names vent port and replenishing port are the terms recommended by the Society of Automotive Engineers (SAE).

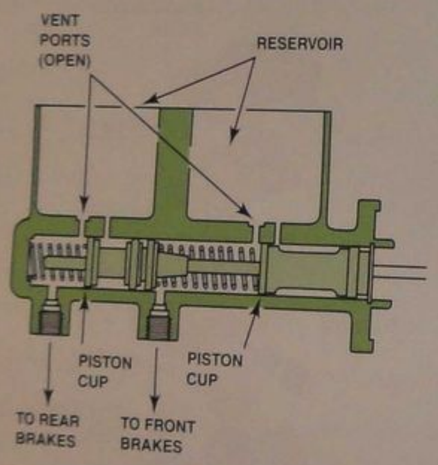


Figure 69–19 The vent ports must remain open to allow brake fluid to expand when heated by the friction material and transferred to the caliper and/or wheel cylinder. As the brake fluid increases in temperature, it expands. The heated brake fluid can expand and flow back into the reservoir through the vent ports.

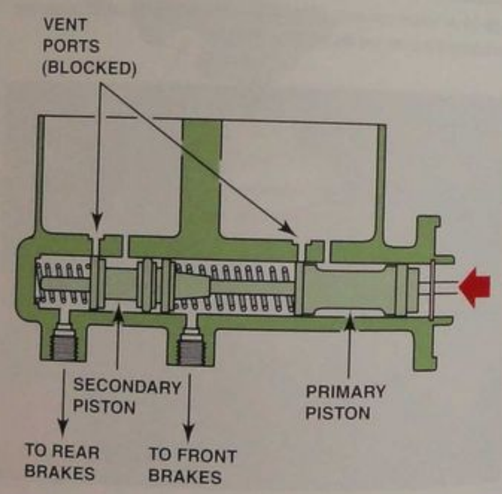


Figure 69–20 As the brake pedal is depressed, the pushrod moves the primary piston forward, closing off the vent port. As soon as the port is blocked, pressure builds in front of the primary sealing cup which pushes on the secondary piston. The secondary piston also moves forward, blocking the secondary vent port and building pressure in front of the sealing cup.

TECH TIP ✓ **Too Much Is Bad**

Some vehicle owners or inexperienced service people may fill the master cylinder to the top. Master cylinders should only be filled to the "maximum" level line or about 1/4 in. (6 mm) from the top to allow room for expansion when the brake fluid gets hot during normal operation. If the master cylinder is filled to the top, the expanding brake fluid has no place to expand and the pressure increases. This increased pressure can cause the brakes to "self-apply," shortening brake friction material life and increasing fuel consumption. Overheated brakes can result and the brake fluid may boil, causing a total loss of braking.

The pistons (primary and secondary) are retained by a clip at the pushrod end and held in position by return springs.

Applied Position When the brake pedal is depressed, the pedal linkage forces the push rod and primary piston down the bore of the master cylinder. See Figure 69–20.

As the piston moves forward, the primary sealing cup covers and blocks off the vent port (compensating port). Hydraulic pressure builds in front of the primary seal as the pushrod moves forward. The back of the piston is kept filled through the replenishing port. See Figure 69–21.

This stops any suction (vacuum) from forming behind the piston. The secondary piston is moved forward as pressure is exerted by the primary piston. If, for any reason, such as a leak, the primary piston cannot build pressure, a mechanical link on the front of the primary piston will touch the secondary piston and move it forward, as the primary piston is pushed forward by the pushrod and brake pedal.

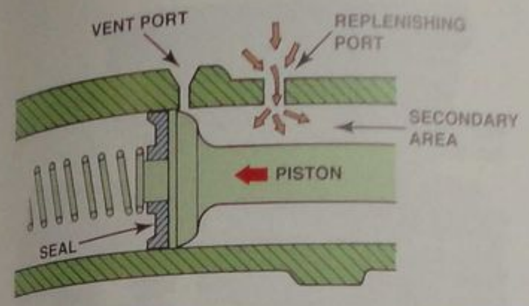


Figure 69–21 The purpose of the replenishing port is to keep the volume behind the primary piston filled with brake fluid from the reservoir as the piston moves forward during a brake application.

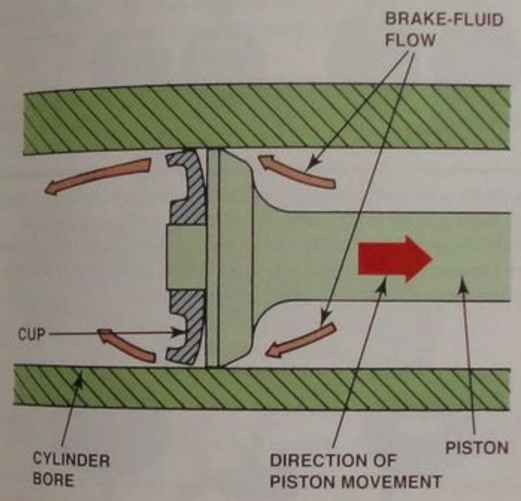


Figure 69–22 When the brake pedal is released, the master cylinder piston moves rearward. Some of the brake fluid is pushed back up through the replenishing port, but most of the fluid flows past the sealing cup. Therefore, when the driver pumps the brake pedal, the additional fluid in front of the pressure-building sealing cup is available quickly.

Released Position Releasing the brake pedal removes the pressure on the pushrod and master cylinder pistons. A spring on the brake pedal linkage returns the brake pedal to its normal at-rest (up) position. The spring in front of the master cylinder piston expands, pushing the pistons rearward. At the same time, pressure is released from the entire braking system and the released brake fluid pressure is exerted on the master cylinder pistons, forcing them rearward. As the piston is pushed back, the lips of the seal fold forward allowing fluid to quickly move past the piston, as shown in Figure 69–22.

Some pistons have small holes that allow the fluid to move more quickly. Once the primary seal passes the vent port, the remaining hydraulic pressure forces any excess fluid into the reservoir.

DUAL SPLIT MASTER CYLINDERS

Dual split master cylinders use two separate pressure-building sections. One section operates the front brakes and the other section operates the rear brakes on vehicles equipped with a front/rear-split system. See Figure 69–23.

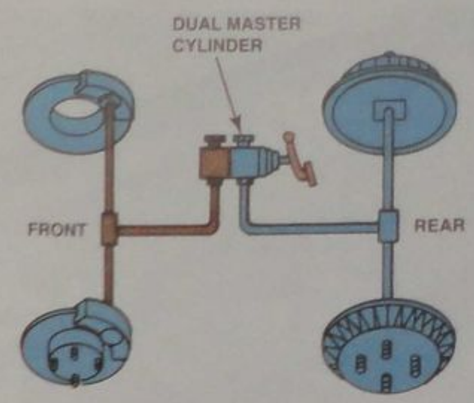


Figure 69–23 Rear-wheel-drive vehicles use a dual-split master cylinder.

The *nose end* of the master cylinder is the closed end toward the front of the vehicle. The open end is often called the *pushrod end* of the master cylinder. See Figure 69–24.

Some manufacturers operate the front brakes (which do the most braking) from the "nose end" section (secondary piston end) of the master cylinder. The secondary piston has only one pressure-building seal. The primary piston (pushrod end) requires two (2) seals to build pressure. Therefore, the nose end of the master cylinder is considered the more reliable of the two master cylinder pressure-building sections.

TECH TIP ✓ **Always Check for Venting (Compensation)**

Whenever diagnosing any braking problem, start the diagnosis at the master cylinder—the heart of any braking system. Remove the reservoir cover and observe the brake fluid for spurting while an assistant depresses the brake pedal.

Normal operation (movement of fluid observed in the reservoir)
There should be a squirt or movement of brake fluid out of the vent port of both the primary and secondary chambers. This indicates that the vent port is open and that the sealing cup is capable of moving fluid upward through the port before the cup seals off the port as it moves forward to pressurize the fluid.

No movement of fluid observed in the reservoir in the primary piston
This indicates that brake fluid is not being moved as the brake pedal is depressed. This can be caused by the following.

a. Incorrect brake pedal height—brake pedal or pushrod adjustment could be allowing the primary piston to be too far forward, causing the seal cup to be forward of the vent port. Adjust the brake pedal height to a higher level and check for a too long pushrod length.
b. A defective or swollen rubber sealing cup on the primary piston could cause the cup itself to block the vent port.

NOTE: If the vent port is blocked for any reason, the brakes of the vehicle may *self-apply* when the brake fluid heats up during normal braking. Since the vent port is blocked, the expanded hotter brake fluid has no place to expand and instead increases the pressure in the brake lines. The increase in pressure causes the brakes to apply. Loosening the bleeder valves and releasing the built-up pressure is a check that the brakes are self-applying. Then check the master cylinder to see if it is "venting."

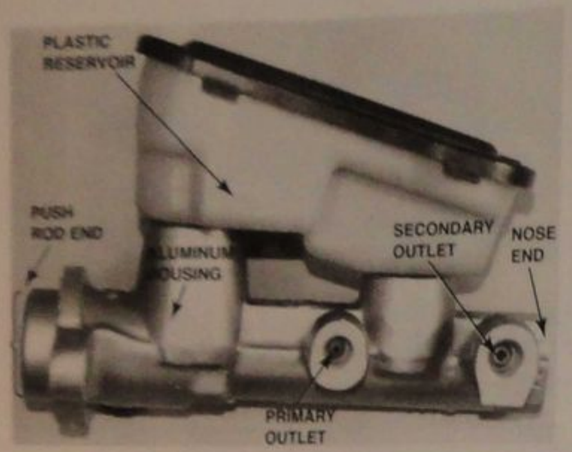


Figure 69–24 The primary outlet is the outlet closest to the pushrod end of the master cylinder and the second outlet is closest to the nose end of the master cylinder.

NOTE: On vehicles equipped with front and rear split master cylinders, the front brakes may or may not be operated from the front chamber. General Motors typically uses the front (nose end) chamber for the front brakes and the rear (pushrod end) for the rear brakes. Many other makes and models of vehicles use the rear chamber for the front brakes. If in doubt, consult the factory service manual for the exact vehicle being serviced.

If the rear section of the hydraulic system fails, the primary piston will not build pressure to operate the secondary piston. To permit the operation of the secondary piston (nose end piston) in the event of a hydraulic failure of the rear section, the primary piston extension will mechanically contact and push on the secondary piston. See Figure 69–25.

If there is a failure of the front section hydraulic system, the primary piston (pushrod end) operates normally and exerts pressure on the secondary piston. The secondary piston, however, will not be able to build pressure because of the leak in the system.

DIAGONAL SPLIT MASTER CYLINDERS

With front-wheel drive vehicles, the weight of the entire power train is on the front wheels and 80% to 90% of the braking force is achieved by the front brakes. This means that only 10% to 20% of the braking force is being handled by the rear brakes. If the front brakes fail, the rear brakes alone would not provide adequate braking force. The solution is the use of a **diagonal split master cylinder.** See Figures 69–26 and 69–27.

In a diagonal split braking system, the left front brake and the right rear brake are on one circuit, and the right front with the left rear is another circuit of the master cylinder. If one circuit fails, the remaining circuit can still stop the vehicle in a reasonable fashion because each circuit has one front brake. To prevent this one front brake from causing the vehicle to pull toward one side during braking, the front suspension is designed with negative scrub radius geometry. This effectively eliminates any handling problem in the event of a brake circuit failure.

QUICK TAKE-UP MASTER CYLINDERS

Many newer vehicles use low drag disc brake calipers to increase fuel economy. However, due to the larger distance between the rotor

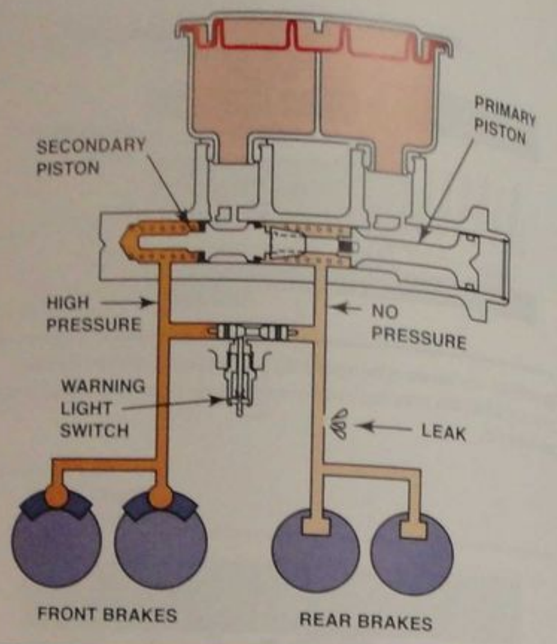


Figure 69–25 In the event of a primary system failure, no hydraulic pressure is available to push the second piston forward. As a result, the primary piston extension contacts the secondary piston and pushes on the secondary piston mechanically rather than hydraulically. The loss of pressure in the primary system is usually noticed by the driver by a lower-than-normal brake pedal and the lighting of the red brake warning lamp.

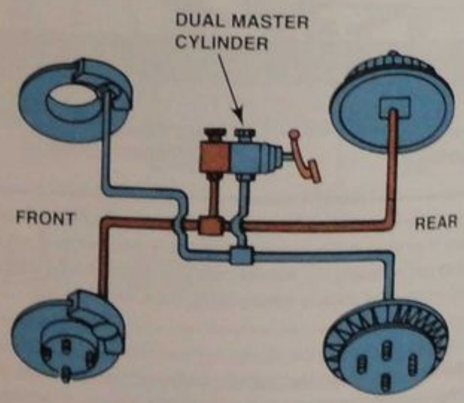


Figure 69–26 Front-wheel-drive vehicles use a diagonal split master cylinder. In this design one section of the master cylinder operates the right front and the left rear brake and the other section operates the left front and right rear. In the event of a failure in one section, at least one front brake will still function. *(Courtesy of Ford)*

and the friction pads, excessive brake pedal travel would be required before the pads touched the rotor. The solution to this problem is a master cylinder design that can take up this extra clearance.

The design of a **quick take-up master cylinder** includes a larger diameter primary piston (low-pressure chamber) and a quick take-up valve. This type of master cylinder is also called **dual diameter bore, step-bore,** or **fast-fill master cylinders.**

A spring-loaded check ball valve holds pressure on the brake fluid in the large diameter rear chamber of the primary piston. When the brakes are first applied, the movement of the rear larger piston forces this larger volume of brake fluid forward past the primary piston seal and into the primary high-pressure chamber. This extra volume of brake fluid "takes up" the extra clearance of the



Figure 69–27 Typical General Motors diagonal split master cylinder. Notice the two aluminum proportioner valves. These valves limit and control brake fluid pressure to the rear brakes to help eliminate rear wheel lockup during a rapid stop.

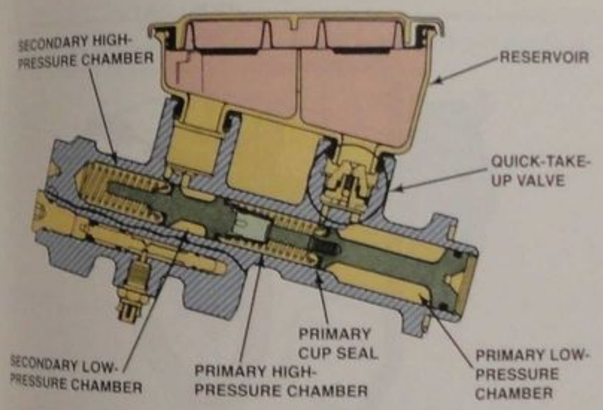


Figure 69–28 Quick take-up master cylinder can be identified by the oversize primary low-pressure chamber.

front disc brake calipers without increasing the brake pedal travel distance. See Figure 69–28.

At 70 to 100 PSI, the check ball valve in the quick take-up valve allows fluid to return to the brake fluid reservoir. Because the quick take-up "works" until 100 PSI is reached, a metering valve is not required to hold back the fluid pressure to the front brakes. See Figures 69–29 through 69–31.

DIAGNOSING AND TROUBLESHOOTING MASTER CYLINDERS

A thorough visual inspection is important when inspecting any master cylinder. The visual inspection should include checking the following items:

1. Check the brake fluid for proper level and condition. (Brake fluid should not be rusty, thick, or contaminated.)
2. Check that the vent holes in the reservoir cover are open and clean.
3. Check that the reservoir cover diaphragm is not torn or enlarged.

NOTE: If the cover diaphragm is enlarged, this is an indication that a mineral oil, such as automatic transmission fluid or engine oil, has been used in or near the brake system, because rubber that is brake fluid resistant expands when exposed to mineral oil.

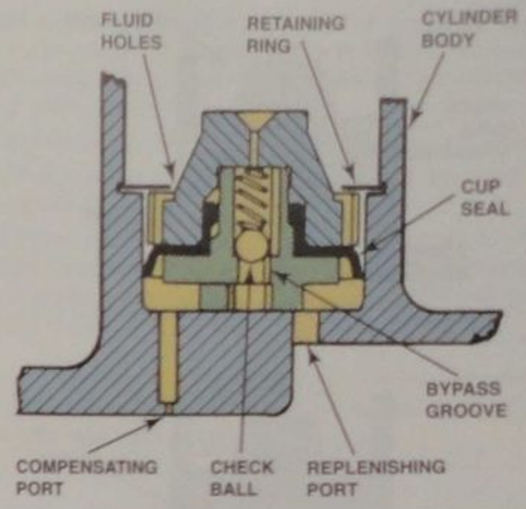


Figure 69–29 The quick take-up valve controls fluid flow to and from the primary low-pressure chamber.

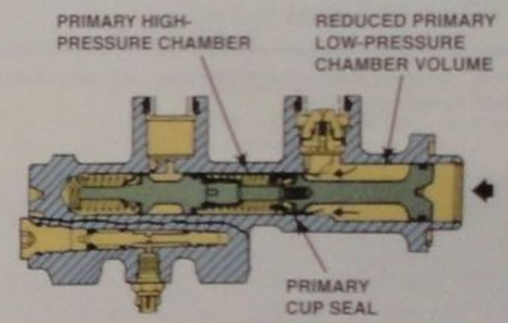


Figure 69–30 As the brakes are applied, reduced low-pressure chamber volume results in a pressure increase that causes fluid to bypass the primary cup seal.

TECH TIP ✓ **The Brake Pedal Depressor Trick**

The master cylinder can be used to *block* the flow of brake fluid. Whenever any hydraulic brake component is removed, brake fluid tends to leak out because the master cylinder is usually higher than most other hydraulic components such as wheel cylinders and calipers.

To prevent brake fluid loss that can easily empty the master cylinder reservoir, simply *depress* the brake pedal slightly or prop a stick or other pedal depressor to keep the brake pedal down. When the brake pedal is depressed, the piston sealing cups move forward, blocking off the reservoir from the rest of the braking system. The master cylinder stays full and the brake fluid stops dripping out of brake lines that have been disconnected. See Figure 69–32.

NOTE: Try this—put a straw into a glass of water. Use a finger to seal the top of the straw and then remove the straw from the glass of water. The water remains in the straw because air cannot get into the top of the straw. This is why the brake pedal depressor trick works to prevent the loss of brake fluid from the system even if the brake line is totally disconnected.

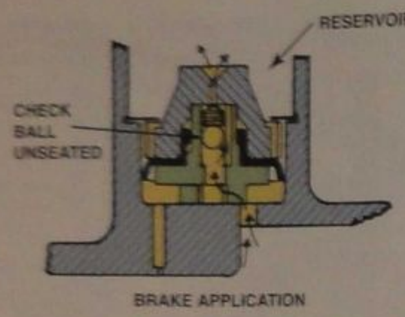


Figure 69–31 The one-way sealing abilities of both a spring-loaded check ball and a cup seal are used in the quick take-up valve.



Figure 69–32 A brake pedal depressor like this, normally used during a wheel alignment, can be used to block the flow of brake fluid from the master cylinder during service work on the hydraulic system.

4. Check for any external leaks at the lines or at the pushrod area. See Figure 69–33.

After a thorough visual inspection, check for proper operation of **pedal height, pedal free play,** and **pedal reserve distance.** See Figures 69–34 and 69–35.

Proper brake pedal height is important for the proper operation of the stop (brake) light switch. If the pedal is not correct, the pushrod may be in too far forward, preventing the master cylinder cups from uncovering the compensation port. If the pedal is too high, the free play will be excessive. Pedal reserve height is easily checked by depressing the brake pedal with the right foot and attempting to slide your left foot under the brake pedal. See Figure 69–36.

Free play is the distance the brake pedal travels before the primary piston in the master cylinder moves. *Most vehicles require brake pedal free play between 1/8 and 1 1/2 in. (3 to 38 mm).* Too little or too much free play can cause braking problems that can be mistakenly contributed to a defective master cylinder.

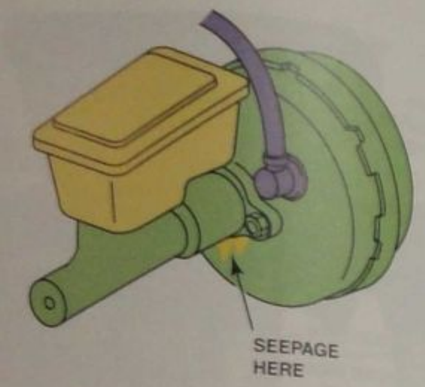


Figure 69–33 Some seepage is normal when a trace of fluid appears on the vacuum booster shell. Excessive leakage, however, indicates a leaking secondary (end) seal.

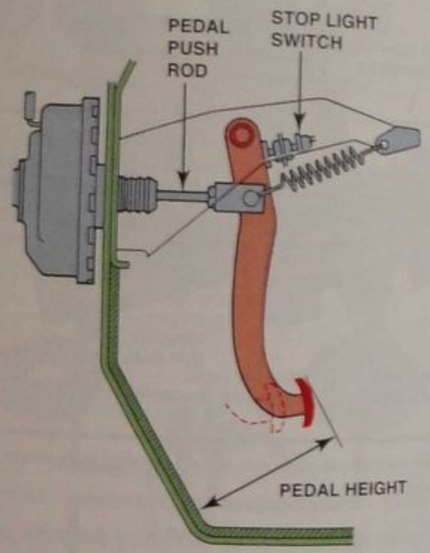


Figure 69–34 Pedal height is usually measured from the floor to the top of the brake pedal. Some vehicle manufacturers recommend removing the carpet and measure from the asphalt matting on the floor for an accurate measurement. Always follow the manufacturer's recommended procedures and measurements. *(Courtesy of Toyota Motor Sales, U.S.A., Inc.)*

Spongy Brake Pedal A spongy pedal with a larger than normal travel indicates air in the lines. Check for leaks and bleed the air from the system as discussed later in this chapter.

Lower Than Normal Brake Pedal A brake pedal that travels downward more than normal and then gets firm is an indication that one circuit of the dual-circuit hydraulic system is probably not working. Check for leaks in the system and repair as necessary. Another possible reason is an out-of-adjustment drum brake allowing too much pedal travel before the shoes touch the brake drum.

NOTE: A lower than normal brake pedal may also be an indication of air in the hydraulic system.

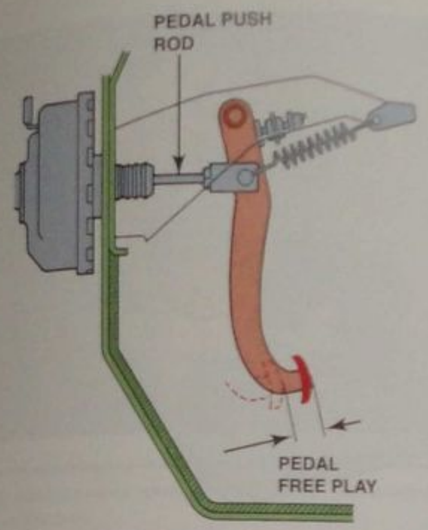


Figure 69–35 Brake pedal free play is the distance between the brake pedal fully released and the position of the brake pedal when braking resistance is felt.



Figure 69–36 Brake pedal reserve is usually specified as the measurement from the floor to the top of the brake pedal with the brakes applied. A quick-and-easy test of pedal reserve is to try to place your left toe underneath the brake pedal while the brake pedal is depressed with your right foot. If your toe will *not* fit, then pedal reserve *may* not be sufficient.

Sinking Brake Pedal If the brake pedal sinks all the way to the floor, suspect a defective master cylinder that is leaking internally. This internal leakage is often called **bypassing** because the brake fluid is leaking past the sealing cup. See the Tech Tip, "Check for Bypassing" later in this chapter.

NOTE: A sinking brake pedal, on a vehicle equipped with an antilock braking system (ABS), could be caused by a defective dump valve.

DISASSEMBLY OF THE MASTER CYLINDER

Many master cylinders can be disassembled, cleaned, and restored to service.

NOTE: Check the vehicle manufacturer's recommendation before attempting to overhaul or service a master cylinder. Many manufacturers recommend replacing the master cylinder as an assembly.

Step #1 Remove the master cylinder from the vehicle, being careful to avoid dripping or spilling brake fluid onto painted surfaces of the vehicle. Dispose of all old brake fluid and clean the outside of the master cylinder.

Step #2 Remove the reservoir, if possible, as shown in Figure 69–37.

Step #3 Remove the retaining bolt that holds the secondary piston assembly in the bore.

Step #4 Depress the primary piston with a *blunt* tool such as a Phillips screwdriver, a rounded wooden dowel, or an engine pushrod. Use of a straight blade screwdriver or other nonrounded tool can damage and distort the aluminum piston.

CAUTION: If holding the master cylinder in a vise, use the flange area. Never clamp the body of the master cylinder.

Step #5 Remove the snap ring and slowly release the pressure on the depressing tool. Spring pressure should push the primary piston out of the cylinder bore. See Figure 69–38.

Step #6 Remove the master cylinder from the vise and tap the open end of the bore against the top of a workbench to force the secondary piston out of the bore. If necessary, use compressed air in the outlet to force the piston out.

CAUTION: Use extreme care when using compressed air. The piston can be shot out of the master cylinder with a great force.

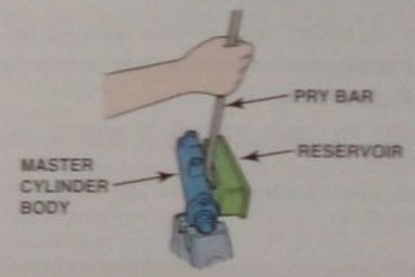


Figure 69–37 Using a pry bar to remove the reservoir from the master cylinder. *(Courtesy of Allied Signal Automotive Aftermarket)*

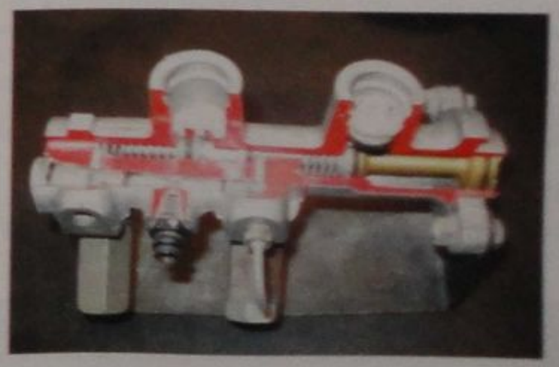


Figure 69–38 Whenever disassembling a master cylinder, note the exact order of parts as they are removed. Master cylinder overhaul kits (when available) often include entire piston assemblies rather than the individual seals.

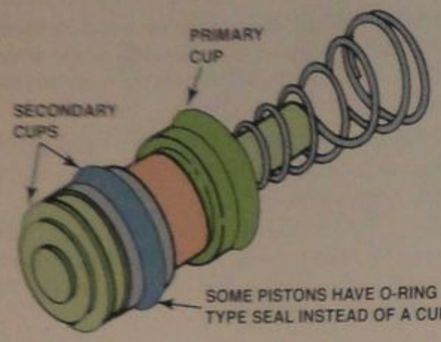


Figure 69–39 Piston assembly. *(Courtesy of Allied Signal Automotive Aftermarket)*

INSPECTION AND REASSEMBLY OF THE MASTER CYLINDER

Thoroughly clean the master cylinder and any other parts to be reused (except for rubber components) in clean denatured alcohol. If the bore is okay, replacement **piston assemblies** can be installed into the master cylinder after dipping them into clean brake fluid.

NOTE: While most master cylinder overhaul kits include the entire piston assemblies, some kits just contain the sealing cups and/or O-rings. Always follow the installation instructions that accompany the kit and always use the installation tool that is included to prevent damage to the replacement seals.

Step #1 Install the secondary (smaller) piston assembly into the bore, spring end first. See Figure 69–39.

Step #2 Install the primary piston assembly, spring end first.

Step #3 Depress the primary piston and install the snap ring.

Step #4 Install the stop bolt.

Step #5 Reinstall the plastic reservoir, if equipped, as shown in Figure 69–40.

Step #6 Bench bleed the master cylinder. This step is very important. See Figure 69–41.

TECH TIP ✔ **Check for Bypassing**

If a master cylinder is leaking internally, brake fluid can be pumped from the rear chamber into the front chamber of the master cylinder. This internal leakage is called *bypassing*. When the fluid bypasses, the front chamber can overflow while emptying the rear chamber. Therefore, whenever checking the level of brake fluid, do not think that a low rear reservoir is always due to an external leak. Also, a master cylinder that is bypassing (leaking internally) will usually cause a lower than normal brake pedal.

INSTALLING THE MASTER CYLINDER

After the master cylinder has been bench bled, it can be installed in the vehicle.

NOTE: Brake fluid can drip from the outlet of the master cylinder and could drip onto the vehicle. Brake fluid is very corrosive and can remove paint. Use fender covers and avoid letting brake fluid touch any component of the vehicle.

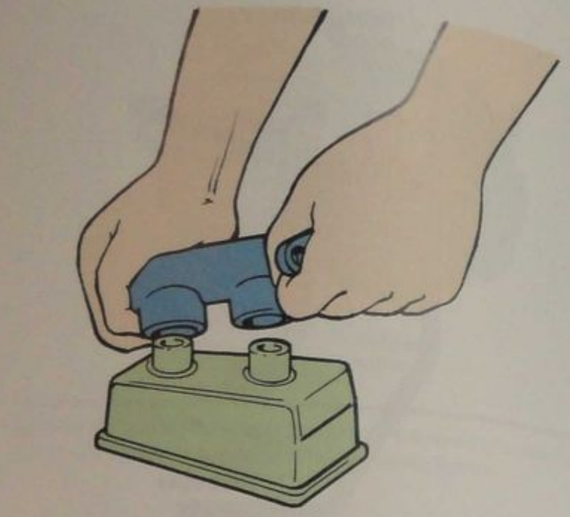


Figure 69–40 To reinstall the reservoir onto a master cylinder, place the reservoir on a clean flat surface and push the housing down onto the reservoir after coating the rubber seals with brake fluid. *(Courtesy of Allied Signal Automotive Aftermarket)*

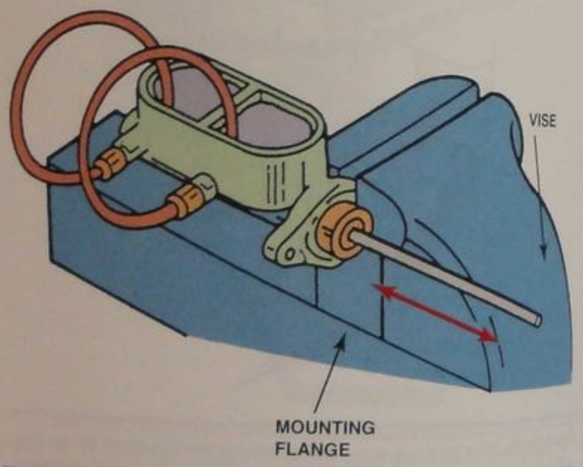


Figure 69–41 Bleeding a master cylinder before installing it on the vehicle. The master cylinder is clamped into a bench vise while using the rounded end of a breaker bar to push on the pushrod end with bleeder tubes down into the brake fluid. Master cylinders should be clamped on the mounting flange as shown to prevent distorting the master cylinder bore.

Tighten the fasteners to factory specifications. See Figure 69–42. Bleed the system as needed.

SUMMARY

1. During a typical brake application, only about 1 teaspoon (5 ml or cc) of brake fluid actually is moved from the master cylinder and into the hydraulic system.
2. Pascal's Law states that: "When a force is applied to a liquid confined in a container or enclosure, the pressure is transmitted equally and undiminished in every direction."
3. Master cylinder reservoirs are large enough for the brakes to be worn completely down and still have a small reserve.
4. The front port of the master cylinder is called the compensating port and the rear port is called the inlet port.



Figure 69–42 Installing a master cylinder. Always tighten the retaining fastener and brake lines to factory specifications.

5. Brake system diagnosis should always start with checking for venting (compensation).
6. Dual split master cylinders that separate the front brakes from the rear brakes are used on rear-wheel-drive vehicles.
7. Diagonal split master cylinders that separate right front and left rear from the left front and right rear brakes are used on front-wheel-drive vehicles.
8. Some master cylinders can be rebuilt, but the cylinder bore should not be honed unless recommended by the manufacturer.

REVIEW QUESTIONS

1. Explain Pascal's Law.
2. Describe how a master cylinder works.
3. Discuss the difference between a dual split and a diagonal split master cylinder.
4. What is the difference between checking for venting (compensation) and bypassing?

CHAPTER QUIZ

1. Two technicians are discussing master cylinders. Technician A says that it is normal to see fluid movement in the reservoir when the brake pedal is depressed. Technician B says a defective master cylinder can cause the brake pedal to slowly sink to the floor when depressed. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. If the brake pedal linkage is not adjusted correctly, brake fluid may not be able to expand back into the reservoir through the _____ port of the master cylinder when the brakes get hot.
   a. Vent port (forward hole)
   b. Replenishing port (rearward hole)
3. The primary brake circuit fails due to a leak in the lines, leaving the rear section of a dual split master cylinder. Technician A says that the driver will notice a lower than normal brake pedal and some reduced braking power. Technician B says that the brake pedal will "grab" higher than normal. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Two technicians are discussing a problem where the brake pedal travels too far before the vehicle starts to slow. Technician A says that the brakes may be out of adjustment. Technician B says that one circuit from the master cylinder may be leaking or defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Air in the lines will cause what type of problem?
   a. Vibration in the brake pedal during stops
   b. Low spongy brake pedal
   c. Brake noise
   d. Hard brake pedal
6. The master cylinder is able to move about how much brake fluid during each brake application?
   a. One tablespoon
   b. One teaspoon
   c. One cu. in.
   d. 50 ml
7. Brake fluid pressure is measured in what unit?
   a. Sq. in.
   b. Pounds
   c. Inches
   d. PSI
8. How much brake fluid is in a typical master cylinder reservoir?
   a. One gallon
   b. Enough to allow all brakes to become completely worn
   c. 15 to 20 liters
   d. One pint
9. What part in the master cylinder helps keep air from contacting the brake fluid yet allows the fluid level to drop as the disc brakes wear?
   a. Vent valve
   b. Compensating valve
   c. Residual valve
   d. Rubber diaphragm or floating disc
10. The brakes on a vehicle work okay for a while, then the vehicle slows because the brakes self-applied. Technician A says that an overfilled master cylinder could be the cause. Technician B says that a blocked vent port (compensating port) could be the cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER

70 Hydraulic Valves and Switches

OBJECTIVES: **After studying Chapter 70, the reader will be able to:** Prepare for ASE Brakes (A5) certification test content area "A" (Hydraulic System Diagnosis and Repair). • Describe the operation of a residual check valve. • Explain how a proportioning valve works. • Discuss the need and use of a metering valve. • List testing procedures used to test hydraulic valves. • Describe how the brake fluid level and brake light switches work.

KEY TERMS: brake fluid level sensor • brake light switch • combination valve • electronic brake proportioning • expander • height-sensing proportioning valve • metering valve • pressure-differential switch • proportioning valve • residual check valve • slope • split point

RESIDUAL CHECK VALVE

A **residual check valve** has been used on some drum brake systems to keep a slight amount of pressure on the entire hydraulic system for drum brakes (5 to 12 PSI). See Figure 70–1.

This residual check valve is located in the master cylinder at the outlet for the drum brakes. The check ball and spring in the residual check valve permit all the brake fluid to return to the master cylinder until the designated pressure is reached.

This slight pressure prevents air leaks from entering into the hydraulic system in the event of a small hole or leak. With a low pressure kept on the hydraulic system, any small hole will cause fluid to leak out rather than permit air to enter the system. This slight pressure also keeps the wheel cylinder sealing cups tight against the inside wall of the wheel cylinder. See Figure 70–2.

Residual check valves are often *not* used on late model vehicles equipped with front disc/rear drum brakes. The residual check valve has been eliminated by equipping the wheel cylinder internal spring with a sealing cup **expander** to prevent sealing cup lip collapse. See Figure 70–3.

PRESSURE-DIFFERENTIAL SWITCH (BRAKE WARNING SWITCH)

A **pressure-differential switch** is used on all vehicles built after 1967 with dual master cylinders to warn the driver of a loss of pressure in one of the two separate systems by lighting the dashboard red brake warning indicator lamp. See Figure 70–4.

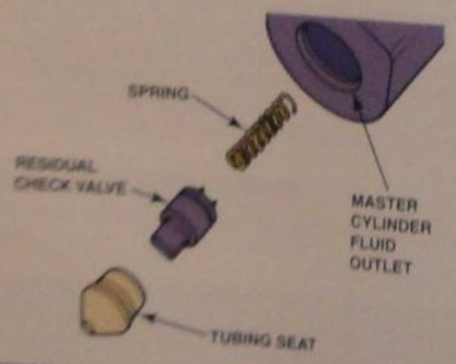


Figure 70–1 Most residual check valves are located under the tubing seats in the master cylinder outlet ports.

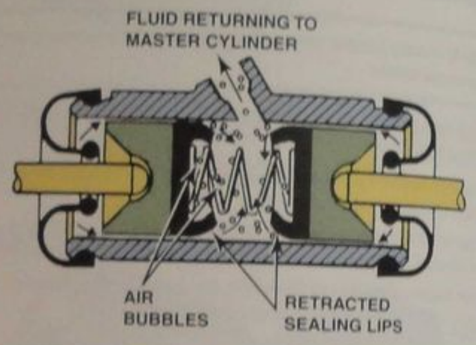


Figure 70–2 The momentary drop in pressure created when the brakes are released can draw air into the hydraulic system.

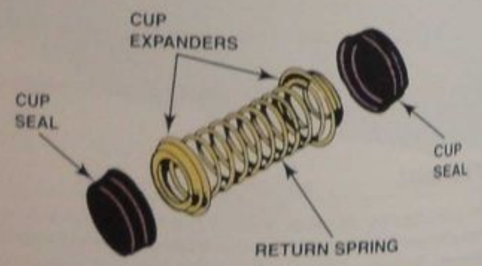


Figure 70–3 The use of cup expanders is the main reason why residual check valves are not used in most braking systems today.

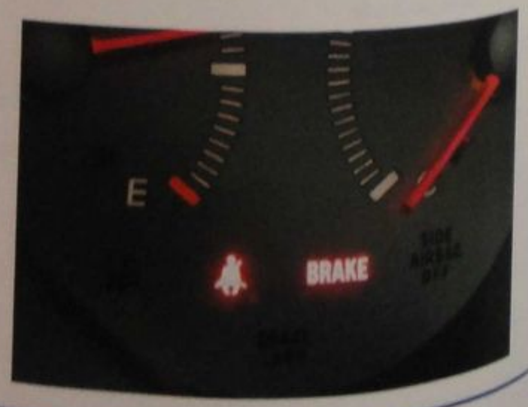


Figure 70–4 A red brake warning lamp.

The brake lines from both the front and the rear sections of the master cylinder are sent to this switch, which lights the brake warning indicator lamp in the event of a "difference in pressure" between the two sections. See Figure 70–5.

A failure in one part of the brake system does not result in a failure of the entire hydraulic system. After the hydraulic system has been repaired and bled, moderate pressure on the brake pedal will center the piston in the switch and turn off the warning lamp.

If the lamp remains on, it may be necessary to do the following:

1. Apply light pressure to the brake pedal.
2. Momentarily open the bleeder valve on the side that did not have the failure.

This procedure should center the pressure-differential switch valve in those vehicles that are not equipped with self-centering springs. See Figure 70–6.

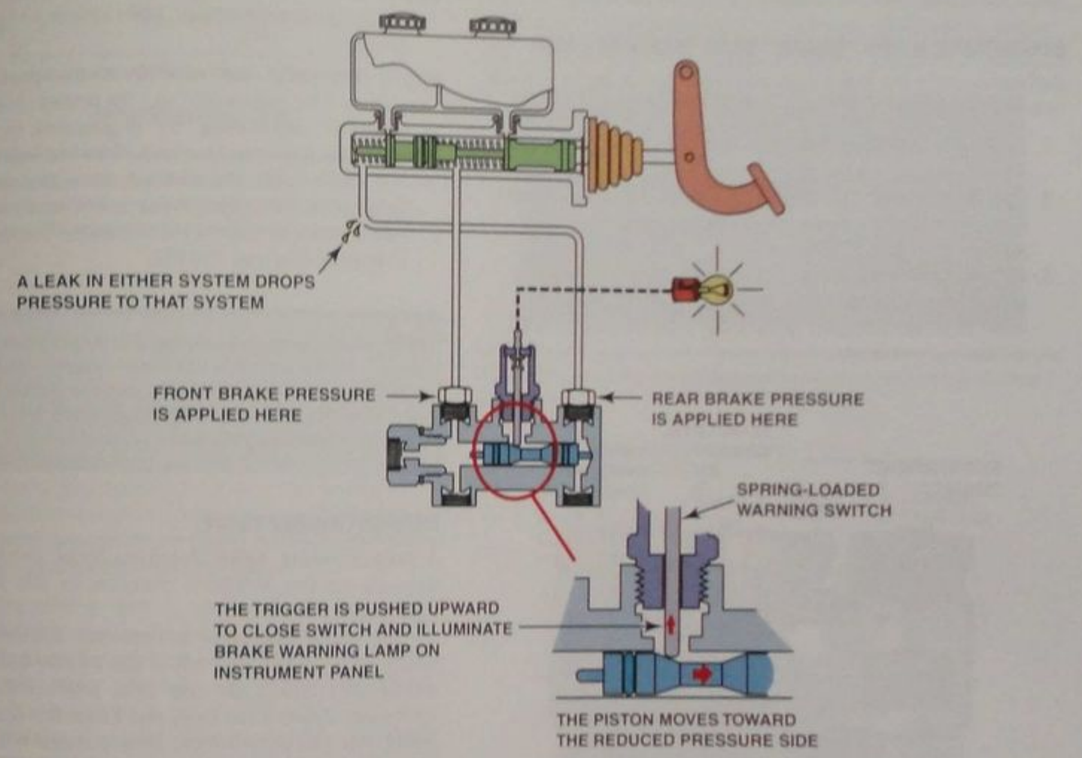


Figure 70–5 A leak in the hydraulic system causes unequal pressures between the two different brake circuits. This difference in pressures causes the plunger inside the pressure-differential switch to move, which completes the electrical circuit for the red brake warning lamp.

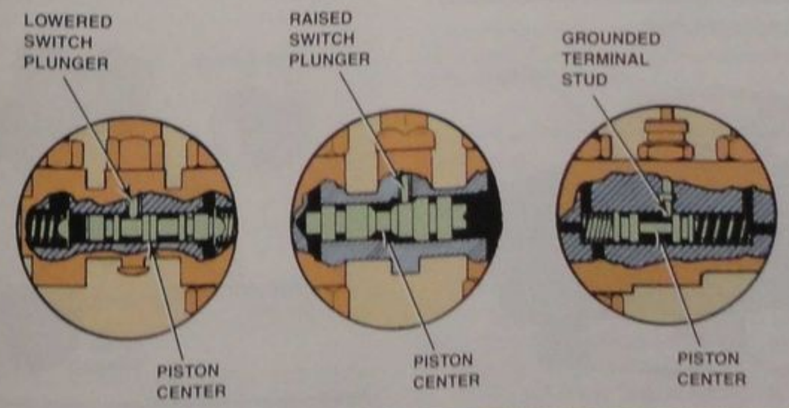


Figure 70–6 The pressure-differential switch piston is used to provide the electrical ground for the red brake warning light circuit.

BRAKE FLUID LEVEL SENSOR SWITCH

Many master cylinders, especially systems that are a diagonal split, usually use a **brake fluid level sensor** or switch in the master cylinder reservoir. This sensor will light the red "brake" warning lamp on the dash if low brake fluid level is detected. A float-type sensor or a magnetic reed switch are commonly used and provide a complete electrical circuit when the brake fluid level is low. After refilling the master cylinder reservoir to the correct level, the red "brake" warning lamp should go out. See Figures 70–7 and 70–8.

DIAGNOSING A RED "BRAKE" DASH WARNING LAMP

Activation of the red brake dash warning lamp can be for any one of several reasons:

1. **Parking Brake "On."** The same dash warning lamp is used to warn the driver that the parking brake is on.
2. **Low Brake Fluid.** This lights the red dash warning lamp on vehicles equipped with a master cylinder reservoir brake fluid level switch.
3. **Unequal Brake Pressure.** The pressure-differential switch is used on most vehicles with a front/rear brake split system to warn the driver whenever there is low brake pressure to either the front or rear brakes.

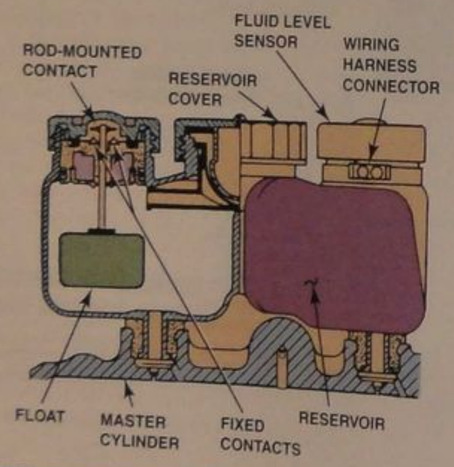


Figure 70–7 A movable contact brake fluid level switch.

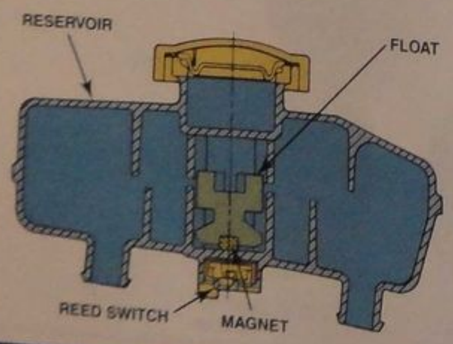


Figure 70–8 A magnetic brake fluid level switch.

NOTE: Brake systems use *either* a pressure-differential switch *or* a low brake fluid switch to light the dash red "brake" lamp, but not both.

The most likely cause of the red "brake" warning lamp being on is low brake fluid caused by a leaking brake line, wheel cylinder, or caliper. Therefore, the first step in diagnosis is to determine the cause of the lamp being on, then to repair the problem.

Step #1 Check the level of the brake fluid. If low, carefully inspect the entire hydraulic brake system for leaks and repair as necessary.

Step #2 Disconnect the wire from the pressure-differential switch. If the lamp is still "on," the problem is due to the parking brake lever switch being "on" or grounded, or the wire going to the switch is shorted to ground. If the red brake warning lamp is "off" after being disconnected from the pressure-differential switch, then the problem is due to a hydraulic failure (a low pressure in either the front or the rear system that creates a difference in pressure of at least 150 PSI).

NOTE: Many Japanese vehicles energize the relay that turns off the red "brake" warning lamp from the output terminal of the alternator. If a quick inspection of the brake system seems to indicate that everything is okay, check for correct charging voltage before continuing a more detailed brake system inspection.

PROPORTIONING VALVE

A **proportioning valve** improves brake balance during hard stops by limiting hydraulic pressure to the rear brakes. See Figure 70–9.

A proportioning valve is necessary because inertia creates weight shift toward the front of the vehicle during braking. The weight shift unloads the rear axle, which reduces traction between the tires and the road, and limits the amount of stopping power that can be delivered. Unless application pressure to the rear wheels is limited, the brakes will lock, making the vehicle unstable and likely to spin. The best overall braking performance is achieved when the front brakes lock just before the rear brakes.

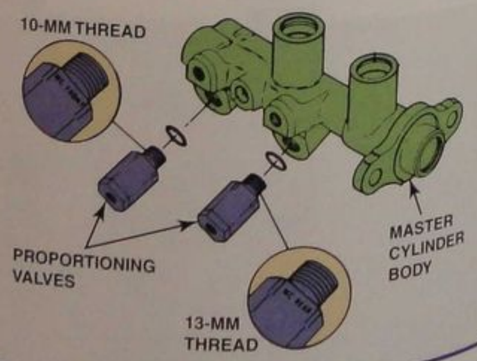


Figure 70–9 Many proportioning valves are mounted directly to the master cylinder in the outlet to the rear brakes.

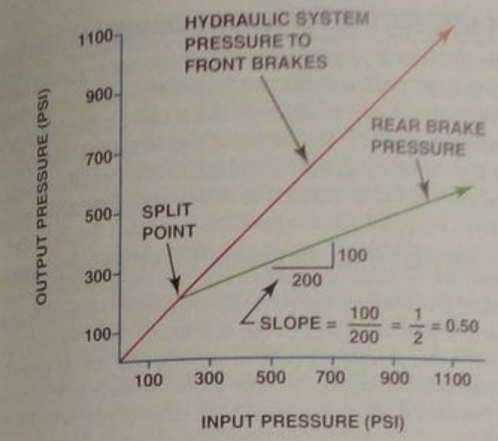


Figure 70–10 Typical proportioner valve pressure relationship. Note that, at low pressures, the pressure is the same to the rear brakes as is applied to the front brakes. After the split point, only a percentage (called the slope) of the master cylinder pressure is applied to the rear brakes.

Vehicles with front disc and rear drum brakes require a proportioning valve for two reasons:

1. Disc brakes require higher hydraulic pressure for a given stop than do drum brakes. In a disc/drum system, the front brakes always need more pressure than the rear brakes.
2. Once braking has begun, drum brakes require less pressure to *maintain* a fixed level of stopping power than they did to *establish* that level. In a disc/drum system, the rear brakes will always need less pressure than the front brakes.

A proportioning valve is used to compensate for these differences because it is easier to reduce pressure to the rear brakes than to increase pressure to the front brakes.

The proportioning valve does not work at all times. During light or moderate braking, there is insufficient weight transfer to make rear wheel locking a problem. Before proportioning action will begin, brake system hydraulic pressure must reach a minimum level called the **split point.** Below the split point full system pressure is supplied to the rear brakes. See Figure 70–10.

Above the split point, the proportioning valve allows only a portion of the pressure through to the rear brakes.

The proportioning valve gets its name from the fact that it regulates pressure to the rear brakes *in proportion* to the pressure applied to the front brakes. Once system hydraulic pressure exceeds the split point, the rear brakes receive a fixed percentage of any further increase in pressure. Brake engineers refer to the ratio of front to rear brake pressure proportioning as the **slope.** Full system pressure to the rear brakes equals a slope of 1, but if only half the pressure is allowed to reach the rear brakes, the proportioning valve is said to have a slope of 0.50. The proportioning valves on most vehicles have a slope between 0.25 and 0.50. See Figures 70–11 and 70–12.

Proportioning Valve Operation A simple proportioning valve consists of a spring-loaded piston that slides in a stepped bore. See Figure 70–13.

The piston is exposed to pressure on both sides. The smaller end of the piston is acted on by pressure from the master cylinder, while the larger end reacts to pressure in the rear brake circuit. The actual proportioning valve is located in the center of the piston and

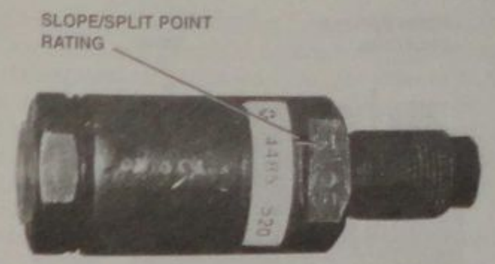


Figure 70–11 A Chrysler proportioning valve. Note that slope and split point are stamped on the housing.



Figure 70–12 These two proportioning valves are found under the vehicle on this Dodge minivan.

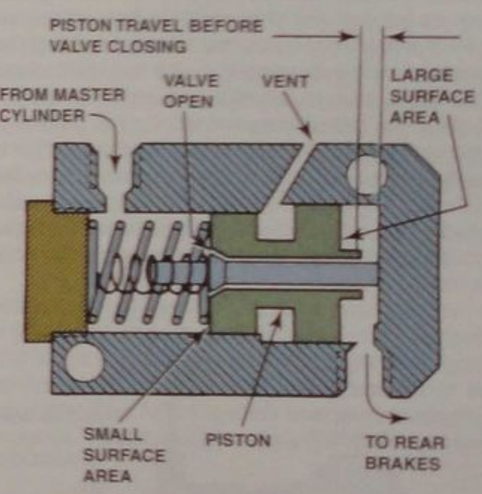


Figure 70–13 The proportioning valve piston can travel within the range shown without reducing pressure to the rear brakes.

is opened or closed depending on the position of the piston in the stepped bore.

When the brakes are first applied, hydraulic pressure passes through the proportioning valve to the rear brakes. Hydraulic pressure is the same on both sides of the piston, but because the side facing the rear brakes has more surface area than the side facing the master cylinder, greater force is developed and the piston moves to the left against the spring tension. At pressures below the split point, the proportioning valve is open, and pressure to both the front and rear brakes is the same.

As the vehicle is braked harder, increased system pressure forces the piston so far to the left that the proportioning valve is closed. See Figure 70–14.

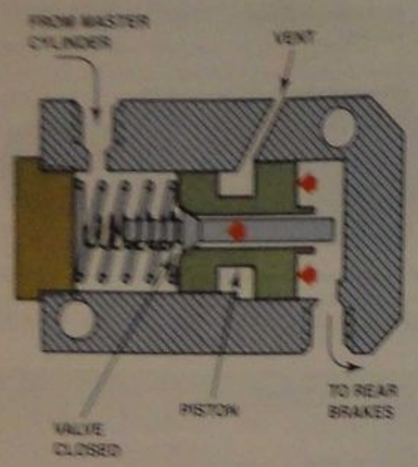


Figure 70–14 At the split point, the proportioning valve piston closes the fluid passage through the valve.

This seals off the brake line and prevents any additional pressure from reaching the rear brakes. The pressure at the moment the proportioning valve first closes is the split point of the valve. From this point on, the rear brakes receive only a portion of the pressure supplied to the front brakes.

As system pressure (the pressure to the front brakes) increases, enough force is developed on the master cylinder side of the piston to overcome the pressure trapped in the rear brake circuit. This forces the piston back to the right and opens the proportioning valve. Some of the higher pressure enters the rear brake circuit, but before pressure in the two circuits can equalize, the force developed on the larger piston area in the rear circuit moves the piston back to the left and closes the valve. The difference in surface area between the two ends of the piston determines the slope of the valve, and thus the percentage of system pressure allowed to reach the rear brakes.

As long as system pressure continues to increase, the piston will repeatedly cycle back and forth, opening and closing the proportioning valve, and maintaining a fixed proportion of full system pressure to the rear brakes. When the brakes are released, the spring returns the piston all the way to the right, which opens the valve and allows fluid to pass in both directions.

TECH TIP ✓ **Always Inspect Both Front and Rear Brakes**

If a vehicle tends to lock up the rear brakes during a stop, many technicians may try to repair the problem by replacing the proportioning valve or servicing the rear brakes. Proportioning valves are simple spring-loaded devices that are usually trouble free. If the rear brakes lock up during braking, carefully inspect the rear brakes looking for contaminated linings or other problems that can cause the rear brakes to grab. Do not stop there—always inspect the front brakes, too. If the front brakes are rusted or corroded, they cannot operate efficiently, and greater force must be exerted by the driver to stop the vehicle. Even if the proportioning valve is functioning correctly, the higher brake pedal pressure by the driver could easily cause the rear brakes to lock up.

A locked wheel has less traction with the road than a rotating wheel. As a result, if the rear wheels become locked, the rear of the vehicle often "comes around" or "fishtails," causing the vehicle to spin. Careful inspection of the entire braking system is required to be assured of a safe vehicle.

HEIGHT-SENSING PROPORTIONING VALVES

Many vehicles use a proportioning valve that varies the amount of pressure that can be sent to the rear brakes depending on the height of the rear suspension. This type of valve is called a **height-sensing proportioning valve.** If the vehicle is lightly loaded, the rear suspension is high, especially during braking. In this case, the amount of pressure allowed to the rear brakes is reduced. This helps prevent rear wheel lockup and possible skidding. Besides, a lightly loaded vehicle requires less braking force to stop than a heavily loaded vehicle.

When the vehicle is loaded, the rear suspension is forced downward. The lever on the proportioning valve moves and allows a greater pressure to be sent to the rear brakes. See Figures 70–15 and 70–16. This greater pressure allows the rear brakes to achieve more braking force, helping to slow a heavier vehicle. When a vehicle is heavily loaded in the rear, the chances of rear wheel lockup are reduced.

CAUTION: Some vehicle manufacturers warn that service technicians should never install replacement air lift shock absorbers or springs that may result in a vehicle height difference than specified by the vehicle manufacturer.

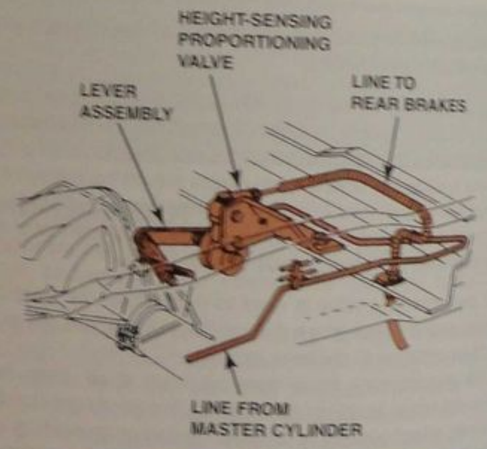


Figure 70–15 A height-sensing proportioning valve provides the vehicle with ample brake balance. The valve allows higher pressure to be applied to the rear brakes when the vehicle is heavily loaded and less pressure when the vehicle is lightly loaded.

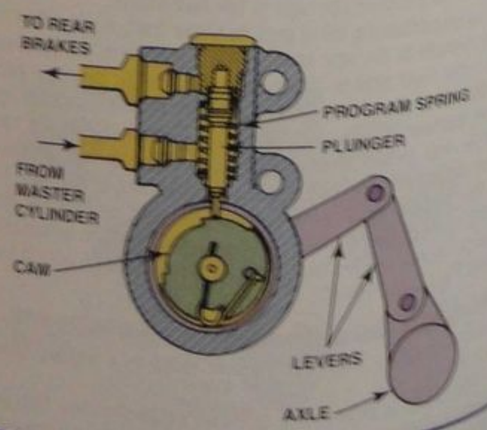


Figure 70–16 A stepped cam is used to alter the split point of this height-sensing proportioning valve.

PROPORTIONING VALVE ADJUSTMENT

Height-sensing proportioning valves should be adjusted when replaced. The proper adjustment ensures that the proper pressure is applied to the rear brakes in relation to the loading of the vehicle.

Procedures vary from one vehicle to another. Always consult the factory service information for the exact procedure. Some trucks require the use of special plastic gauges available from the dealer.

PROPORTIONING VALVE DIAGNOSIS AND TESTING

A defective proportioning valve usually allows rear brake pressure to increase too rapidly, causing the rear wheels to lock up during hard braking. When the rear brakes become locked, the traction with the road surface decreases and the vehicle often skids. Whenever rear brakes tend to lock during braking, the proportioning valve should be checked for proper operation. If the proportioning valve is height sensing, verify the proper vehicle ride (trim) height and adjustment of the operating lever. See Figure 70–17.

Pressure gauges can also be used to check for proper operation. Install one gauge into the brake line from the master cylinder and the second gauge to the rear brake outlet of the proportioning valve. While an assistant depresses the brake pedal, observe the two gauges. Both gauges should register an increasing pressure as the brake pedal is depressed until the split point. After the split point, the gauge connected to the proportioning valve (rear brakes) should increase at a slower rate than the reading on the gauge connected to the master cylinder.

If the pressures do not react as described, the proportioning valve should be replaced. The same procedure can be performed on a diagonal split-type system as used on most front-wheel-drive vehicles.

ELECTRONIC BRAKE PROPORTIONING

The Delphi DBC-7 eliminates the need for a conventional brake proportioning valve. A proportioning valve is usually necessary to reduce pressure to the rear brakes to keep them from locking up. This is because there is less weight over the rear wheels, and weight shifts forward when braking. Proportioning is needed most when a vehicle is lightly loaded or braking from a high speed. Most proportioning valves are calibrated to reduce pressure to the rear brakes by a fixed amount, which may increase the risk of rear-wheel lockup if the vehicle is loaded differently or is braking on a wet or slick surface. Dynamic rear proportioning is overcome by adjusting brake balance to match the need of the vehicle to changing road and load conditions.

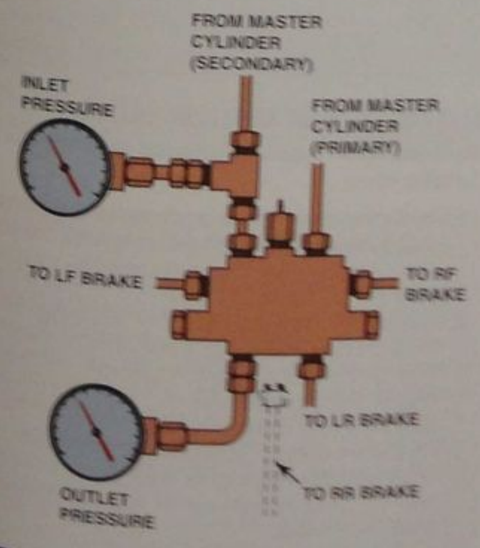
Electronic brake proportioning in the DBC-7 system is accomplished by monitoring front- and rear-wheel speeds, and reducing pressure to the rear brakes as needed using the ABS solenoids when there is a difference in wheel deceleration rates. The controller energizes the inlet valve solenoids for both rear brakes to hold pressure in the lines, and then energizes both rear outlet valve solenoids to release pressure as needed. The pump may also run to clear the accumulators if a sufficient number of release cycles are required.

The dynamic rear proportioning function is enabled at all times unless there is a failure of the EBCM or two wheel speed sensors on the same axle both fail simultaneously. But as long as there is at least one functional speed sensor on the front and rear axles, the Electronic Brake Control Module (EBCM) can compare the relative speeds of the front and rear wheels.

METERING VALVE (HOLD-OFF) OPERATION

A **metering valve** is used on all front-disc, rear-drum brake-equipped vehicles. The metering valve prevents the full operation (holds off) the disc brakes until between 75 and 125 PSI is sent to the rear drum brakes to overcome rear-brake return spring pressure. This allows the front and rear brakes to apply at the same time for even stopping. Most metering valves also allow for the pressure to the front brakes to be gradually blended up to the metering valve pressure to prevent front brake locking under light pedal pressures on icy surfaces.

A metering valve consists of a piston controlled by a strong spring and a valve stem controlled by a weak spring. See Figure 70–18.



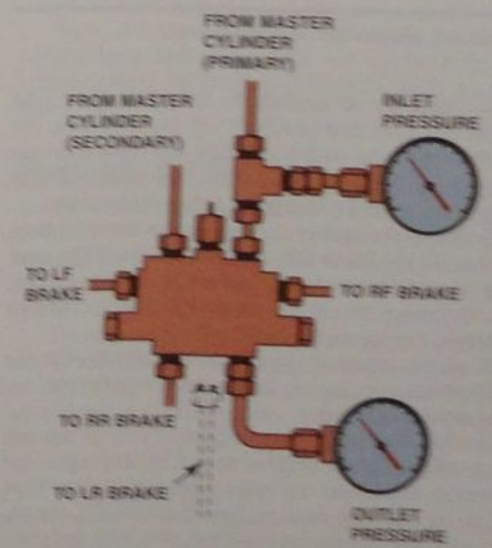


Figure 70–17 A proportioning valve pressure test can be performed using two pressure gauges—one to register the pressure from the master cylinder and the other gauge to read the pressure being applied to the rear brakes. This test has to be repeated in order to read the pressure to each rear wheel.

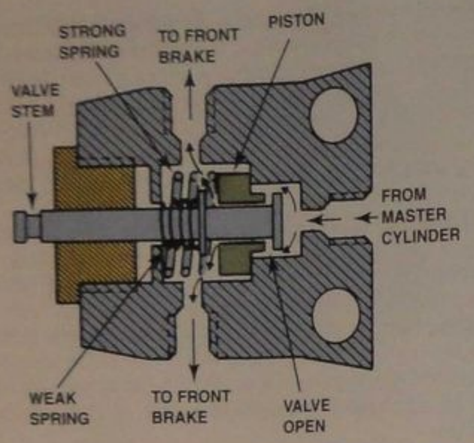


Figure 70–18 A metering valve when the brakes are not applied. Notice the brake fluid can flow through the metering valve to compensate for brake fluid expansion and contraction that occurs with changes in temperature.

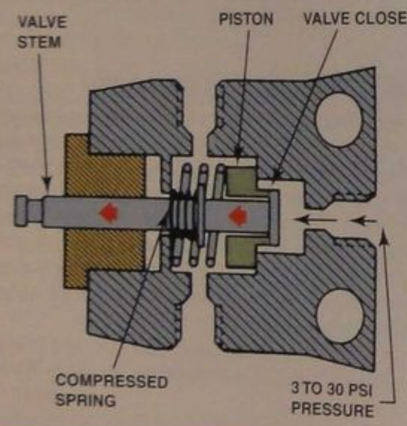


Figure 70–19 A metering valve under light brake pedal application.

When the brakes are not applied, the strong spring seats the piston and prevents fluid flow around it. At the same time, the weak spring holds the valve stem to the right and opens a passage through the center of the piston. Brake fluid is free to flow through this passage to compensate for changes in system fluid volume.

When the brakes are applied and pressure in the front brake line reaches 3 to 30 PSI (20 to 200 kPa), the tension of the weak spring is overcome and the metering valve stem moves to the left, which closes the passage through the piston and prevents fluid flow to the front brakes. See Figure 70–19.

The small amount of pressure applied to the calipers before the metering valve closes is enough to take up any clearance, but not enough to generate braking force.

While the fluid flow to the front calipers is shut off, the rear brake shoes move into contact with the drums, braking begins, and hydraulic pressure throughout the brake system increases. When the pressure at the metering valve reaches 75 to 300 PSI, the tension of the strong spring is overcome and the valve stem and piston move farther to the left. See Figure 70–20.

This opens a passage around the outside of the piston and allows fluid to flow through the valve to the front brake calipers.

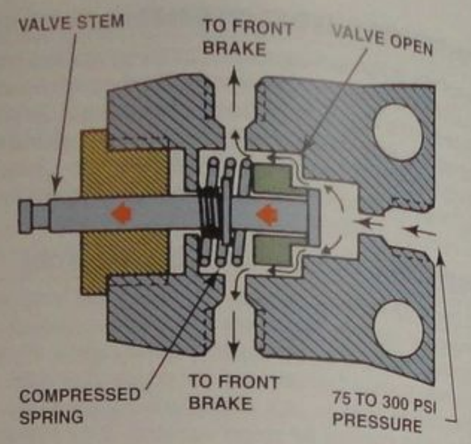


Figure 70–20 A metering valve during a normal brake application.

When the brakes are released, the strong spring seats the piston and prevents fluid flow around it. At the same time, the weak spring opens the fluid passage through the center of the piston. Excess fluid returns to the master cylinder through this passage and the valve is ready for another brake application.

TECH TIP ✔ **No Valves Can Cause a Pull**

When diagnosing a pull to one side during braking, some technicians tend to blame the metering valve, proportional valve, the pressure differential switch, or the master cylinder itself.

Just remember that if a vehicle pulls during braking that the problem has to be due to an individual wheel brake or brake line. The master cylinder and all the valves control front or rear brakes together or diagonal brakes and cannot cause a pull if not functioning correctly.

NOTE: Braking systems that are diagonal split, such as those found on most front-wheel-drive vehicles, do *not* use a metering valve. A metering valve is only used on front/rear split braking systems such as those found on most rear-wheel-drive vehicles.

SYSTEMS WITHOUT METERING VALVES

There are three reasons front-wheel-drive vehicles do not use metering valves:

1. Front-wheel-drive vehicles usually have a diagonally split dual braking system that would require a separate metering valve for each hydraulic circuit. This would make the brake system more costly and complicated.
2. Front-wheel-drive vehicles have a forward weight bias that requires the front brakes to supply up to 80% of the total braking power. Since the front brakes do most of the work, it is desirable to apply them as soon as possible when the brake pedal is depressed. A metering valve would create a slight delay.
3. Until all the clearance in the brake system is taken up, there will not be enough pressure in the brake hydraulic system for the front disc brakes to overcome the engine torque applied to the driven front wheels.

Engine torque and a heavy front weight bias help prevent front wheel lockup from being a problem during light braking or when the brakes are first applied.

Most rear-wheel-drive vehicles without metering valves are equipped with four-wheel disc brakes. Because the clearance between the pads and rotors is approximately the same at all four wheels, there is no need to delay front brake actuation. Some of these vehicles also have antilock brake systems that prevent the wheels from locking at any time. Other rear-wheel-drive vehicles without metering valves have a predominantly forward weight bias, like front-wheel-drive vehicles, and therefore benefit from having the front brakes applied sooner.

METERING VALVE DIAGNOSIS AND TESTING

A defective metering valve can leak brake fluid and/or cause the front brakes to apply before the rear brakes. This is most commonly noticed on slippery surfaces such as on snow or ice or on rain-slick roads. If the front brakes lock up during these conditions, the front wheels cannot be steered. Inspect the metering for these two conditions:

1. Look around the bottom of the metering valve for brake fluid leakage. (Ignore slight dampness.) Replace the metering valve assembly if it is leaking.
2. As the pressure builds to the front brakes, the metering valve stem should move. If it does not, replace the valve.

More accurate testing of the metering valve can be accomplished using pressure gauges. Install two gauges, one in the pressure line coming from the master cylinder and the other in the outlet line leading to the front brakes. When depressing the brake pedal, both gauges should read the same until about 3 to 30 PSI (20 to 200 kPa) when the metering valve shuts, thereby delaying the operation of the front brakes. The master cylinder outlet gauge should show an increase in pressure as the brake pedal is depressed further.

Once 75 to 300 PSI is reached, the gauge showing pressure to the front brakes should match the pressure from the master cylinder. If the pressures do not match these ranges, the metering valve assembly should be replaced.

NOTE: Neither the metering valve nor the proportioning valve can cause a pull to one side if defective. The metering valve controls *both* front brakes, and the proportioning valve controls *both* rear brakes. A defective master cylinder cannot cause a pull either. Therefore, if a vehicle pulls to one side during a stop, look for problems in the individual wheel brakes, hoses, or suspension.

TECH TIP ✔ **Push-In or Pull-Out Metering Valve?**

Whenever bleeding the air out of the hydraulic brake system, the metering valve should be bypassed. The metering valve stops the passage of brake fluid to the front wheels until pressure exceeds about 125 PSI (860 kPa). It is important not to push the brake pedal down with a great force so as to keep from dispersing any trapped air into small and hard-to-bleed bubbles. To bypass the metering valve, the service technician has to push or pull a small button located on the metering valve. An easy way to remember whether to push in or to pull out is to inspect the button itself. *If the button is rubber coated, then you push in. If the button is steel, then pull out.*

Special tools allow the metering valve to be held in the bypass position. Failure to remove the tool after bleeding the brakes can result in premature application of the front brakes before the rear drum brakes have enough pressure to operate.

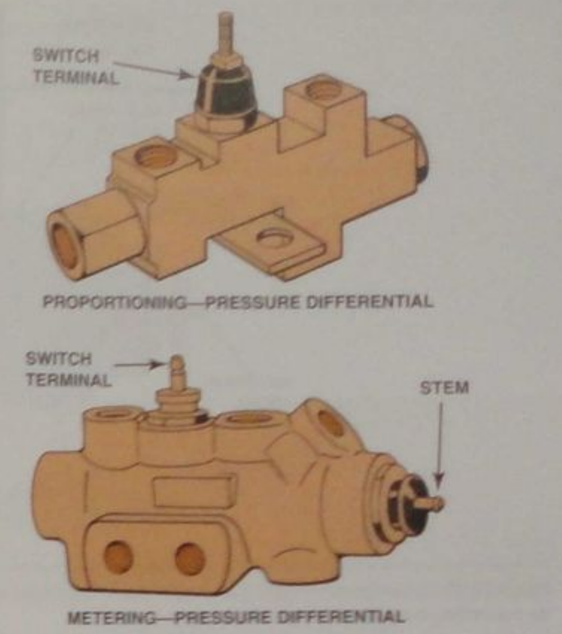


Figure 70–21 Typical two-function combination valves.

COMBINATION VALVE

Most vehicle manufacturers combine the function of a proportioning valve with one or more other valves into one unit called a **combination valve.** See Figures 70–21 and 70–22.

On a typical rear-wheel-drive vehicle, a typical combination valve consists of the following components all in one replaceable unit:

- Metering valve
- Proportioning valve
- Pressure-differential switch

Some combination valves have only two functions and contain the pressure-differential and the metering valve, while others combine the pressure-differential with the proportioning valve.

BRAKE LIGHT SWITCH

The job of the **brake light switch** is to turn on the brake lights at the back of the vehicle when the brakes are applied. A properly adjusted light switch will activate the brake lights as soon as the brake pedal is applied and before braking action actually begins at the wheels.

Mechanical switches that operate directly off the brake pedal arm are most often used. See Figure 70–23.

Brake light switches are normally open. When the brakes are applied, the switch closes, which completes the brake light circuit.

CAUTION: Always check service information for the specified procedures to follow when replacing and/or adjusting a brake switch to ensure proper operation.

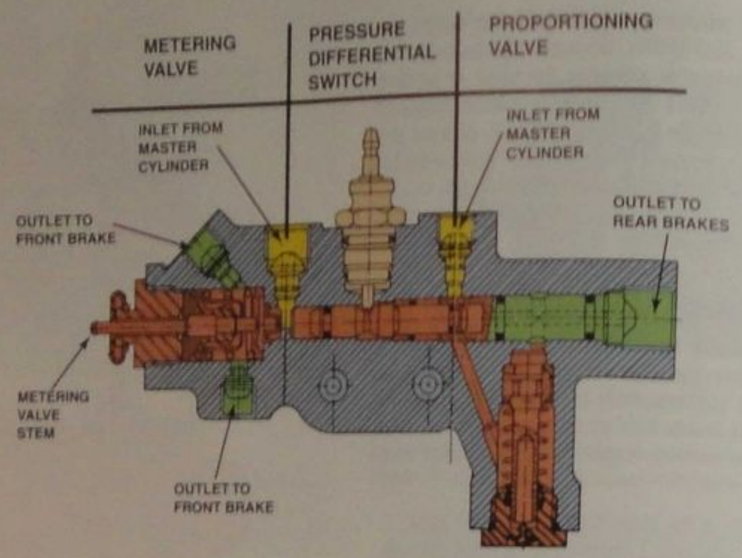


Figure 70–22 Combination valve containing metering, pressure-differential (warning switch), and proportioning valves all in one unit. This style is often called a "pistol grip" design because the proportioning valve section resembles the grip section of a hand gun.



Figure 70–23 Typical brake light switches.

SUMMARY

1. Residual check valves are used in older vehicles to keep a slight amount of pressure on the system to help prevent air from entering the system when the brake pedal is released.
2. A pressure-differential switch is used to turn on the red brake warning lamp in the event of a hydraulic pressure failure.
3. Brake fluid level sensors are used in many vehicles to warn the driver that the brake fluid level is low.
4. Proportioning valves are used to limit the maximum fluid pressure sent to the rear wheel brakes during heavy braking to help prevent rear wheel lockup.
5. Metering valves are used on some vehicles to keep the front disc brakes from locking up on slippery surfaces.
6. Combination valves include two or more hydraulic valves in one assembly.

REVIEW QUESTIONS

1. Why are residual check valves not used in most vehicles?
2. List the three possible reasons that could cause the red brake warning lamp to come on during driving.
3. Explain why metering valves are not used on all vehicles.
4. Explain the split point and the slope of a proportioning valve.

CHAPTER QUIZ

1. Technician A says a pull to the right during braking could be caused by a defective metering valve. Technician B says a pull to the left could be caused by a defective proportioning valve. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. The rear brakes lock up during a regular brake application. Technician A says the metering valve could be the cause. Technician B says that stuck front disc brake calipers could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. The rear wheels lock up during hard braking. Technician A says that a defective metering valve could be the cause. Technician B says that a defective proportioning valve could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. A combination valve includes _____.
   a. Metering and proportioning valves
   b. Proportioning and pressure-differential valves
   c. Proportioning, metering, and pressure-differential valves
   d. Any of the above depending on the make and model of the vehicle
5. A residual check valve is used to _____.
   a. Maintain a slight pressure on the hydraulic system
   b. Prevent front wheel lockup during hard braking
   c. Prevent rear wheel lockup during hard braking
   d. Speed brake release to reduce brake wear
6. Technician A says that the red brake warning light can be turned on if a difference in pressure is detected by the pressure-differential switch. Technician B says that the red brake warning light can be turned on if the brake fluid level sensor detected low brake fluid level. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Which type of vehicles most often do not use metering valves?
   a. Rear-wheel drive
   b. Four-wheel drive
   c. Front-wheel drive
   d. All-wheel drive
8. A spongy brake pedal is being diagnosed. Technician A says that air in the hydraulic system could be the cause. Technician B says a defective pressure-differential switch could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. The button on the _____ valve should be held when pressure bleeding the brakes.
   a. Metering
   b. Proportioning
   c. Pressure-differential
   d. Residual check
10. A typical brake light is electrically _____.
    a. Normally open
    b. Normally closed

CHAPTER 71

Brake Fluid and Lines

OBJECTIVES: After studying Chapter 71, the reader will be able to: Prepare for ASE Brakes (A5) certification test. • List the types of brake fluids. • Describe where armored brake line is used. • Discuss the differences between double-flare and ISO flare. • Explain how flexible brake lines should be handled during service. • List the precautions necessary when handling or disposing of brake fluid. • Discuss the types of rubber that are used in brake system components.

KEY TERMS: armored brake line • brake fluid • brake lines • brake pipes • brake tubing • DOT 3 • DOT 4 • DOT 5 • DOT 5.1 • double flare • elastomers • flexible brake hoses • hydraulic system mineral oil (HSMO) • hygroscopic • International Standards Organization (ISO) • nonhygroscopic • polyglycol • silicone brake fluid

BRAKE FLUID

Brake fluid is designed to function in the hydraulic brake system under all operating conditions. Brake fluid boiling point is one of the most critical aspects and ratings for brake fluid. As brake fluid ages, it absorbs moisture, which lowers its boiling point and causes increased corrosion of the brake system components.

All automotive experts agree that brake fluid should be changed regularly as part of normal routine service. Even though the driver may not notice an immediate improvement, the reduced corrosion will eventually result in less money being spent for brake system component replacement in the future. Getting the old low-boiling-point brake fluid out of the system could prevent a total loss of brakes due to brake fluid boiling!

All brake fluids must be able to pass tests for the following:

1. Fluidity at low temperatures
2. Controlled percentage loss due to evaporation at high temperatures [tested at 212°F [100°C]]
3. Compatibility with other brake fluids
4. Resistance to oxidation
5. Specific effects on rubber, including:
   a. No disintegration
   b. No increase in hardness of the rubber tested
   c. Limited amount of decrease in hardness of the rubber

BRAKE FLUID TYPES

Brake fluid is made from a combination of various types of glycol, a non-petroleum-based fluid. Brake fluid is a polyalkylene-glycol–ether mixture called **polyglycol** for short. *All polyglycol brake fluid is clear to amber in color.* Brake fluid has to have the following characteristics:

- A high boiling point
- A low freezing point
- No ability to damage rubber parts in the brake system

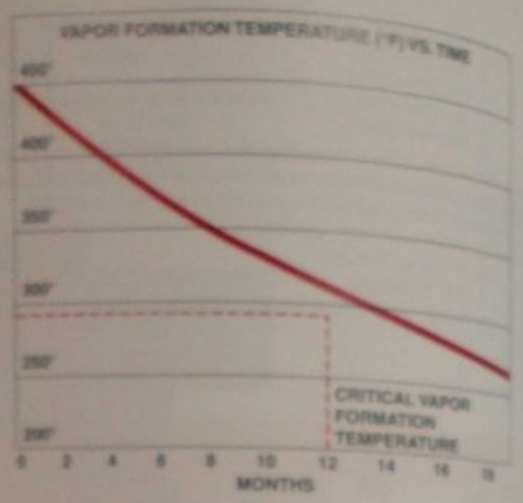
BRAKE FLUID SPECIFICATIONS

All automotive brake fluid must meet federal Motor Vehicle Safety Standard 116. The Society of Automotive Engineers (SAE) and the Department of Transportation (DOT) have established brake fluid specification standards as shown in the following chart.

	DOT 3	DOT 4	DOT 5.1	DOT 5
Dry Boiling Point				
°F	401	446	500	500
°C	205	230	260	260
Wet Boiling Point				
°F	284	311	356	356
°C	140	155	180	180

The wet boiling point is often referred to as ERBP, or equilibrium reflux boiling point. ERBP refers to the method in the specification (SAE J1703) by which the fluid is exposed to moisture and tested.





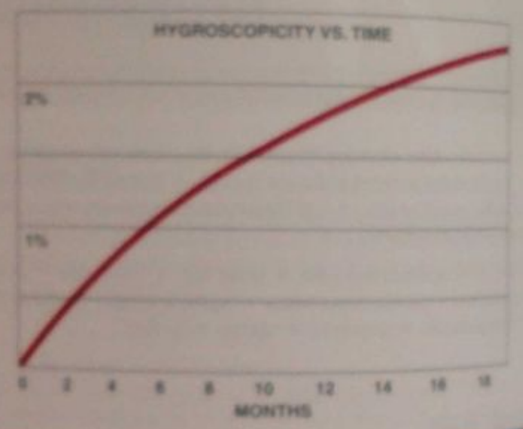


Figure 71–2 Brake fluid absorbs moisture from the air at the rate of about 2% per year. As the brake fluid absorbs water, its boiling temperature decreases.

DOT 5 DOT 5 brake fluid is commonly called **silicone brake fluid** and is made from polydimethylsiloxanes. It does not absorb any water, and is therefore called **nonhygroscopic.**

FREQUENTLY ASKED QUESTION ???

What Is Blue Brake Fluid?

Some brake fluid vendors market a high-performance DOT 4 brake fluid that is dyed blue and is called "super blue" while others market a super DOT 4 that is yellow. These brake fluids are designed to be sold in Europe. The advertising claim that the bright color of the brake fluid makes it easy to see when all of the old fluid has been purged from the system during a brake fluid replacement procedure.

NOTE: Even though DOT 5 does not normally absorb water, it is still tested using standardized SAE procedures in a humidity chamber. After a given amount of time, the brake fluid is measured for boiling point. Since it has had a chance to absorb moisture, the boiling point after this sequence is called the minimum wet boiling point.

DOT 5 brake fluid is purple (violet) in color to distinguish it from DOT 3 or DOT 4 brake fluid. Silicones have about three times the amount of dissolved air as glycol fluids (about 15% of dissolved air versus only about 5% for standard glycol brake fluid). It is this characteristic of silicone brake fluid that causes the most concern about its use.

1. Silicone brake fluid has an affinity for air; therefore, it is more difficult to bleed the hydraulic system of trapped air.
2. The trapped air expands with increasing temperature. This causes the brake pedal to feel "mushy" because the pressure exerted on the hydraulic system simply compresses the air in the system and does not transfer the force to the wheel cylinders and calipers as it should.

NOTE: The characteristics of DOT 5 silicone brake fluid to absorb air is one of the major reasons why it is not recommended for use with an antilock braking system (ABS). In an ABS, valves and pumps are used which can aerate the brake fluid. Brake fluid filled with air bubbles cannot properly lubricate the ABS components and will cause a low, soft brake pedal.

3. The air trapped in the silicone brake fluid can also "off-gas" at high altitudes, causing a mushy brake pedal and reduced braking performance. DOT 5 brake fluid has been known to create a braking problem during high-altitude (over 5,000 ft [1,500 m]) and high-temperature driving. The high altitude tends to vaporize (or gasify) some parts of the liquid, creating bubbles in the brake system, similar to having air in the brake system.
4. DOT 5 brake fluid should not be mixed with any other type of brake fluid. Therefore, the entire braking system must be completely flushed and refilled with DOT 5.
5. DOT 5 does not affect rubber parts and will not cause corrosion.
6. DOT 5 is expensive. It is approximately four times the cost of DOT 3 brake fluid.

HYDRAULIC SYSTEM MINERAL OIL

Some French-built Citroen and British-designed Rolls-Royce vehicles use **hydraulic system mineral oil (HSMO)** as part of their hydraulic control systems. The systems in these vehicles use a hydraulic pump to pressurize hydraulic oil for use in the suspension leveling and braking systems.

REAL WORLD FIX **The Sinking Brake Pedal**

This author has experienced what happens when brake fluid is not changed regularly. Just as many technicians will tell you, we do not always do what we know should be done to our own vehicles.

While driving a four-year-old vehicle on vacation in very hot weather in mountainous country, the brake pedal sank to the floor. When the vehicle was cold, the brakes were fine. But after several brake applications, the pedal became soft and spongy and sank slowly to the floor if pressure was maintained on the brake pedal. Because the brakes were OK when cold, I knew it had to be boiling brake fluid. Old brake fluid (four years old) often has a boiling point under 300°F (150°C). With the air temperature near 100°F (38°C), it does not take much more heat to start boiling the brake fluid. After bleeding over a quart (1 liter) of new brake fluid through the system, the brakes worked normally. I'll never again forget to replace the brake fluid as recommended by the vehicle manufacturer. See Figure 71–3 for a tester that can be used to measure the boiling point of brake fluid.

CAUTION: Mineral hydraulic oil should never be used in a braking system that requires DOT 3 or DOT 4 polyglycol-based brake fluid. If any mineral oil, such as engine oil, transmission oil, or automatic transmission fluid (ATF), gets into a braking system that requires glycol brake fluid, every rubber part in the entire braking system must be replaced. Mineral oil causes the rubber compounds that are used in glycol brake fluid systems to swell. See Figure 71–4.



Figure 71–3 A brake fluid tester can test brake fluid for boiling point.



Figure 71–4 Both rubber sealing cups were exactly the same size. The cup on the left was exposed to mineral oil. Notice how the seal greatly expanded.



Figure 71–5 New brake fluid is clear or amber in color as shown here.

To help prevent hydraulic system mineral oil from being mixed with glycol brake fluid, *hydraulic mineral oils are green.*

BRAKE FLUID INSPECTION AND TESTING

The brake fluid should be inspected regularly, including the following items:

1. **Proper level.** The brake fluid level should be above the minimum level (labeled MIN) and below the maximum (labeled MAX) on the side of the master cylinder reservoir. Do not add brake fluid unless the entire brake system is carefully inspected for worn brake pads and shoes and for signs of any external leakage.
2. **Color/condition.** New brake fluid is clear or amber in color, as seen in Figure 71–5. If the brake fluid is black or discolored as shown in Figure 71–6, the fluid should be changed.

NOTE: Some experts recommend replacing the brake fluid if it looks like coffee, either black coffee or coffee with cream.

3. **Tested using a tester or test strips.** Often, brake fluid does not look as if it is bad but has absorbed moisture enough to reduce its effectiveness. See Figure 71–7.
4. **Brake fluid contamination test.** If brake fluid is mixed with any mineral oil, such as engine oil, power steering fluid, or automatic transmission fluid, rubber components will swell and cause brake system failure. To check for possible contamination,

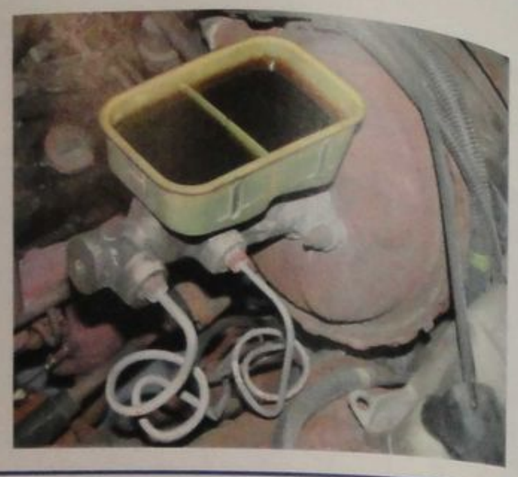
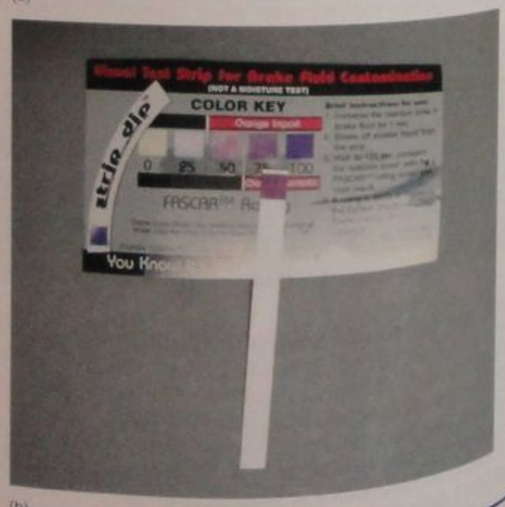


Figure 71–6 This brake fluid is black in color and should be replaced.



(a)



(b)

Figure 71–7 (a) A brake fluid test strip is being used to test the condition of the brake fluid. (b) The color of the test strip is then compared with a chart on the package, which indicates the condition.

remove the reservoir cover from the master cylinder. If the rubber diaphragm is swelled or distorted, brake fluid contamination is likely. To check the brake fluid, use a Styrofoam cup filled with water. Place a teaspoon (1 ml) of brake fluid from the master cylinder into the water. Pure brake fluid will completely dissolve in the water. Petroleum or mineral oil fluids will float on the surface of the water and retain their color. Petroleum fluids will also dissolve the Styrofoam cup at the waterline. If the brake fluid is contaminated, the entire braking system must be drained and flushed and all rubber components replaced.

BRAKE FLUID SERVICE PROCEDURES AND PRECAUTIONS

1. Store brake fluid only in its original container.

NOTE: To help prevent possible contamination with moisture, air, or other products, purchase brake fluid in small containers. Keep all brake fluid containers tightly closed to prevent air (containing moisture) from being absorbed.

2. Before opening a brake fluid container, remove any dirt, moisture, or other contamination from the top and outside of the container.
3. When a brake fluid container is empty, it should be discarded—the container should never be used for anything except brake fluid.
4. Do not transfer brake fluid to any other container that may have contained oil, kerosene, gasoline, antifreeze, water, cleaners, or any other liquids or chemicals.
5. Do not reuse brake fluid that has been siphoned from another vehicle or drawn out during a brake bleeding operation. (Brake bleeding means to open special bleeder valves in the hydraulic system to rid the system of any trapped air.)
6. Use only fresh new brake fluid for flushing the hydraulic brake system.

CAUTION: Alcohol or flushing fluids should not be used because they cannot be totally removed and will contaminate the system. Disassembled parts, however, can and should be cleaned with denatured alcohol or spray brake cleaner where the parts can be visually inspected to be free of cleaning solutions.

REAL WORLD FIX — **The Pike's Peak Brake Inspection**

All vehicles must stop about halfway down Pike's Peak mountain in Colorado (14,110 ft [4,300 m]) for a "brake inspection." When this author stopped at the inspection station, a uniformed inspector simply looked at the right front wheel and waved us on. I pulled over and asked the inspector what he was checking. He said that when linings and drums/rotors get hot, the vehicle loses brake effectiveness. But if the brake fluid boils, the vehicle loses its brakes entirely. The inspector was listening for boiling brake fluid at the front wheel and feeling for heat about 1 ft (30 cm) from the wheel. If the inspector felt heat 1 ft away from the brakes, the brakes were definitely too hot to continue, and you would be instructed to pull over and wait for the brakes to cool. The inspector recommended placing the transmission into a lower gear, which uses the engine to slow the vehicle during the descent without having to rely entirely on the brakes.

BRAKE FLUID HANDLING AND DISPOSAL

Polyglycol brake fluid presents little toxicity hazard, but for some individuals, brake fluid may produce moderate eye and skin irritation. For good safety practice, protective clothing and safety glasses or goggles should be worn.

Brake fluid spilled on the floor should be cleaned up using absorbent material and the material disposed of in the regular trash. Brake fluid becomes a hazardous waste if spilled onto open ground, where it can seep into groundwater. The disposal requirements for brake fluid spilled onto open ground vary with the exact amount spilled and other factors. Refer to local EPA guidelines and requirements for the exact rules and regulations in your area.

RUBBER TYPES

Vehicles use a wide variety of rubber in the braking system, suspension system, steering system, and engine. Rubber products are called **elastomers.** Some are oil- and grease-resistant elastomers and can be harmed by brake fluid, while others are brake-fluid resistant and can swell or expand if they come in contact with oil or grease. See the chart for types and compatible fluids.

Rubber Compatibility Chart

Name	Abbreviations	OK	Not OK	Uses
Ethylene propylene diene (developed in 1963)	EPM, EPDM, EPR	Brake fluid, silicone fluids	Petroleum fluids	Most brake system seals and parts
Styrene, butadiene (developed in 1929)	SBR, BUNA S, GRS	Brake fluid, silicone fluids, alcohols	Petroleum fluids	Some drum brake seals, O-rings
Nitrile (nitrile butadiene rubber)	NBR, BUNA N	Petroleum fluids, ethylene glycol (antifreeze)	Brake fluid	Engine seals, O-rings
Neoprene (polychloroprene)	CR	Refrigerants (Freons: R-12 and R-134a), petroleum fluids	Brake fluids	Refrigerant, O-rings
Polyacrylate	ACM	Petroleum fluids, automatic transmission fluids	Brake fluids	Automatic transmission and engine seals
Viton (fluorocarbon)	FKM	Petroleum fluids	Brake fluid, 134a refrigerant	Engine seals, fuel system parts
Natural rubber	NR	Water, brake fluid	Petroleum fluids	Tires

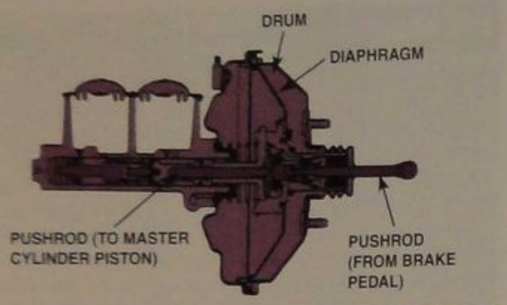


Figure 71–8 The master cylinder piston seals are usually constructed from EPDM rubber, and the diaphragm of the vacuum power brake booster is usually made from SBR.

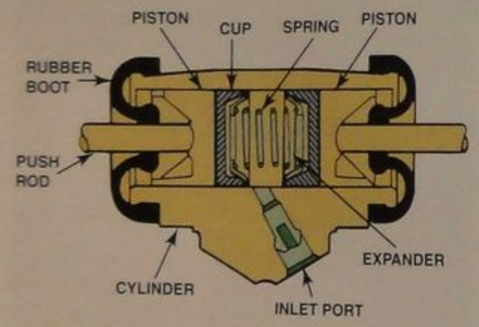


Figure 71–9 Cross-sectional view of a typical drum brake wheel cylinder. Most wheel cylinder boots and cups are either SBR or EPDM rubber.

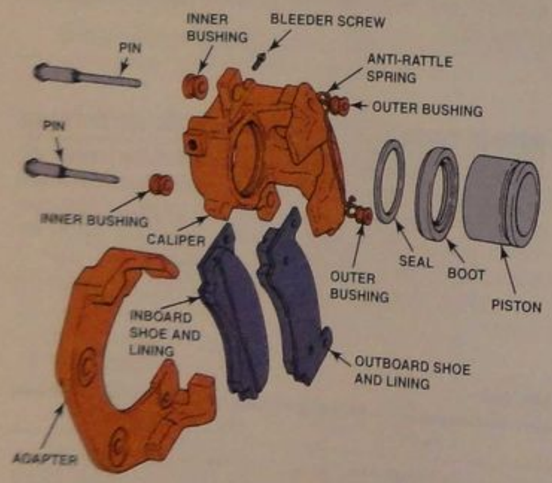


Figure 71–10 Exploded view of a typical disc brake caliper. Both the caliper seal and dust boot are constructed of EPDM rubber.

See Figures 71–8 through 71–10 for examples of where rubber is used in the braking system.

Brake fluid (DOT 3 or DOT 4 glycol brake fluid) affects all elastomers and causes a slight swelling effect (about 5%). This swelling action is necessary for the seals to withstand high hydraulic pressures. Silicone (DOT 5) brake fluid does not cause rubber to swell; therefore, a rubber swell additive is used in silicone brake fluid. While these additives work well for EPDM rubber, it can cause SBR rubber to swell too much. Although most seals today use EPDM, many drum brakes still use SBR seals. This is a major reason that DOT 5 brake fluid is not recommended by many vehicle manufacturers.

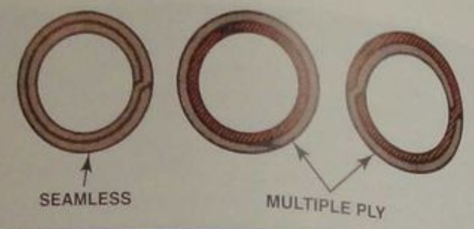


Figure 71–11 Steel brake tubing is double-walled for strength and plated for corrosion resistance.

BRAKE LINES

High-pressure double-walled steel brake lines or high-strength flexible lines are used to connect the master cylinder to each wheel. The steel **brake lines** are also called **brake pipes** or **brake tubing.** Brake lines carry brake fluid from the master cylinder to the wheel cylinder and brake calipers. The brake lines contain and direct the pressure of the brake hydraulic system.

Most of the total length of the brake line consists of rigid tubing. For maximum strength and durability, all brake systems use double-walled brake tubing made from plated steel sheet. There are two types of double-walled tubing. See Figure 71–11.

- Seamless
- Multiple ply

All double-walled brake tubing is plated with tin, zinc, or other similar substances for protection against rust and corrosion. The Society of Automotive Engineers (SAE) has guidelines for brake tubing. SAE Standard J1047 specifies that a sample section of brake line must be able to withstand 8,000 PSI (55,000 kPa) plus other standards for resistance to fatigue, heat, rust, and corrosion.

CAUTION: Copper tubing should *never* be used for brake lines. Copper tends to burst at a lower pressure than steel.

All steel brake lines have one of two basic types of ends:

- **Double Flare.** See Figure 71–12.
- **ISO,** which stands for **International Standards Organization** (also called a *ball flare* or *bubble flare*). See Figure 71–13.

When replacing steel brake line, new steel tubing should be used and a double lap flare or an ISO flare completed at each end using a special flaring tool. See Figures 71–14 and 71–15 on page 856.

Brake line can also be purchased in selected lengths already correctly flared. They are available in different diameters, the most commonly used being 3/16 in. (4.8 mm), 1/4 in. (6.4 mm), and 5/16 in. (7.9 mm) outside diameter (O.D.).

CAUTION: According to vehicle manufacturers' recommended procedures, compression fittings should never be used to join two pieces of steel brake line. Only use double-flare ends and connections, if necessary, when replacing damaged steel brake lines.

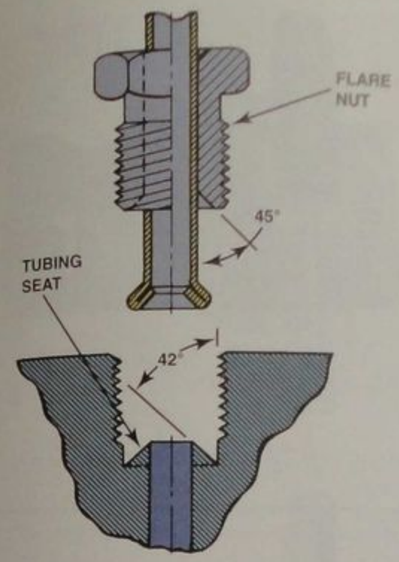


Figure 71–12 Because of the slight difference in flare angle, double-flare fitting seals cause a wedging action.

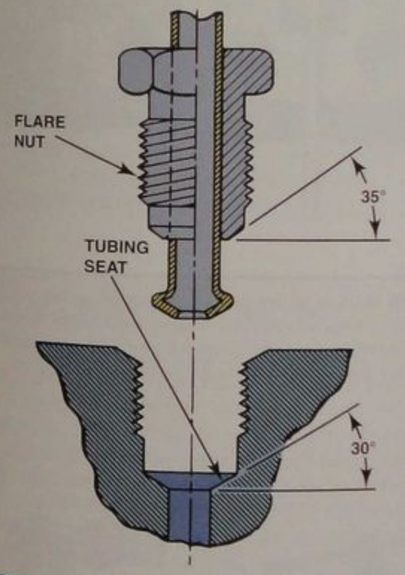
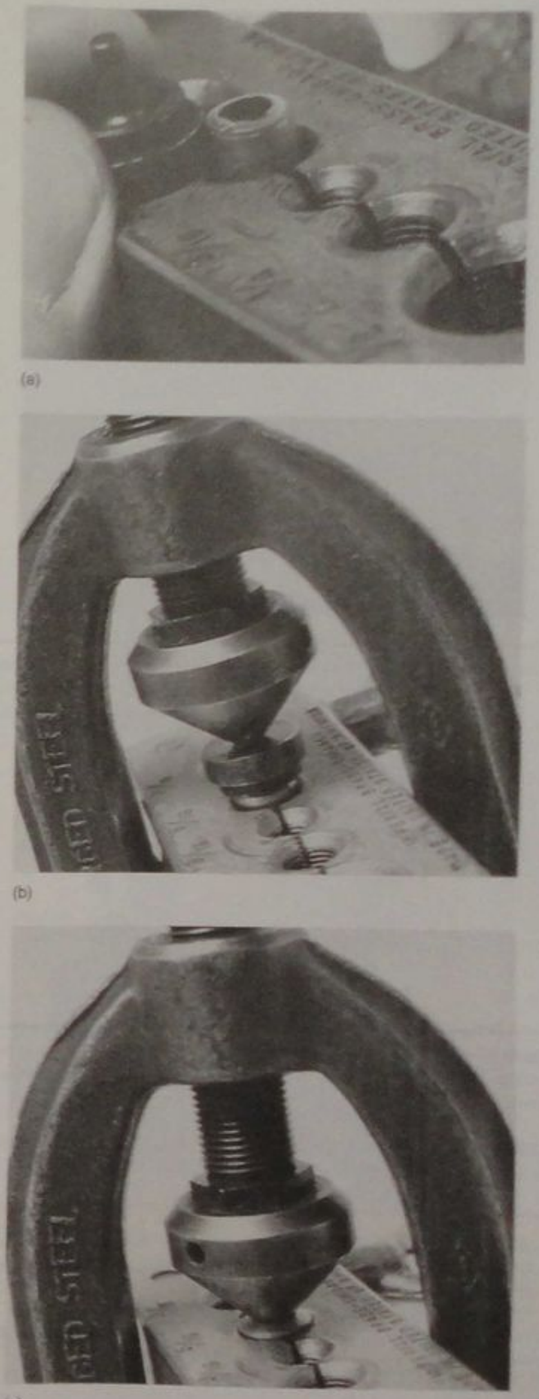


Figure 71–13 An ISO fitting.

Brake line diameter is also very important and replacement lines should be the same as the original. Many vehicle manufacturers use larger diameter brake lines for the rear brakes because the larger line decreases brake response time. *Response time is the amount of time between the pressure increase at the master cylinder and the pressure increase at the brakes.* On most vehicles, the brake lines to the front wheels are shorter. To help assure that the rear brakes apply at the same time as the front brakes, the diameter of the brake lines is increased to the rear brakes. Brake engineers size each line to keep the time lag to less than 0.2 second (200 milliseconds). Fast response time is critical for the proper operation of the antilock



(a)

(b)

(c)

Figure 71–14 Double flaring the end of a brake line. (a) Clamp the line at the correct height above the surface of the clamping tool using the shoulder of the insert as a gauge. (b) The insert is pressed into the end of the tubing. This creates the first bend. (c) Remove the insert and use the pointed tool to complete the overlap double flare.



(d)



(e)

Figure 71–14 (d) The completed operation as it appears while still in the clamp. (e) The end of the line as it appears after the first operation on the left and the completed double flare on the right.

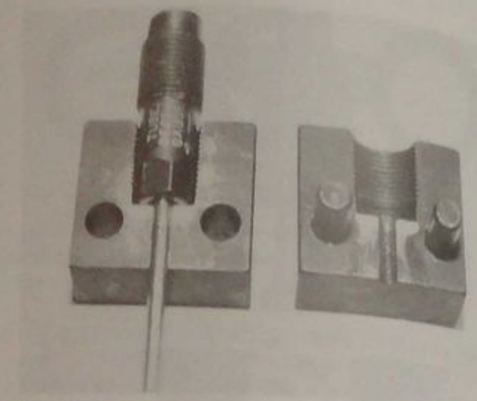
braking system (ABS). Also, as brake fluid ages, its viscosity (resistance to flow) increases, resulting in longer response time.

CAUTION: The exhaust system near brake lines should be carefully inspected for leaks when diagnosing a "lack of brakes" complaint. Exhaust gases can hit the brake line going to the rear brakes, causing the brake fluid to boil. Since brake fluid vapors are no longer liquid, they can be compressed, resulting in a total loss of brakes. After the vehicle is stopped and allowed to cool, the brakes often return to normal.

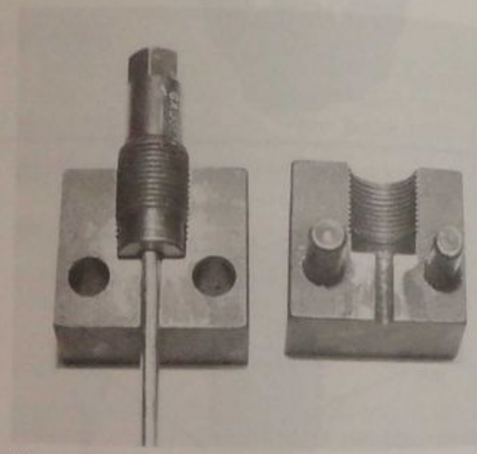
Always use two line wrenches when disconnecting or reattaching brake lines. See Figure 71–16.

COILED BRAKE LINE

Steel brake line is often coiled, as shown on a race car in Figure 71–17. The purpose of the coils is to allow movement between the brake components without stress that could lead to metal fatigue



(a)



(b)

Figure 71–15 Making an ISO flare requires this special tool. (a) Position the brake line into the two-part tool at the correct height using the gauge end of the tool. (b) Assemble the two blocks of the tool together and clamp in a vise. Turn the tool around and thread it into the tool block. The end of the threaded part of the tool forms the "bubble" or ISO flare.

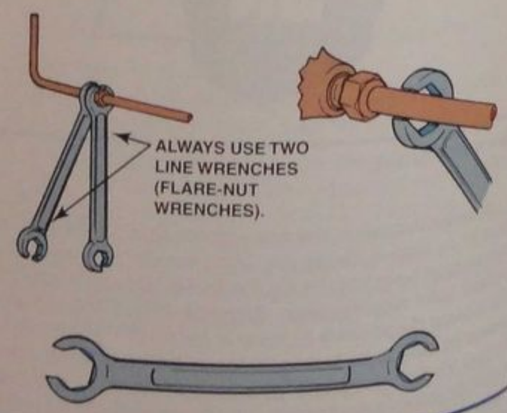


Figure 71–16 Whenever disconnecting or tightening a brake line, always use the correct size flare nut wrench. A flare nut wrench is also called a tube nut wrench or a line wrench.

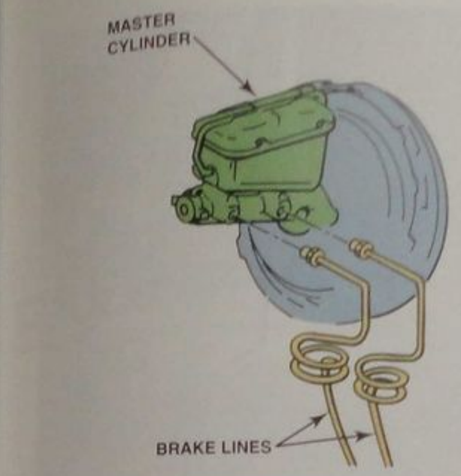


Figure 71–17 The coils in the brake line help prevent cracks caused by vibration.

and brake line breakage. The typical master cylinder attaches to the bulkhead of the vehicle and the combination valve is often attached to the frame. Because the body and frame are usually insulated from each other using rubber isolators, some movement occurs while driving.

ARMORED BRAKE LINE

In many areas of the brake system, the steel brake line is covered with a wire coil wrap, as shown in Figure 71–18. This type of brake line is called **armored brake line.**

TECH TIP ✔ **Bend It Right the First Time**

Replacing rusted or damaged brake line can be a difficult job. It is important that the replacement brake line be located in the same location as the original to prevent possible damage from road debris or heat from the exhaust. Often this means bending the brake line with many angles and turns. To make the job a lot easier, use a stiff length of wire and bend the wire into the exact shape necessary. Then use the wire as a pattern to bend the brake line. Always use a tubing bender to avoid kinking the brake line. A kink not only restricts the flow of brake fluid, but also weakens the line. To bend brake line without a tubing bender tool, use an old V-belt pulley. Clamp the pulley in a vise, lay the tubing in the groove, and smoothly bend the tubing. Different diameter pulleys will create various radius bends. See Figure 71–19.

NOTE: Always use a tubing cutter instead of a hacksaw when cutting brake line. A hacksaw will leave a rough and uneven end that will not flare properly except when forming. An ISO flare and a hacksaw is used to provide a rough surface to allow the flaring tool to grip the line during the procedure.

This armor is designed to prevent damage from stones and other debris that could dent or damage the brake line. If a section of armored brake line is to be replaced, armored replacement line should be installed.

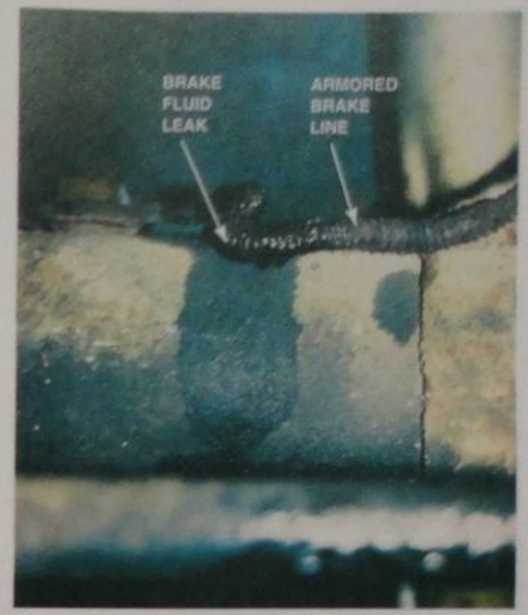


Figure 71–18 Armored brake line is usually used in the location where the line may be exposed to rock or road debris damage. Even armored brake line can leak and a visual inspection is an important part of any brake service.

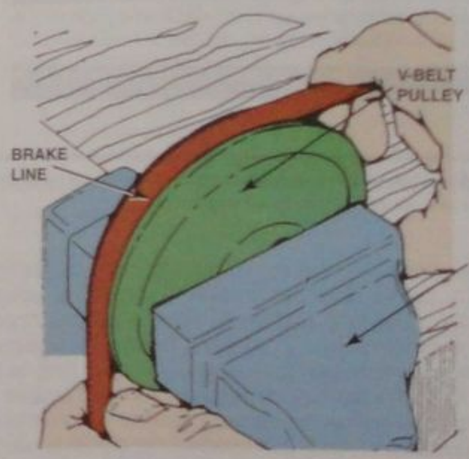


Figure 71–19 Using a V-belt pulley in a vise to bend brake line.

FLEXIBLE BRAKE HOSE

Flexible brake hoses are used on each front wheel to allow for steering and suspension movement and at the rear to allow for rear suspension travel. See Figure 71–20.

These rubber high-strength hoses can crack, blister, or leak, and should be inspected at least every six months. See Figure 71–21.

Flexible brake hose is made from synthetic yarn (poly vinyl alcohol, abbreviated PVA) that is braided into position from multi-end yarn spindles. By braiding the yarn, all of the strands operate in tension and, therefore, have great strength to withstand braking system pressure over 1000 PSI (6,900 kPa). See Figure 71–22.

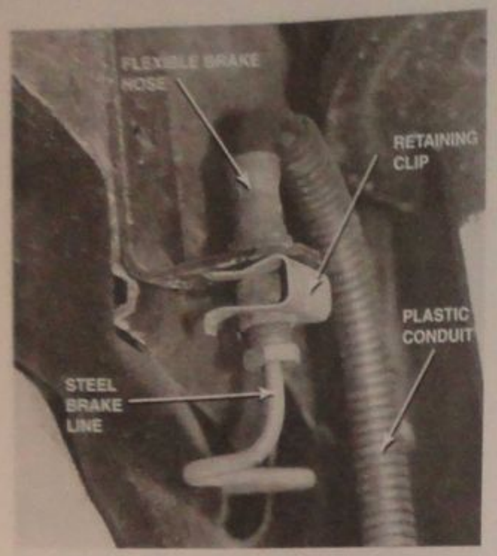


Figure 71–20 Flexible brake hoses are used between the frame or body of the vehicle and the wheel brakes. Because of suspension and/or steering movement, these flexible brake lines must be strong enough to handle high brake fluid pressures, yet remain flexible. Note that this flexible brake hose is further protected against road debris with a plastic conduit covering.

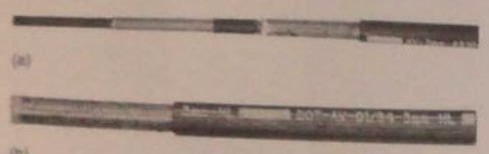


Figure 71–21 (a) Typical flexible brake hose showing the multiple layers of rubber and fabric. (b) The inside diameter (ID) is printed on the hose (3 mm).

A typical brake hose has an inner tube for conveying the brake fluid and a cushion liner that is between the braided layers to prevent the braids from chafing. All three layers use ethylene-propolyene-diene-monomer (EPDM)-type thermosetting polymers, which help prevent the hose from absorbing moisture from the outside air. An outside jacket is made from rubber and protects the reinforcement fabric from moisture and abrasion. The outside covering is also ribbed as part of the manufacturing process to hide surface blemishes. These ribs also make it easy for the technician to see if the hose is twisted. It is not unusual for flexible brake lines to become turned around and twisted when the disc brake caliper is removed and then replaced during a brake pad change. See Figures 71–23 and 71–24.

A constricted brake hose can cause the brakes to remain applied, thereby causing excessive brake pad wear and unequal braking. A constricted flexible brake line can also cause the vehicle to pull to one side. See Figure 71–25.

CAUTION: Never allow a disc brake caliper to hang by the flexible brake line. Damage to the line can result. Always use a wire to support the weight of the caliper.

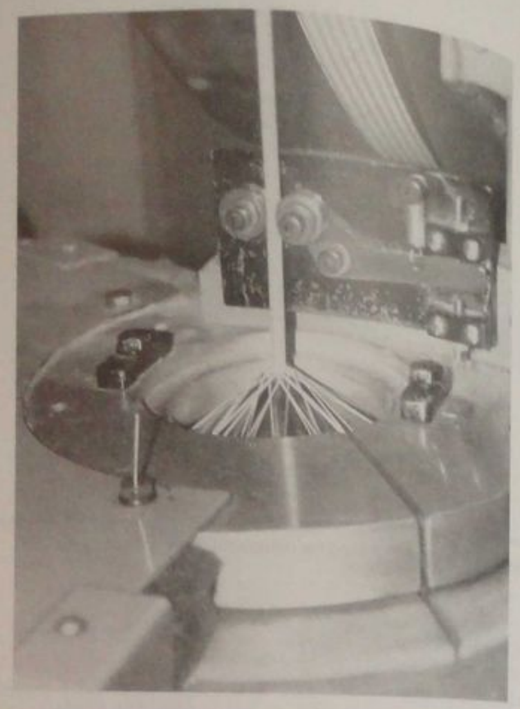


Figure 71–22 Brake hose fabric being woven at the Delco Chassis plant in Dayton, Ohio, USA.

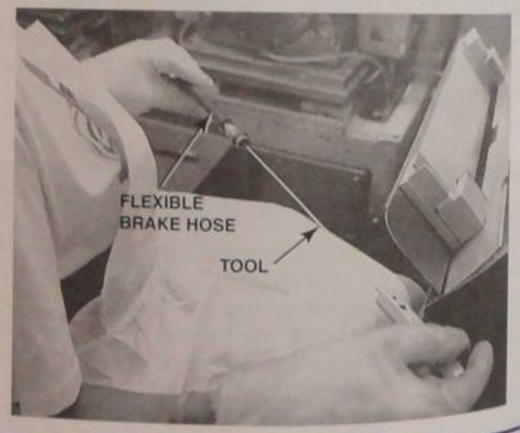


Figure 71–23 All brake hose is carefully inspected and a 3-mm-diameter gauging tool is inserted through the hose to make sure the hose is not restricted. Notice the small diameter of the tool compared to the outside diameter of the hose. Seeing how small the inside diameter of the hose actually is makes it easier to visualize how easy it would be to have a restricted or blocked flexible hose.

SUMMARY

1. Most brake fluid is amber in color and polyglycol based.
2. DOT 3 is the type of brake fluid most often recommended for use.
3. Brake fluid absorbs moisture over time and can remove paint.
4. DOT 4 and DOT 5.1 are also polyglycol-based fluids, whereas DOT 5 is silicone based.
5. Brake fluid should be checked for proper level and color and tested for condition or for contamination.
6. Brake fluid should be disposed of according to local and state guidelines.

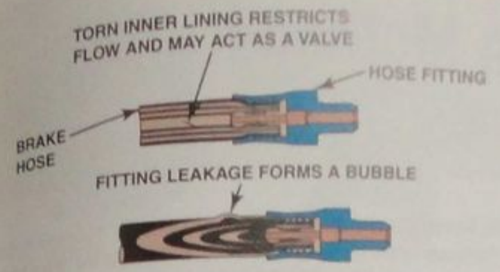


Figure 71–24 Typical flexible brake hose faults. Many faults cannot be seen, yet can cause the brakes to remain applied after the brake pedal is released.



Figure 71–25 Flexible brake hose should be carefully inspected for cuts or other damage, especially near sections where the brake hose is attached to the vehicle. Notice the crack and cut hose next to the mounting bracket.

7. Most brake systems use EPR or SBR-type rubber that is compatible with brake fluid but they can swell in size if exposed to mineral oil such as power steering fluid, engine oil, or automatic transmission fluid.
8. Brake lines are double-walled steel with a rust prevention coating with either a double lap flare or an ISO flare end.
9. Flexible brake hose is constructed of braided synthetic yarn and EPDM rubber.

REVIEW QUESTIONS

1. What is the difference between DOT 3, DOT 4, DOT 5.1, and DOT 5 brake fluid?
2. List four things that should be done during a thorough inspection of the brake fluid.
3. List four precautions that should be followed when handling brake fluid.
4. What are the two types of flares used on brake lines?
5. Why are some brake lines coiled?

CHAPTER QUIZ

1. The type of brake fluid most often recommended by vehicle manufacturers is _____.
   a. DOT 3
   b. DOT 4
   c. DOT 5
   d. DOT 5.1
2. Which of the following is *not* a characteristic of conventional brake fluid?
   a. Absorbs moisture from the air
   b. Removes paint if spilled on vehicle surfaces
   c. Lasts the life of the vehicle unless there is a leak
   d. Is clear or amber in color
3. Technician A says that DOT 5 brake fluid can be added to DOT 3 brake fluid. Technician B says that it is wise to purchase brake fluid that is in metal rather than plastic containers. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. As brake fluid ages, what happens?
   a. The boiling temperature decreases
   b. The boiling temperature increases
   c. The viscosity (thickness) decreases
   d. The color changes to purple
5. Technician A says that glycol-based brake fluid causes the seals to swell slightly. Technician B says the DOT 5 (silicone-based) brake fluid causes rubber seals to swell slightly. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. The two types of flares used on brake lines are _____.
   a. SAE and DOT
   b. Double flare and ISO
   c. Ball flare and bubble flare
   d. SAE and double flare
7. Two technicians are discussing why the brake lines are coiled near the master cylinder on many vehicles. Technician A says that these coils help prevent moisture from flowing from the master cylinder to the calipers. Technician B says that they help prevent cracks that could be caused by vibrations. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Flexible brake hose should be inspected for all of the following *except* _____.
   a. Cracks
   b. Leakage
   c. Twisted
   d. Worn outer ribs
9. Why should brake calipers be supported by a wire during brake service and not allowed to hang by the flexible brake hose?
   a. To keep air from getting into the system
   b. To help prevent damage to the brake hose
   c. To hold the caliper higher than the master cylinder to prevent fluid loss
   d. To prevent bending the hose support bracket
10. Used brake fluid should be _____.
    a. Mixed with and recycled with used oil
    b. Poured down the drain
    c. Absorbed with a cloth or absorbent material and disposed of in regular trash
    d. Poured onto open ground to reduce dust

CHAPTER 72

Brake Bleeding Methods and Procedures

OBJECTIVES: After studying Chapter 72, the reader will be able to: Prepare for ASE Brakes (A5) certification test content area "A" (Hydraulic System Diagnosis and Repair). • Explain how to bench bleed a master cylinder. • Describe the proper brake bleeding sequence. • Describe the single stroke manual brake bleeding procedure. • Discuss how to gravity bleed the hydraulic brake system. • List the steps needed to perform a pressure bleed procedure.

KEY TERMS: bleeder valve • brake bleeding • gravity bleeding • power bleeding • pressure bleeding • reverse fluid injection • single stroke bleeding method • surge bleeding • vacuum bleeding

BRAKE BLEEDING

Brake bleeding is removing any trapped air from the hydraulic system. Air can get into the hydraulic system whenever any hydraulic brake line or unit is opened. Air can also be drawn into the hydraulic system through small holes or loose brake line connections during the release of the brake pedal. A common source of air in the brake system of this type can occur through very small holes in rubber flexible brake lines. Another source of air in the braking system is through the absorption of moisture by the brake fluid. When moisture is absorbed, the boiling point of the brake fluid is reduced. During severe braking, the heat generated can cause the brake fluid to boil and create air bubbles in the hydraulic brake system. Air eventually travels to the highest part of the brake system, if not restricted by pressure control valves. Air in the system results in a spongy brake pedal.

BLEEDING THE MASTER CYLINDER

Whenever the master cylinder is replaced or the hydraulic system has been left opened for several hours, the air may have to be bled from the master cylinder. Bleed the master cylinder "on the bench" before installing it on the vehicle. See Figure 72–1.

If bleeding the master cylinder after working on the hydraulic system, follow these steps:

Step #1 Fill the master cylinder with clean brake fluid from a sealed container up to the recommended "full" level.



Figure 72–1 Always clamp a master cylinder in a vise by the mounting flange to prevent distortion of the cylinder bore.

Step #2 Have an assistant slowly depress the brake pedal as you "crack open" the master cylinder bleed screw starting with the section closest to the bulkhead. It is very important that the primary section of the master cylinder be bled before attempting to bleed the air out of the secondary section of the master cylinder. Before the brake pedal reaches the floor, close the bleeder valve.

NOTE: A proper manual bleeding of the hydraulic system requires that accurate communications occur between the person depressing the brake pedal and the person opening and closing the bleeder valve(s). The **bleeder valve** (also called a *bleed valve*) should be open only when the brake pedal is being depressed. The valve *must* be closed when the brake pedal is released to prevent air from being drawn into the system.

Step #3 Repeat the procedure several times until a solid flow of brake fluid is observed leaving the bleeder valve. If the master cylinder is not equipped with bleeder valves, the outlet tube nuts can be loosened instead.

BRAKE BLEEDER VALVE LOOSENING METHODS

Attempting to loosen a bleeder valve often results in breaking (shearing off) the bleeder valve. Several of these service procedures can be tried that help prevent the *possibility* of breaking a bleeder valve. Bleeder valves are tapered and become wedged in the caliper on the wheel cylinder housing. See Figures 72–2 and 72–3.

All of these methods use shock to "break the taper" and to loosen the stuck valve.



Figure 72–2 Typical bleeder valve from a disc brake caliper. The arrows point to the tapered section that does the actual sealing. It is this taper that requires a shock to loosen. If the bleeder is simply turned with a wrench, the bleeder usually breaks off because the tapered part at the bottom remains adhered to the caliper or wheel cylinder. Once loosened, brake fluid flows around the taper and out through the hole in the side of the bleeder valve. The hole is clogged in this example and needs to be cleaned out.

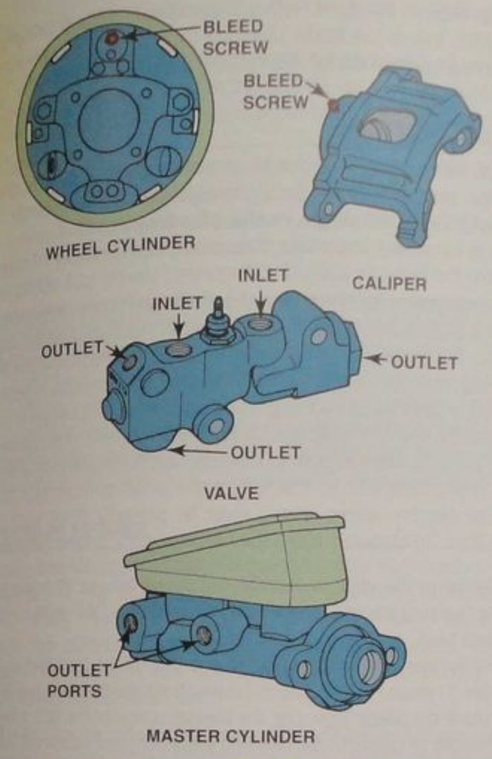


Figure 72–3 Typical bleeder locations. Note that the combination valve and master cylinder shown do not have bleeder valves; therefore, bleeding is accomplished by loosening the brake line at the outlet parts. *(Courtesy of Allied Signal Automotive Aftermarket)*

TECH TIP ✔ **Do It Right—Replace the Brake Fluid**

Often, used brake fluid looks like black coffee or coffee with cream. Both conditions indicate contaminated or moisture-laden brake fluid that should be replaced. The following steps will help assure a complete brake fluid change:

Step #1 Remove the old brake fluid from the master cylinder using a suction bulb. (Dispose of this old brake fluid properly.)

Step #2 Fill the master cylinder with new clean brake fluid from a sealed container.

Step #3 Bleed each wheel brake until the brake fluid is clean.

CAUTION: Do not allow the master cylinder to run out of brake fluid. Recheck and refill as necessary during the bleeding process.

This brake fluid replacement will fully restore the brake hydraulic system to as-new condition and help protect the system from rust and corrosion. Replacing only the friction pads and/or linings is not a complete and thorough brake system service. Customers should be educated as to the importance of this service procedure.

Air Impact Method Use a 6-point socket for the bleeder valve and use the necessary adapters to fit an air impact wrench to the socket. Apply some penetrating oil to the bleeder valve and allow it to flow around the threads. Turn the pressure down on the impact wrench to limit the force. The hammering effect of the impact wrench loosens the bleeder valve without breaking it off.



Figure 72–4 Using an air punch next to the bleeder valve to help "break the taper" on the bleeder valve.

Hit and Tap Method

Step #1 Tap on the end of the bleeder valve with a steel hammer. This shock often "breaks the taper" at the base of the bleeder valve. The shock also breaks loose any rust or corrosion on the threads.

Step #2 Using a 6-point wrench or socket, *tap* the bleeder valve in the clockwise direction (tighten).

Step #3 Using the same 6-point socket or wrench, *tap* the bleeder valve counterclockwise to loosen and remove the bleeder valve.

NOTE: It is the *shock* of the tap on the wrench that breaks loose the bleeder valve. Simply pulling on the wrench often results in breaking off the bleeder.

Step #4 If the valve is still stuck (frozen), repeat Step 1 through Step 3.

Air Punch Method Use an air punch near the bleeder valve while attempting to loosen the bleeder valve at the same time. See Figure 72–4.

The air punch creates a shock motion that often loosens the taper and threads of the bleeder valve from the caliper or wheel cylinder. It is also helpful to first attempt to turn the bleeder valve in the clockwise (tightening) direction, then turn the bleeder in the counterclockwise direction to loosen and remove the bleeder valve.

Heat and Tap Method Heat the area around the bleeder valve with a torch. The heat expands the size of the hole and usually allows the bleeder to be loosened and removed.

CAUTION: The heat from a torch will damage the rubber seals inside the caliper or wheel cylinder. Using heat to free a stuck bleeder valve will *require* that all internal rubber parts be replaced.

Wax Method

Step #1 Heat the bleeder valve itself with a torch. The heat causes the valve itself to expand.

Step #2 Remove the heat from the bleeder valve. As the valve is cooling, touch paraffin wax or candle wax to the hot valve. The wax will melt and run down around the threads of the bleeder valve.

Step #3 Allow the bleeder valve to cool until it can be safely touched with your hand. This assures that the temperature is low enough for the wax to return to a solid and provide the lubricating properties necessary for the easy removal of the bleeder valve. Again, turn the bleeder valve clockwise before turning the valve counterclockwise to remove.

BLEEDING SEQUENCE

After bleeding the master cylinder, the combination valve should be bled if equipped. Follow the same procedure as when bleeding the master cylinder, being careful not to allow the master cylinder to run dry.

NOTE: The master cylinder is located in the highest section of the hydraulic braking system. Some master cylinders are equipped with bleeder valves. All master cylinders can be bled using the same procedure as that used for bleeding calipers and wheel cylinders. If the master cylinder is not equipped with bleeder valves, it can be bled by loosening the brake line fittings at the master cylinder.

Check the level in the master cylinder frequently and keep it filled with clean brake fluid throughout the brake bleeding procedure.

For most rear-wheel-drive vehicles equipped with a front/rear split system, start the bleeding with the wheel farthest from the master cylinder and work toward the closest. See Figure 72–5.

For most vehicles, this sequence is as follows:

1. Right rear
2. Left rear
3. Right front
4. Left front

NOTE: If the vehicle has two wheel cylinders on one brake, bleed the upper cylinder first.

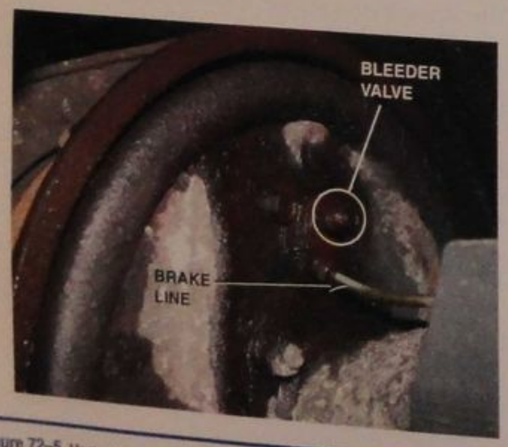


Figure 72–5 Most vehicle manufacturers recommend starting the brake bleeding process at the rear wheel farthest from the master cylinder.

For vehicles equipped with a diagonal split section or equipped with ABS, follow the brake bleeding procedure recommended in the service information for the vehicle.

MANUAL BLEEDING

Manual bleeding uses hydraulic pressure created by the master cylinder to pump fresh fluid through the brake system. This method is called the **single stroke bleeding method.**

It is extremely important when manually bleeding a brake system that the pedal be applied and released slowly and gently. Rapid pedal pumping can churn up the fluid and reduce the size of trapped air bubbles, making them more difficult to bleed from the system. There are, however, special situations where rapid pedal pumping may be helpful in brake system bleeding. These are covered in the "Surge Bleeding" section later in the chapter.

Manual bleeding requires an assistant to apply and release the brake pedal, a bleeder screw wrench, approximately two feet of clear, plastic hose with an inside diameter small enough to fit snugly over the bleeder screws, and a clear jar partially filled with clean brake fluid. To manually bleed the brake system, follow these steps:

1. Discharge the vacuum or hydraulic power booster (if equipped) by pumping the brake pedal with the ignition OFF until the pedal feels hard.
2. Fill the master cylinder reservoir with new brake fluid and make sure it remains at least half full throughout the bleeding procedure.
3. Attach the plastic hose over the bleeder screw of the first wheel cylinder or caliper in the bleeding sequence, and submerge the end of the tube in the jar of brake fluid. See Figure 72–6.
4. Loosen the bleeder screw approximately one-half turn, and have an assistant slowly depress the brake pedal. Air bubbles leaving the bleeder screw will be visible in the hose to the jar.

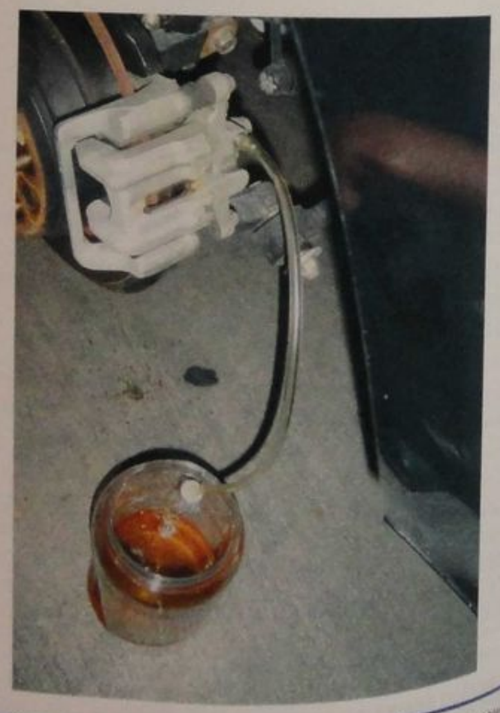


Figure 72–6 Bleeding brakes using clear plastic tubing makes it easy to see air bubbles. Submerging the hose in a container of clean brake fluid helps ensure that all of the air will be purged by the system.

5. Tighten the bleeder screw, then have your assistant slowly release the brake pedal.
6. Wait at least 15 seconds to allow time for any small bubbles to form into larger bubbles. See the Tech Tip called, "Tiny Bubbles."
7. Repeat steps 4 and 5 until no more air bubbles emerge from the bleeder.
8. Transfer the plastic hose to the bleeder screw of the next wheel cylinder or caliper in the bleeding sequence, and repeat steps 4 through 7. Continue around the vehicle in the specified order until the brakes at all four wheels have been bled.

NOTE: Make certain all the brake components such as calipers and wheel cylinders are correctly installed with the bleeder valve located on the highest section of the part. Some wheel cylinders and calipers (such as many Ford calipers) can be installed upside down! This usually occurs whenever both front calipers are off the vehicle and they accidentally get reversed left to right. If this occurs, the air will never be completely bled from the caliper.

VACUUM BLEEDING

Vacuum bleeding uses a special suction pump that attaches to the bleeder screw. The pump creates a low-pressure area at the bleeder screw, which allows atmospheric pressure to force brake fluid through the system when the bleeder screw is opened. Vacuum bleeding requires only one technician. To vacuum bleed a brake system follow these steps.

1. Fill the master cylinder reservoir with new brake fluid and make sure it remains at least half full throughout the bleeding procedure.
2. Attach the plastic tube from the vacuum bleeder to the bleeder screw of the first wheel cylinder or caliper in the bleeding sequence. See Figure 72–7. If necessary, use one of the adapters provided with the vacuum in the catch bottle.
3. Operate the pump handle to create a partial vaccum in the catch bottle.

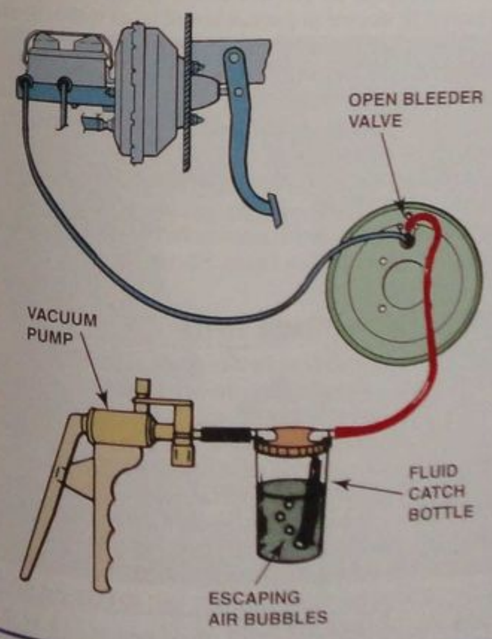


Figure 72–7 Vacuum bleeding uses atmospheric pressure to force brake fluid through the hydraulic system.

4. Loosen the bleeder screw approximately one-half turn. Brake fluid and air bubbles will flow into the bottle. When the fluid flow stops, tighten the bleeder screw.
5. Repeat steps 3 and 4 until no more air bubbles emerge from the bleeder.

TECH TIP ✓ **Tiny Bubbles**

Do not use excessive brake pedal force while bleeding and never bleed the brake with the engine running! The extra assist from the power brake unit greatly increases the force exerted on the brake fluid in the master cylinder. The trapped air bubbles may be dispersed into tiny bubbles that often cling to the inside surface of the brake lines. These tiny air bubbles may not be able to be bled from the hydraulic system until enough time has allowed the bubbles to reform. To help prevent excessive force, do *not* start the engine. Without power assistance, the brake pedal force can be kept from becoming excessive. If the dispersal of the air into tiny bubbles is suspected, try tapping the calipers or wheel cylinders with a plastic hammer. After this tapping, simply waiting for a period of time will cause the bubbles to re-form into larger and easier-to-bleed air pockets. Most brake experts recommend waiting *15 seconds or longer* between attempts to bleed each wheel. This waiting period is critical and allows time for the air bubbles to form.

NOTE: To help prevent depressing the brake pedal down too far, some experts recommend placing a 2 × 4 in. board under the brake pedal. This helps prevent the seals inside the master cylinder from traveling over unused sections inside the bore that may be corroded or rusty.

6. Transfer the vacuum bleeder to the bleeder screw of the next wheel cylinder or caliper in the bleeding sequence, and repeat steps 3 and 4. Continue around the vehicle in the specified order until the brakes at all four wheels have been bled.

GRAVITY BLEEDING

Gravity bleeding is a slow, but effective, method that will work on many vehicles to rid the hydraulic system of air. The procedure involves simply opening the bleeder valve and waiting until brake fluid flows from the open valve. Any air trapped in the part being bled will rise and escape from the port when the valve is opened. It may take several minutes before brake fluid escapes. If no brake fluid comes out, remove the bleeder valve entirely—it may be clogged. Remember, nothing but air and brake fluid will be *slowly* coming out of the wheel cylinder or caliper when the bleeder valve is removed. *Do not press on the brake pedal with the bleeder valve out while gravity bleeding.*

Gravity bleeding works because any liquid tends to seek its own level. This means that the brake fluid in the master cylinder tends to flow downward toward the wheel cylinders or calipers. As long as the brake fluid level in the master cylinder is higher than the bleeder valve, the brake fluid will flow downward and out the open bleeder valve, as shown in Figure 72–8.

This flow of brake fluid can even get past the metering valve and proportioning valve. The proportioning valve is normally open to the rear brakes until the pressure reaches a predetermined level when it starts to limit increasing pressure to the rear brakes. The metering valve used to control or delay the operation of the front brakes is open to the front wheels until the pressure exceeds 10 to 15 PSI (70 to 100 kPa). Therefore, as long as no one is pushing on the brake pedal, the metering valve remains open to the front wheels and the brake fluid from the master cylinder can easily flow downward through the valve and out the open bleeder valve.



Figure 72–8 Gravity bleeding is simply opening the bleeder valve and allowing gravity to force the brake fluid out of the bleeder valve. Because air is lighter than brake fluid all of the air escapes before the brake fluid runs out.

Since no pressure is exerted on the brake fluid, the large air bubbles remain large air bubbles and are not separated into smaller, harder-to-bleed air bubbles that can occur with manual bleeding.

All four wheel brakes can be bled at one time using the gravity method. In this process, the bleeder screws at all four wheels are opened at the same time, and the system is allowed to drain naturally until the fluid coming out of the bleeders is free of air.

TECH TIP ✔ **The Master Cylinder One-Drip-per-Second Test**

Excessive brake wear is often caused by misadjusted brake linkage or brake light switches keeping the brake pedal from fully releasing. If the brake pedal is not fully released, the primary piston sealing cup blocks the compensating port from the brake fluid reservoir. To test if this is the problem, loosen both lines from the master cylinder. Brake fluid should drip out of both lines about one drip per second. This is why this test is also called the "Master Cylinder Drip Test" If the master cylinder does not drip, the brake pedal may not be allowing the master cylinder to fully release. Have an assistant pull up on the brake pedal. If the dripping starts, the problem is due to a misadjusted brake light or speed (cruise) control switch or pedal stop. If the master cylinder still does not drip, loosen the master cylinder from the power booster. If the master cylinder now starts to drip, the pushrod adjustment is too long.

If the master cylinder still does not drip, the problem is in the master cylinder itself. Check for brake fluid contamination. If mineral oil, such as engine oil, power steering fluid, or automatic transmission fluid (ATF), has been used in the system, the rubber sealing cups swell and can block off the compensating port. If contamination is discovered, every brake component that contains rubber must be replaced.

Gravity bleeding is a slow process that can take an hour or more. In addition, this procedure cannot be used on brake systems with residual pressure check valves because the valves restrict the fluid flow. The advantage of gravity bleeding is that it can be done by a single technician, who is freed to attend to other jobs while the brakes bleed. When other bleeding procedures fail, gravity bleeding can sometimes be effective on brake systems that trap small pockets of air.

Gravity bleeding requires a bleeder wrench, four lengths of plastic hose that fit snugly over the bleeder screws, and four jars to catch the dripping fluid. Unless a plastic hose is used to "start a siphon" at each bleeder screw, it is possible that air may enter the system rather than be bled from it. This can occur because the total open area of the four bleeder screws is somewhat larger than that of the two compensating ports through which the fluid must enter the system. To gravity bleed the brake system, follow these steps:

1. Fill the master cylinder reservoir with new brake fluid. During the bleeding process, check the fluid level periodically to ensure that the reservoir remains at least half full.
2. Attach a length of plastic tubing to each bleeder screw, and place the ends of the tubes in jars to catch the drainage.
3. Open each bleeder screw approximately one full turn and make sure that fluid begins to drain. Allow the system to drain until the fluid flowing from the bleeder screws is free of air bubbles.
4. Close the bleeder screws and top up the fluid level in the master cylinder reservoir.

TECH TIP ✔ **Gravity Bleed during an Oil Change**

Brake fluid tends to absorb moisture near the wheel brakes through the flexible brake lines and other connections. Some service technicians open the bleeder valves whenever the vehicle is in for an oil change service. As the brake fluid slowly flows from the open bleeder valve, any trapped air is also released. After a few minutes, the bleeder valves are closed and the vehicle lowered. The brake fluid level is checked and the oil change is completed. This procedure not only helps provide the vehicle owner with an air-free brake system, but opening the bleeder at every oil change helps keep the bleeder free and easy to open.

PRESSURE BLEEDING

Pressure bleeding, sometimes called **power bleeding,** is a common method used to bleed the brake hydraulic system. In this process, a pressure bleeder attached to the master cylinder forces brake fluid through the system under pressure to purge any trapped air. Once the hydraulic system is pressurized, the technician simply opens the bleeder screws in the prescribed order and allows fluid to flow until it is free of air bubbles.

The tools required for pressure bleeding include a plastic hose and fluid catch jar as used in manual bleeding, as well as a pressure bleeder, a source of air pressure to charge the bleeder, and an adapter to attach the pressure bleeder to the master cylinder fluid reservoir. Cast-metal cylinders with integral reservoirs commonly use a flat, plate-type adapter that seals against the same surface as the reservoir cover. See Figure 72–9.

Some plastic master cylinder reservoirs also use plate-type adapters, but others require adapters that seal against the bottom of the reservoir. Pressure bleeder manufacturers offer many adapters to fit specific applications. See Figure 72–10.

METERING VALVE OVERRIDE TOOLS

In addition to the tools previously described, a metering valve override tool is required when pressure bleeding the front brakes of certain vehicles. The override tool is used to deactivate the metering valve because the operating pressure of power bleeders is within the range where the metering valve blocks fluid flow to the front brakes. Metering valves that require an override tool have a stem or button on one end that is either pushed in or pulled out to hold the valve open. The override tool performs this service.

To install the override tool used on General Motors vehicles, loosen the combination valve mounting bolt and slip the slot in the tool under the bolt head. See Figure 72–11.

Push the end of the tool toward the valve body until it depresses the valve plunger, then tighten the mounting bolt to hold the tool in place.



Figure 72–9 A typical pressure bleeder. The brake fluid inside is pressurized with air pressure in the air chamber. This air pressure is applied to the brake fluid in the upper section. A rubber diaphragm separates the air from the brake fluid. *(Courtesy of EIS Brake Parts)*

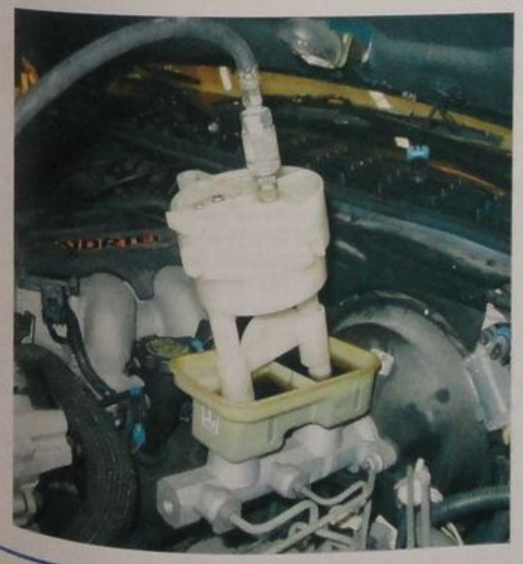


Figure 72–10 Brake fluid under pressure from the power bleeder is applied to the top of the master cylinder. It is very important that the proper adapter be used for the master cylinder. Failure to use the correct adapter or failure to release the pressure on the brake fluid before removing the adapter can cause fluid to escape under pressure.

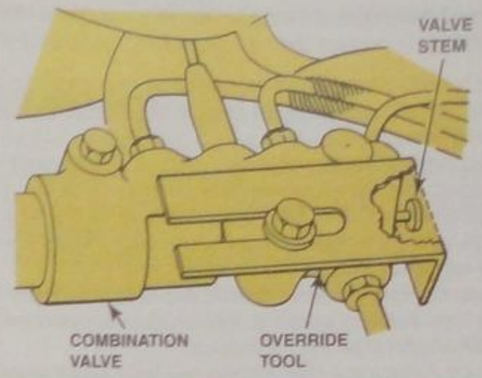


Figure 72–11 Metering valve override tool on a General Motors vehicle.

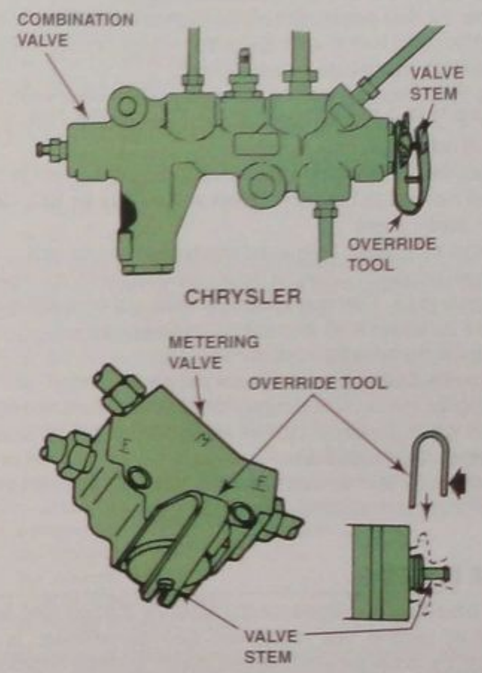


Figure 72–12 Pull-out-type metering valves being held out using a special override tool.

Some full-size Ford vehicles have a metering valve with a stem that must be pushed in to bleed the front brakes, but Ford does not offer a special tool for this purpose. An assistant is needed to override the valve when the front brakes are being bled.

To install the override tool used on older Chrysler and Ford vehicles, slip one fork of the tool under the rubber boot, and the other fork under the valve stem head. See Figure 72–12.

The spring tension of the tool holds the valve open, but allows the valve stem to move slightly when the system is pressurized. If the valve is held rigidly open, internal damage will result.

PRESSURE BLEEDING PROCEDURE

Just as in manual bleeding, it is important to follow the proper sequence when pressure bleeding a brake system. Some manufacturers

recommend one sequence for manual bleeding and another for pressure bleeding. To pressure bleed a brake system, follow these steps:

1. If it has not already been done, consult the equipment manufacturer's instructions and fill the pressure bleeder with the proper type of brake fluid.
2. Make sure the bleeder is properly sealed and the fluid supply valve is closed, then use compressed air to pressurize the bleeder until approximately 30 PSI (207 kPa) is indicated on the bleeder gauge.
3. If the vehicle is equipped with a metering valve, override it with the appropriate tool.
4. Clean the top of the master cylinder, then remove the master cylinder cover and clean around the gasket surface. Be careful not to allow any dirt to fall into the reservoir.
5. Fill the reservoir about half full with new brake fluid, then install the proper pressure bleeder adapter on the master cylinder.
6. Connect the pressure bleeder fluid supply hose to the adapter, making sure the hose fitting is securely engaged.
7. Open the fluid supply valve on the pressure bleeder to allow pressurized brake fluid to enter the system. Check carefully for fluid leaks that can damage the vehicle finish.
8. Slip the plastic hose over the bleeder screw of the first wheel cylinder or caliper to be bled, and submerge the end of the tube in the jar of brake fluid.
9. Open the bleeder screw approximately one-half turn, and let the fluid run until air bubbles no longer emerge from the tube. Close the bleeder screw.
10. Transfer the plastic hose to the bleeder screw of the next wheel cylinder or caliper in the bleeding sequence, and repeat steps 8 and 9. Continue around the vehicle in the specified order until the brakes at all four wheels have been bled.
11. Remove the metering valve override tool.
12. Close the fluid supply valve on the pressure bleeder.
13. Wrap the end of the fluid supply hose in a shop towel, and disconnect it from the master cylinder adapter. Do not spill any brake fluid on the vehicle finish.
14. Remove the master cylinder adapter, adjust the fluid level to the full point, and install the fluid reservoir cover.

SURGE BLEEDING

Surge bleeding is a supplemental bleeding method used to help remove air bubbles that resist other bleeding processes. In surge bleeding, the brake pedal is pumped rapidly to create turbulence in the hydraulic system. This agitation helps dislodge air bubbles that cling to the pores of rough castings, or become trapped at high points or turns in the brake lines. Surge bleeding is *not* recommended for systems filled with silicone DOT 5 brake fluids. These fluids tend to trap tiny air bubbles that are very difficult to bleed from the hydraulic system. The added agitation of surge bleeding only makes the problem worse.

Surge bleeding requires an assistant to pump the brake pedal, a bleeder screw wrench, approximately two feet of clear, plastic hose with an inside diameter small enough to fit snugly over the bleeder screw, and a jar partially filled with clean brake fluid. To surge bleed a brake system, follow these steps.

1. Slip the plastic hose over the bleeder screw of the wheel cylinder or caliper to be bled and submerge the end of the tube in the jar of brake fluid.
2. Open the bleeder screw approximately one-half turn.
3. With the bleeder screw *open*, have your assistant rapidly pump the brake pedal several times. Air bubbles should come out with the brake fluid.
4. While your assistant holds the brake pedal to the floor, close the bleeder screw.
5. Repeat steps 2 through 4 at each bleeder screw in the recommended order.
6. Re-bleed the system using one of the four other methods previously described.

FREQUENTLY ASKED QUESTION ???

What Is Reverse Fluid Injection?

Reverse fluid injection is a procedure that uses an air- or hand-operated injection gun that pushes brake fluid from the bleeder value into the hydraulic system. See Figure 72–13.

By forcing brake fluid into the bleeder valve, any trapped air is forced upward into the master cylinder.

CAUTION: This procedure should only be done after a thorough flushing of the hydraulic system. Many experts warn that debris and sediment in the hydraulic system can be back-flushed into the ABS hydraulic unit and/or master cylinder. Many brake and ABS failures have been caused by forcing old brake fluid back into the system.



Figure 72–13 A reverse fluid injection unit that is used to bleed hydraulic brake and clutch systems by forcing brake fluid up from the bleeder valve into the master cylinder, thereby forcing any trapped air up and out of the system.

FLUID CHANGING

In addition to removing air, brake systems need to be bled in order to clean out old and/or contaminated fluid. This process is called fluid changing or flushing. The hygroscopic (water attracting) nature of most brake fluid makes it necessary to flush the brake system periodically because moisture in the fluid drastically lowers the boiling point. Water also causes rust and corrosion of system components that can lead to brake failure. To avoid these problems, brake fluid should be changed yearly in humid climates and every other year in dry climates.

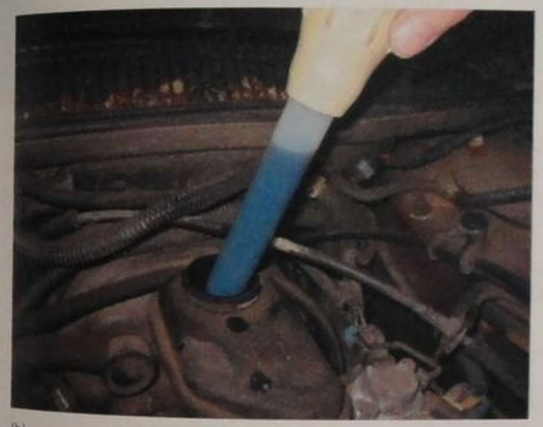
Brake fluid changing or flushing is done by bleeding the system until all of the old fluid is purged from the system. Because fluid changing requires the ability to flush out contamination and move a great deal of fluid, the best method to use is pressure bleeding. Other acceptable choices are manual bleeding and vacuum bleeding. Gravity bleeding is *not* recommended for fluid changing because it is slow, and without significant pressure behind the fluid flow, there is no guarantee that contamination will be completely flushed from the system.

To change a vehicle's brake fluid, remove all the old brake fluid from the master cylinder reservoir.

NOTE: A low-cost turkey baster can be used to draw the old brake fluid from the master cylinder reservoir. See Figure 72–14.



(a)



(b)

Figure 72–14 (a) A turkey baster can be used to remove the old brake fluid from the master cylinder reservoir. (b) Use care to avoid dripping brake fluid after drawing from the master cylinder reservoir.

Fill the reservoir with new fluid, then follow the procedures outlined earlier in the chapter for the chosen method of bleeding. Continue to bleed at each wheel until the fluid that emerges from the bleeder screw is free of any discoloration and contamination.

SUMMARY

1. Bleeding the brakes means to pump the hydraulic system free of air.
2. A new or replacement master cylinder should be bled before installing it in the vehicle.
3. Bleeder valves are located on all disc brake calipers and drum brake wheel cylinders.
4. The most commonly used method of brake bleeding is the single stroke bleeding method.
5. Vacuum bleeding is used to draw the old fluid and any trapped air from the hydraulic system through the bleeder value.
6. Gravity bleeding is an excellent but slow method.
7. Pressure bleeding requires adapters and special equipment, plus the metering valve must be held open to allow fluid to flow to the front brakes.
8. Surge bleeding is the least desirable method of bleeding, but is necessary at times.

REVIEW QUESTIONS

1. Describe how to bench bleed a master cylinder.
2. List the steps necessary to manually bleed a brake hydraulic system.
3. Discuss the equipment and the procedures needed to pressure bleed a brake hydraulic system.
4. Explain how to gravity bleed a brake hydraulic system.
5. Describe how to vacuum bleed a brake hydraulic system.
6. Discuss the surge method of brake bleeding.

CHAPTER QUIZ

1. The button on the _____ valve should be held when bleeding the brakes.
   a. Metering
   b. Proportioning
   c. Pressure-differential
   d. Residual check
2. The brake bleeding procedure usually specified for a rear-wheel vehicle with a dual split master cylinder is _____.
   a. RR, LR, RF, LF
   b. LF, RF, LR, RR
   c. RF, LR, LF, RR
   d. LR, RR, LF, RF
3. Two technicians are discussing bench bleeding a master cylinder. Technician A says that the front (nose end) of the master cylinder should be bled first. Technician B says that rear (brake pedal end) should be bled first. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Two technicians are discussing how to loosen bleeder valves. Technician A says that a shock is usually necessary to break the taper at the base of the valve. Technician B says to apply steady, loosening torque to the bleeder valve using a 6-point wrench. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that the brake pedal should be depressed with as much force as possible during the normal bleeding procedure. Technician B says that the brake pedal should be pumped rapidly during this manual bleeding procedure to force the air down toward the bleeder valve(s). Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Vacuum is applied where during vacuum bleeding?
   a. At each wheel brake bleeder valve
   b. At the master cylinder reservoir
   c. At the vacuum booster check valve.
   d. At the metering valve end of the combination valve
7. The bleeder is opened at a caliper and no brake fluid flows out. Technician A says that this is normal and that brake fluid should not flow or drip out of an open bleeder valve. Technician B says that the vent port in the master cylinder may be blocked. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. The usual maximum pressure that should be used when pressure bleeding a brake system is _____.
   a. 20 PSI
   b. 30 PSI
   c. 50 PSI
   d. 70 PSI

9. Why do many vehicle manufactures recommend that brake fluid be changed regularly?
   a. Brake fluid absorbs moisture over time
   b. The boiling point of the brake fluid decreases
   c. Old brake fluid can cause rust and corrosion of brake system components
   d. All of the above

10. Air in the brake hydraulic system can cause all except _____.
   a. Spongy brake pedal
   b. Hard brake pedal
   c. Lower than normal brake pedal
   d. May require the drive to "pump up" the brakes before they will stop the vehicle

CHAPTER

73 Wheel Bearings and Service

OBJECTIVES: **After studying Chapter 73, the reader will be able to:** Prepare for Suspension and Steering (A4) ASE certification test content area "C" (Related Suspension and Steering Service). • Discuss the various types, designs, and parts of automotive antifriction wheel bearings. • Describe the symptoms of defective wheel bearings. • Explain wheel bearing inspection procedures and causes of spalling and brinelling. • List the installation and adjustment procedures for front wheel bearings. • Explain how to inspect, service, and replace rear wheel bearings and seals.

KEY TERMS: antifriction bearings • axial load • ball bearings • brinelling • cage • C-lock axle • cone • cup • dynamic seals • garter spring • GC-LB • grease • grease seal • inner ring • National Lubricating Grease Institute (NLGI) • outer ring • radial load • retainer plate-type axle • roller bearings • spalling • static seal • tapered roller bearings

ANTIFRICTION BEARINGS

Bearings allow the wheels of a vehicle to rotate and still support the weight of the entire vehicle. **Antifriction bearings** use rolling parts inside the bearing to reduce friction. Four styles of rolling contact bearings include ball, roller, needle, and tapered roller bearings, as shown in Figure 73–1. All four styles convert sliding friction into rolling motion. All of the weight of a vehicle or load on the bearing is transferred through the rolling part. In a ball bearing, all of the load is concentrated into small spots where the ball contacts the *inner and outer race (rings)*. See Figure 73–2.

Ball Bearings **Ball bearings** use hardened steel balls between the inner and outer race to reduce friction. While ball bearings cannot support the same weight as roller bearings, there is less friction in ball bearings and they generally operate at higher speeds. Ball bearings can control thrust movement of an axle shaft because the balls ride in grooves on the inner and outer races. The groove walls resist lateral movement of the wheel on the spindle. The most frequent use of ball bearings is at the rear wheels of a rear-wheel-drive vehicle with a solid rear axle. See Figure 73–3. These bearings are installed into the axle housing and are often press fitted to the axle shaft. Many front-wheel-drive vehicles use sealed double-row ball bearings as a complete sealed unit and are nonserviceable except as an assembly.



Figure 73–1 Rolling contact bearings include (left to right) ball, roller, needle, and tapered roller.

Roller Bearings **Roller bearings** use rollers between the inner and outer race to reduce friction. A roller bearing having a greater (longer) contact area can support heavier loads than a ball bearing. See Figure 73–4.

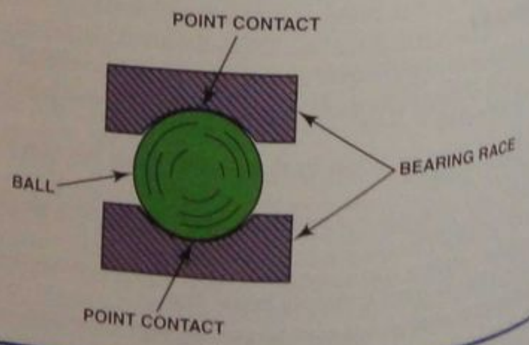


Figure 73–2 Ball bearing point contact.

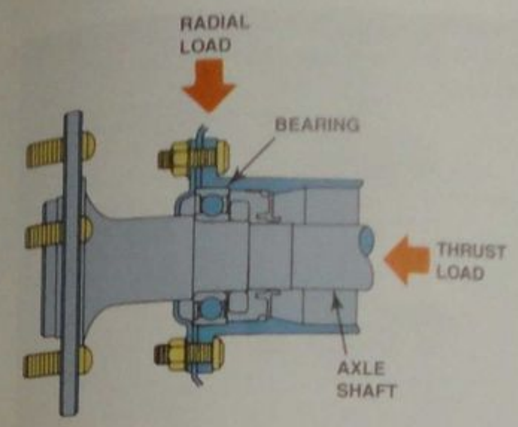


Figure 73–3 Radial load is the vehicle weight pressing on the wheels. The thrust load occurs as the chassis components exert a side force during cornering.

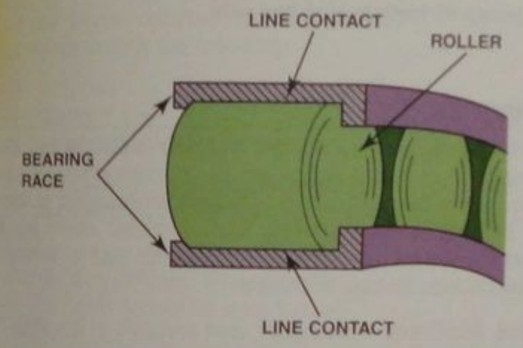


Figure 73–4 Roller bearing line contact.

A needle bearing is a type of roller bearing that uses smaller rollers called needle rollers. The clearance between the diameter of the ball or straight roller is manufactured into the bearing to provide the proper *radial clearance* and is *not adjustable*.

Tapered Roller Bearings The most commonly used automotive wheel bearing is the **tapered roller bearing.** Not only is the bearing itself tapered, but the rollers are also tapered. By design, this type of bearing can withstand **radial loads** (up and down) as well as **axial loads** (thrust) in one direction. See Figure 73–5.

Many non-drive-wheel bearings use tapered roller bearings. The taper allows more weight to be handled by the friction-reducing bearings because the weight is directed over the entire length of each roller rather than concentrated on a small spot, as with ball bearings. The rollers are held in place by a **cage** between the inner race (also called the **inner ring** or **cone**) and the outer race (also called the **outer ring** or **cup**). Tapered roller bearings must be loose in the cage to allow for heat expansion. Tapered roller bearings should always be adjusted for a certain amount of free play to allow for heat expansion. On non-drive-axle vehicle wheels, the cup is tightly fitted to the wheel hub and the cone is loosely fitted to the wheel spindle. New bearings come packaged with the rollers, cage, and inner race assembled together with the outer race wrapped with moisture-resistant paper. See Figure 73–6.

Inner and Outer Wheel Bearings Many rear-wheel-drive vehicles use an inner and an outer wheel bearing on the front

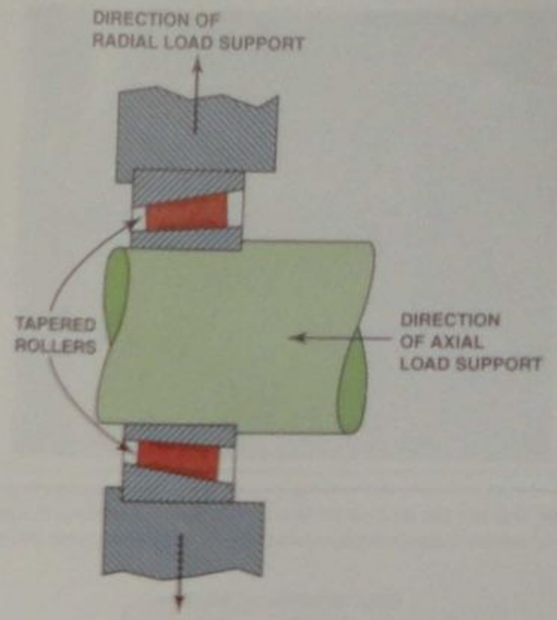


Figure 73–5 A tapered roller bearing will support a radial load and an axial load in only one direction.



Figure 73–6 Many tapered roller bearings use a plastic cage to retain the rollers.

wheels. The inner wheel bearing is always the larger bearing because it is designed to carry most of the vehicle weight and transmit the weight to the suspension through to the spindle. See Figure 73–7. Between the inner wheel bearing and the spindle, there is a grease seal, which prevents grease from getting onto the braking surface and prevents dirt and moisture from entering the bearing.

Standard Bearing Sizes Bearings use standard dimensions for inside diameter, width, and outside diameter. The standardization of bearing sizes helps interchangeability. The dimensions that are standardized include bearing bore size (inside diameter), bearing series (light to heavy usage), and external dimensions. When replacing a wheel bearing, note the original bearing brand name and number. Replacement bearing catalogs usually have cross-over charts from one brand to another. The bearing number is usually the same because of the interchangeability and standardization within the wheel bearing industry.

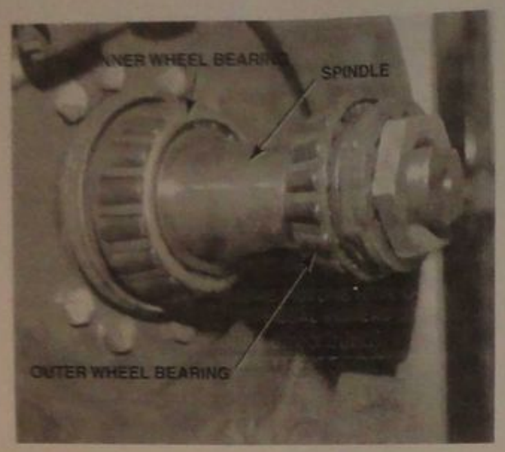


Figure 73–7 Non-drive-wheel hub with inner and outer tapered roller bearings. By angling the inner and outer in opposite directions, axial (thrust) loads are supported in both directions.

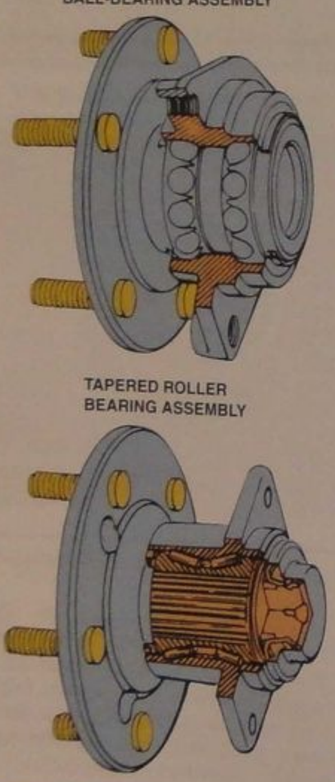


Figure 73–8 Sealed bearing and hub assemblies are used on the front and rear wheels of many vehicles.

Sealed Front-Wheel-Drive Bearings Most front-wheel-drive (FWD) vehicles use a sealed nonadjustable front wheel bearing. This type of bearing can include either two preloaded tapered roller bearings or a double row ball bearing. This type of sealed bearing is also used on the rear of many front-wheel-drive vehicles.

Double row ball bearings are often used because of their reduced friction and greater seize resistance. See Figures 73–8 and 73–9.



Figure 73–9 Sealed bearing and hub assemblies are serviced as a complete unit as shown. This assembly includes the wheel speed sensor.

BEARING GREASES

Vehicle manufacturers specify the type and consistency of grease for each application. The technician should know what these specifications mean. **Grease** is an oil with a thickening agent to allow it to be installed in places where a liquid lubricant would not stay. Greases are named for their thickening agent, such as aluminum, barium, calcium, lithium, or sodium.

Grease Additives Commonly used additives in grease include the following:

- Antioxidants
- Antiwear agents
- Rust inhibitors
- Extreme pressure (EP) additives such as sulfurized fatty oil or chlorine

Grease also contains a dye to not only provide product identification but also to give the grease a consistent color.

The grease contains a solid such as graphite or molybdenum disulfide (moly), which acts as an antiseize additive.

FREQUENTLY ASKED QUESTION ???

What Do Different Grease Colors Mean?

Nothing. According to grease manufacturers, grease is colored for identification, marketing, and for consistency color reasons.

- *Identification.* The color is often used to distinguish one type of grease from another within the same company. The blue grease from one company may be totally different from the blue grease produced or marketed by another company.
- *Marketing.* According to grease manufacturers, customers tend to be attracted to a particular color of grease and associate that color with quality.
- *Consistency of color.* All greases are produced in batches, and the color of the finished product often varies in color from one batch to another. By adding color to the grease, the color can be made consistent.

Always use the grease recommended for the service being performed.

NLGI Classification The National Lubricating Grease Institute (NLGI) uses the penetration test as a guide to assign the grease a number. Low numbers are very fluid and higher numbers are more firm or hard. See the chart.

National Lubricating Grease Institute (NLGI) Numbers

NLGI Number	Relative Consistency
000	Very fluid
00	Fluid
0	Semi-fluid
1	Very soft
2	Soft (typically used for wheel bearings)
3	Semi-firm
4	Firm
5	Very firm
6	Hard

Grease is also classified according to quality. Wheel bearing classifications include the following:

- GA—mild duty
- GB—moderate duty
- GC—severe duty, high temperature (frequent stop and go service)

GC indicates the highest quality. Chassis grease, such as is used to lubricate steering and suspension components, include the following:

- LA—mild duty (frequent relubrication)
- LB—high loads (infrequent relubrication)

LB indicates the highest quality. Most multipurpose greases are labeled with both wheel bearing and chassis grease classifications such as **GC-LB.**

More rolling bearings are destroyed by overlubrication than by underlubrication because the heat generated in the bearings cannot be transferred easily to the air through the excessive grease. Bearings should never be filled beyond one-third to one-half of their grease capacity by volume.

SAFETY TIP **Smoking Can Kill You**

Some greases contain polymers such as Teflon® that turn to a deadly gas when burned. Always wash your hands thoroughly after handling grease that contains these ingredients before smoking. If some of the grease is on the cigarette paper and is burned, these polymers turn into nitrofluoric acid—a deadly toxin.

SEALS

Seals are used in all vehicles to keep lubricant, such as grease, from leaking out and to prevent dirt, dust, or water from getting into the bearing or lubricant. Two general applications of seals are static and dynamic. **Static seals** are used between two surfaces that do not move. **Dynamic seals** are used to seal between two surfaces that move. Wheel bearing seals are dynamic type seals that must seal between rotating axle hubs and the stationary spindles or axle housing. Most dynamic seals use a synthetic rubber lip seal encased in metal. The lip is often held in contact with the moving part with the aid of a **garter spring,** as seen in Figure 73–10.

The sealing lip should be installed toward the grease or fluid being contained. See Figure 73–11.



Figure 73–10 Typical lip seal with a garter spring.

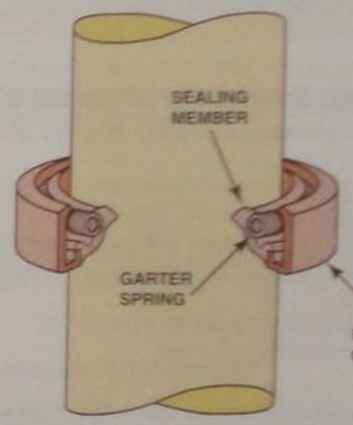


Figure 73–11 A garter spring helps hold the sharp lip edge of the seal tight against the shaft. *(Courtesy of Dana Corporation)*

SYMPTOMS AND DIAGNOSIS OF DEFECTIVE BEARINGS

Wheel bearings control the positioning and reduce the rolling resistance of vehicle wheels. Whenever a bearing fails, the wheel may not be kept in position and noise is usually heard. Symptoms of defective wheel bearings include the following:

1. A hum, rumbling, or growling noise that increases with vehicle speed
2. Roughness felt in the steering wheel that changes with the vehicle speed or cornering
3. Looseness or excessive play in the steering wheel especially while driving over rough road surfaces
4. A loud grinding noise in severe cases of a defective front wheel bearing
5. Pulling during braking

With the vehicle off the ground, rotate the wheel by hand, listening and feeling carefully for bearing roughness. Grasp the wheel at the top and bottom and wiggle it back and forth, checking for bearing looseness.

NOTE: Excessive looseness in the wheel bearings can cause a low brake pedal. If any of the above symptoms are present, carefully clean and inspect the bearings.

TECH TIP ✓ **"Bearing Overload"**

It is not uncommon for vehicles to be overloaded. This is particularly common with pickup trucks and vans. Whenever there is a heavy load, the axle bearings must support the entire weight of the vehicle, including its cargo. If a bump is hit while driving with a heavy load, the balls of a ball bearing or the rollers of a roller bearing can make an indent in the race of the bearing. This dent or imprint is called **brinelling**, named after Johann A. Brinell, a Swedish engineer who developed a process of testing for surface hardness by pressing a hard ball with a standard force into a sample material to be tested.

Once this imprint is made, the bearing will make noise whenever the roller or ball rolls over the indent. Continued use causes wear to occur on all of the balls or rollers and eventual failure. While this may take months to fail, the cause of the bearing failure is often overloading of the vehicle. Avoid shock loads and overloading for safety and for longer vehicle life.

NON-DRIVE-WHEEL BEARING INSPECTION AND SERVICE

The steps in a non-drive-wheel bearing inspection include the following:

1. Hoist the vehicle safely.
2. Remove the wheel.
3. Remove the brake caliper assembly and support it with a coat hanger or other suitable hook to avoid allowing the caliper to hang by the brake hose.
4. Remove the grease cap (dust cap). See Figure 73–12.
5. Remove the old cotter key and discard.

NOTE: The term *cotter*, as in cotter key or cotter pin, is derived from the Old English verb meaning "to close or fasten."

6. Remove the spindle nut (castle nut).
7. Remove the washer and the outer wheel bearing. See Figure 73–13.
8. Remove the bearing hub from the spindle. The inner bearing will remain in the hub and may be removed (simply lifted out) after the grease seal is pried out. See Figure 73–14.
9. Most vehicle and bearing manufacturers recommend cleaning the bearing thoroughly in solvent or acetone. If there is no acetone, clean the solvent off the bearings with denatured alcohol to make certain that the thin solvent layer is completely washed off and dry. *All solvent must be removed or allowed to dry from the bearing because the new grease will not stick to a layer of solvent.*
10. Carefully inspect the bearings and the races for the following:
    a. The outer race for lines, scratches, or pits. See Figure 73–15.
    b. The cage should be round. If the round cage has straight sections, this is an indication of an over-tightened adjustment or a dropped cage. If either of the above is observed, then the bearing, including the outer race, must be replaced. Failure to replace the outer race (which is included when purchasing a bearing) could lead to rapid failure of the new bearing. See Figures 73–16 and 73–17.

TECH TIP ✓ **Bearing Noise—Tire Noise**

A defective wheel bearing is often difficult to diagnose because the noise is similar to a noisy winter tire or a severely cupped tire. Customers often request that tires be replaced as a result of the noise when the real problem is a bad wheel bearing. To help determine if the noise is caused by a wheel bearing or a tire, try these tips:

Tip 1 Drive the vehicle over a variety of road surfaces. If the noise changes with a change in road surface, then the noise is caused by a tire(s). If the noise remains the same, then the cause is a defective wheel bearing.

Tip 2 Try temporarily overinflating the tires. If the noise changes, then the tires are the cause. If the noise is the same, then defective wheel bearings are the cause.

11. Pack the cleaned or new bearing thoroughly with clean, new, approved wheel bearing grease using hand packing or a wheel bearing packer. Always clean out all of the old grease before applying the recommended type of new grease. *Because of compatibility problems, it is not recommended that greases be mixed.* See Figure 73–18.



Figure 73–12 Removing the grease cap with grease cap pliers.

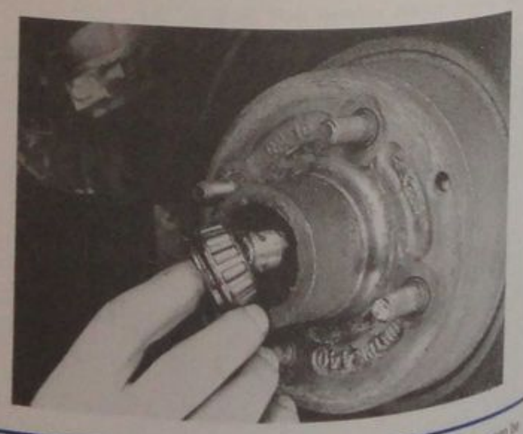


Figure 73–13 After wiggling the brake rotor slightly, the washer and outer bearing can be easily lifted out of the wheel hub.



Figure 73–14 Some technicians remove the inner wheel bearing and the grease seal at the same time by jerking the rotor off the spindle after reinstalling the spindle nut. While this is a quick-and-easy method, sometimes the bearing is damaged (deformed) from being jerked out of the hub using this procedure.

NOTE: Some vehicle manufacturers do *not* recommend that "stringy-type" wheel bearing grease be used. Centrifugal force can cause the grease to be thrown outward from the bearing. Because of the stringy texture, the grease may not flow back into the bearing after it has been thrown outward. The final result is a lack of lubrication and eventual bearing failure.

12. Place a thin layer of grease on the outer race.
13. Apply a thin layer of grease to the spindle, being sure to cover the outer bearing seat, inner bearing seat, and shoulder at the grease seal seat.
14. Install a new **grease seal** (also called a *grease retainer*) flush with the hub using a seal driver.
15. Place approximately 3 tablespoons of grease into the grease cavity of the wheel hub. Excessive grease could cause the inner grease seal to fail, with the possibility of grease getting on the brakes. Place the rotor with the inner bearing and seal in place over the spindle until the grease seal rests on the grease seal shoulder.
16. Install the outer bearing and the bearing washer.
17. Install the spindle nut and, while rotating the tire assembly, tighten to about 12 to 30 lb. ft. with a wrench to "seat" the bearing correctly in the race (cup) and on the spindle. See Figure 73–19.
18. While still rotating the tire assembly, loosen the nut approximately one-half turn and then *hand tighten only* (about 5 lb. in.).

NOTE: If the wheel bearing is properly adjusted, the wheel will still have about 0.001 to 0.005 in. (0.03 to 0.13 mm) end play. This looseness is necessary to allow the tapered roller bearing to expand when hot and not bind or cause the wheel to lock up.

19. Install a new cotter key. (An old cotter key could break a part off where it was bent and lodge in the bearing, causing major damage.)

NOTE: Most vehicles use a cotter key that is 1/8 in. in diameter by 1 1/2 in. long.

20. If the cotter key does not line up with the hole in the spindle, loosen slightly (no more than 1/16 in. of a turn) until the hole lines up. Never tighten more than hand tight.
21. Bend the cotter key ends up and around the nut, not over the end of the spindle where the end of the cotter key could rub on the grease cap, causing noise. See Figure 73–20.

TECH TIP ✓ **Wheel Bearing Looseness Test**

Looseness in a front wheel bearing can allow the rotor to move whenever the front wheel hits a bump, forcing the caliper piston in, which causes the brake pedal to kick back and creates the feeling that the brakes were locking up.

Loose wheel bearings are easily diagnosed by removing the cover of the master cylinder reservoir and watching the brake fluid as the front wheels are turned left and right with the steering wheel. If the brake fluid moves while the front wheels are being turned, caliper piston(s) are moving in and out, caused by loose wheel bearing(s). If everything is okay, the brake fluid should not move.

NOTE: Loose wheel bearings can also cause the brake pedal to sink due to movement of the rotor, causing the caliper piston to move. This sinking brake pedal is usually caused by a defective master cylinder. Before replacing a master cylinder, check the wheel bearings.

22. Install the grease cap (dust cap) with a rubber mallet or soft-faced hammer to help prevent denting or distorting the grease cap. Install the wheel cover or hub cap.

CAUTION: Clean grease off the disc brake rotors or drums after servicing the wheel bearings. Use a brake cleaner and a shop cloth. Even a slight amount of grease on the friction surfaces of the brakes can harm the friction lining and/or cause brake noise.

SEALED BEARING REPLACEMENT

Most front-wheel-drive vehicles use a sealed bearing assembly that is bolted to the steering knuckle and supports the drive axle or the rear, as shown in Figure 73–21.

Many front-wheel-drive vehicles use a bearing that must be pressed off the steering knuckle. Special aftermarket tools are also available to remove many of the bearings without removing the knuckle from the vehicle. Check the factory service manual and tool manufacturers for exact procedures for the vehicle being serviced. See Figures 73–22 and 73–23.

Diagnosing a defective front bearing on a front-wheel-drive vehicle is sometimes confusing. A defective wheel bearing is usually noisy while driving straight, and the noise increases with vehicle speed (wheel speed). A drive axle shaft U-joint (CV joint) can also be the cause of noise on a front-wheel-drive vehicle, but usually makes *more noise* while turning and accelerating.

REAR-DRIVE-AXLE CLASSIFICATIONS

There are three rear-drive-axle classifications:

- Full-floating
- Three-quarter-floating
- Semi-floating

These classifications indicate whether the axle shafts or the axle housing supports the wheel. The category of a rear drive axle is determined by how the wheel and wheel bearing mount to the axle or housing.

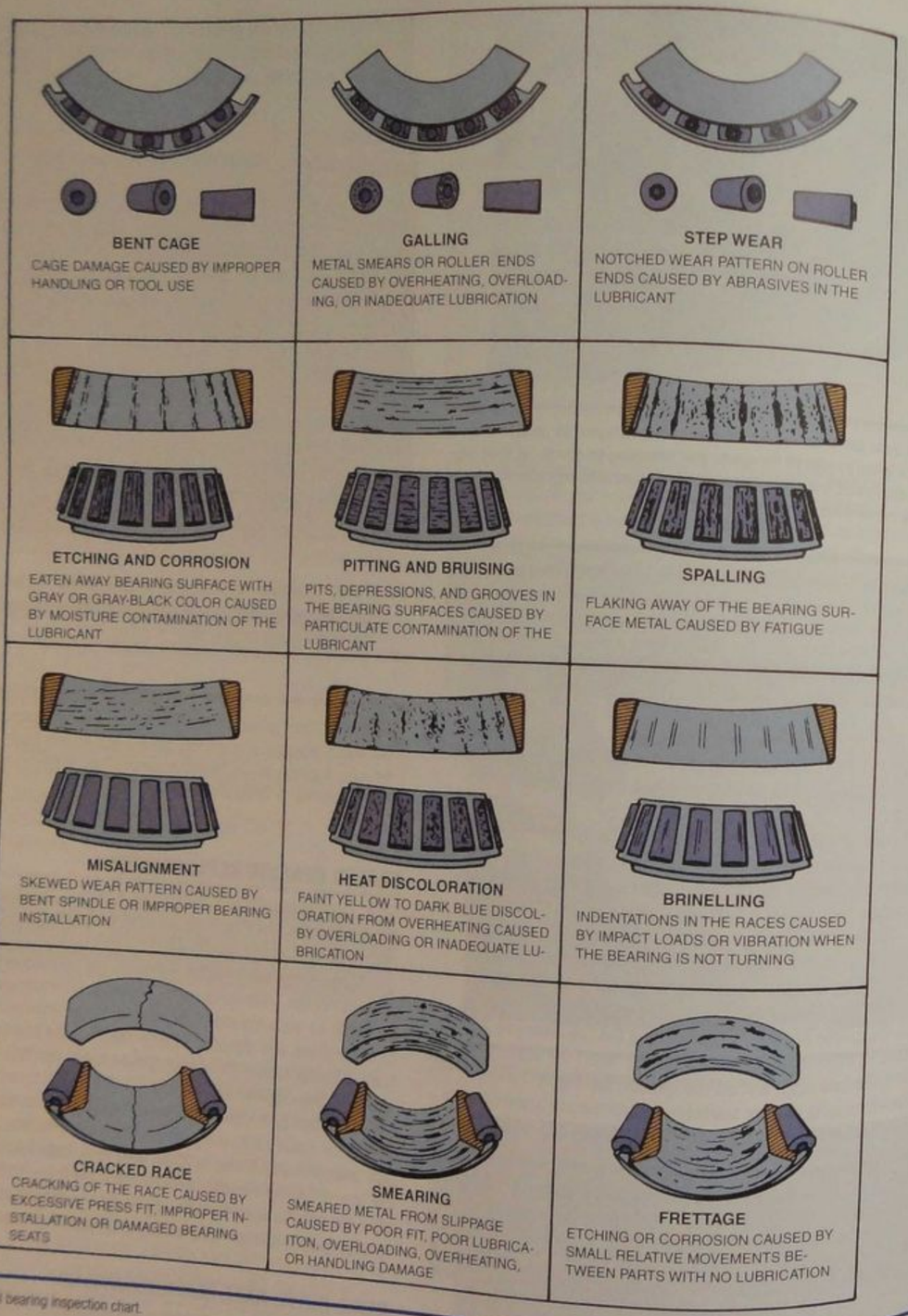


Figure 73–15 Wheel bearing inspection chart.

Full-Floating Axle On a full-floating axle, the bearings are mounted and retained in the hub of the brake drum or rotor. The hub and bearing mount onto the axle housing, and are held in place by a bearing retainer or adjustment nuts and safety locks. The flanged end of the drive axle is attached to the hub by bolts or nuts. The inner end of the axle splines into the differential side gears. The wheel mounts onto the hub, and lug bolts or nuts retain it. In this design, the axle shafts "float" in the axle housing and drive the wheels without supporting their weight. Because the axle shafts do not retain the wheel, the axle shafts can usually be removed from the vehicle while it is standing on the wheels. Most three-quarter-ton pickups, all heavy-duty truck tractors, and trailers use full-floating axles. See Figure 73–24 on page 876.

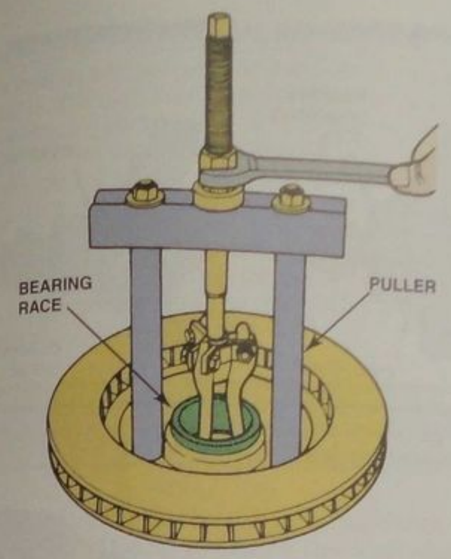


Figure 73–16 A wheel bearing race puller.

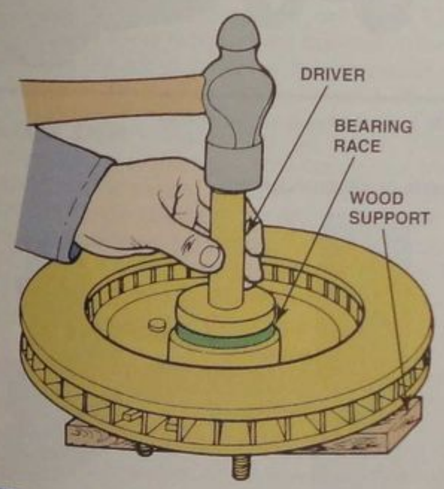


Figure 73–17 Installing a bearing race with a driver.

Three-Quarter-Floating Axle The bearings in a three-quarter-floating axle are mounted and retained in the brake drum or rotor hub, which mounts onto the axle housing. The outer extension of the hub fits onto the end of the axle, which is usually splined and tapered, and a nut and cotter pin secure the hub to the axle. The axle shaft splines to the side gears inside the differential. The wheels are mounted on the hub and retained by lug bolts or nuts. As in the full-floating axle, the axle housing and bearings in the hub support the weight in a three-quarter-floating axle. Because of the construction of a three-quarter-floating axle, the wheel must be removed before removing the axle shaft from the vehicle.

Semi-Floating Axle The wheel bearings in a semi-floating axle either press onto the axle shaft or are installed in the outer end of the axle housing. A retainer plate at the outer end of the axle shaft or a C-clip inside the differential at the other end keeps the axle shaft in the housing. The brake drum or rotor fits onto the end of the axle, and lug bolts or nuts fasten the wheel to the drum or rotor and to the axle. These axles are called "semi-floating" because only the inboard ends of the axle shaft "float" in the housing. The outboard end of the shaft retains the wheel and transmits the weight of the wheel to the housing. Most solid-axle rear-wheel-drive cars and light trucks use a semi-floating type of axle. See Figure 73–25.

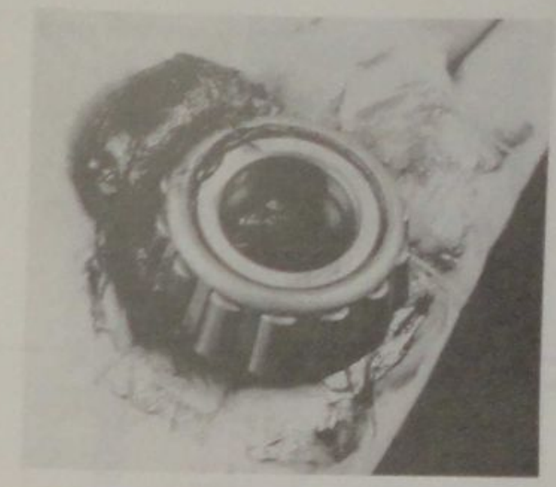


Figure 73–18 When packing grease into a cleaned bearing force grease around each roller as shown.

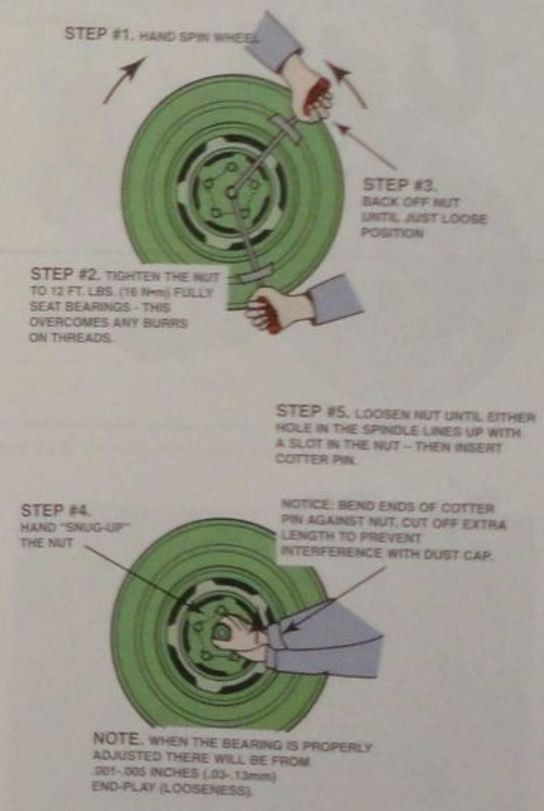


Figure 73–19 The wheel bearing adjustment procedure as specified for rear-wheel-drive vehicles.

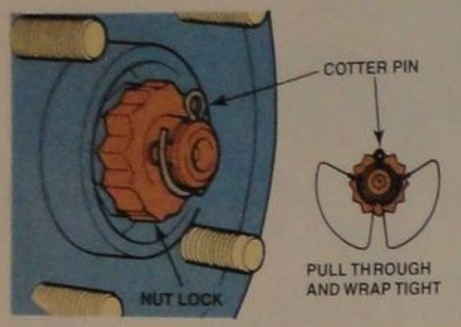


Figure 73–20 A properly secured wheel bearing adjust nut.

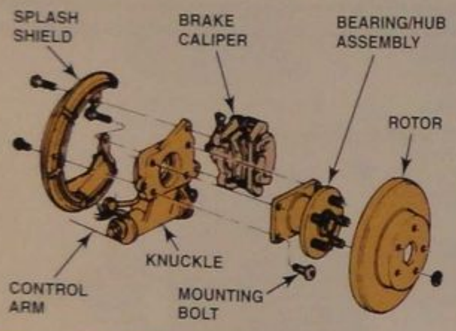


Figure 73–21 A rear wheel sealed bearing hub assembly.

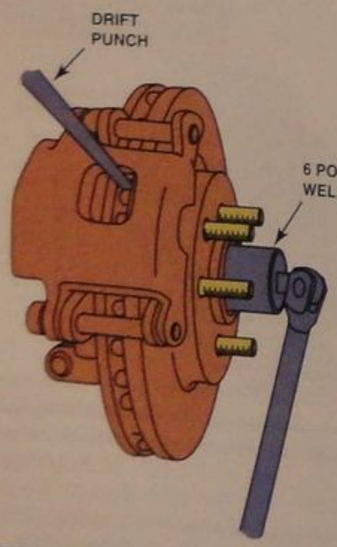


Figure 73–22 Removing the drive axle shaft hub nut. This nut is usually very tight and the drift (tapered) punch wedged into the cooling fins of the brake rotor keeps the hub from revolving when the nut is loosened.

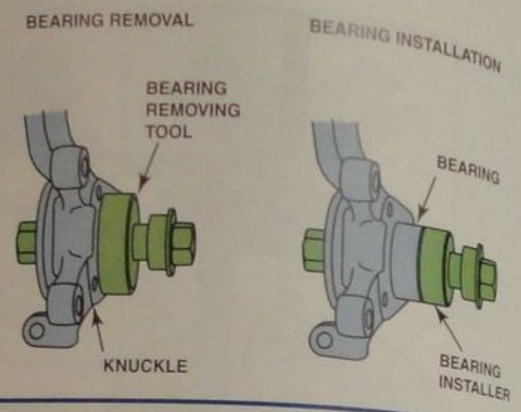


Figure 73–23 A special puller makes the job of removing the hub bearing from the knuckle easy without damaging any component.

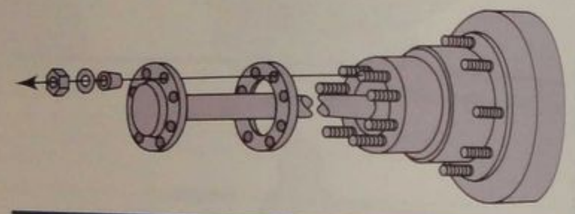


Figure 73–24 A typical full-floating rear axle assembly.

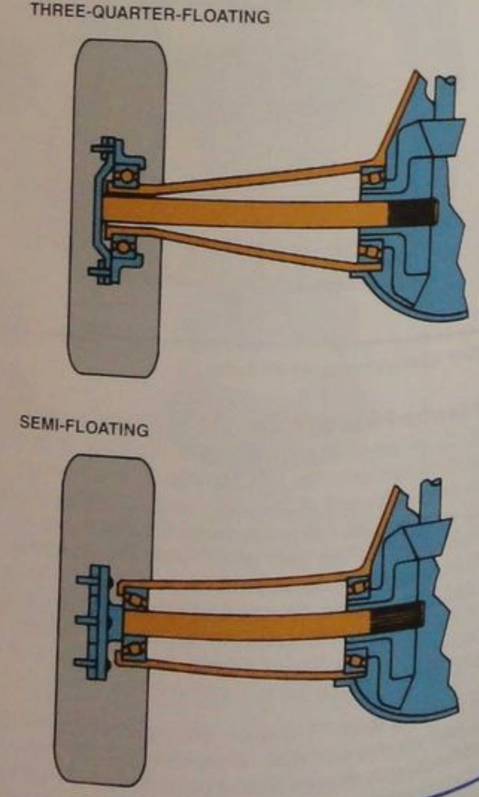


Figure 73–25 Rear axle shafts may be full-floating, three-quarter-floating, or semi-floating, depending on whether the shafts or the axle housing support the wheels.

REAR AXLE BEARING AND SEAL REPLACEMENT

The rear bearings used on rear-wheel-drive vehicles are constructed and serviced differently from other types of wheel bearings. Rear axle bearings are either sealed or lubricated by the rear-end lubricant. The rear axle must be removed from the vehicle to replace the rear axle bearing. There are two basic types of axle retaining methods, **retainer plate-type** and the **C-lock.**

Retainer Plate-Type Rear Axles The retainer plate-type rear axle uses four fasteners that retain the axle in the axle housing. To remove the axle shaft and the rear axle bearing and seal, the retainer bolts or nuts must be removed.

NOTE: If the axle flange has an access hole, then a retainer plate-type axle is used.

The hole or holes in the wheel flange permit a socket wrench access to the fasteners. After the fasteners have been removed, the axle shaft must be removed from the rear axle housing. With the retainer plate-type rear axle, the bearing and the retaining ring are press fit onto the axle and the bearing cup (outer race) is also tightly fitted into the axle housing tube. See Figure 73–26. See Figure 73–27 for one way to remove the axle shaft. It is often necessary to remove the axle to perform a visual inspection especially if trying to diagnose driveline noises. See Figure 73–28.

C-Lock-Type Axles Vehicles that use C-locks (clips) use a straight roller bearing supporting a semi-floating axle shaft inside the axle housing. The straight rollers do not have an inner race. The rollers ride on the axle itself. If a bearing fails, both the axle and the bearing usually need to be replaced. The outer bearing race holding the rollers is pressed into the rear axle housing. The axle bearing is usually lubricated by the rear-end lubricant and a grease seal is located on the outside of the bearing.

TECH TIP ✔ **The Brake Drum Slide Hammer Trick**

To remove the axle from a vehicle equipped with a retainer plate-type rear axle, simply use the brake drum as a slide hammer to remove the axle from the axle housing. See Figure 73–29. If the brake drum does not provide enough force, a slide hammer can also be used to remove the axle shaft.

NOTE: Some replacement bearings are available that are designed to ride on a fresh, unworn section of the old axle. These bearings allow the use of the original axle, saving the cost of a replacement axle.

The C-lock-type rear axle retaining method requires that the differential cover plate be removed. After removal of the cover, the differential pinion shaft has to be removed before the C-lock that retains the axle can be removed. See Figures 73–30 and 73–31.

NOTE: When removing the differential cover, rear axle lubricant will flow from between the housing and the cover. Be sure to dispose of the old rear axle lubricant in the environmentally approved way, and refill with the proper type and viscosity (thickness) of rear-end lubricant. Check the vehicle specifications for the recommended grade.

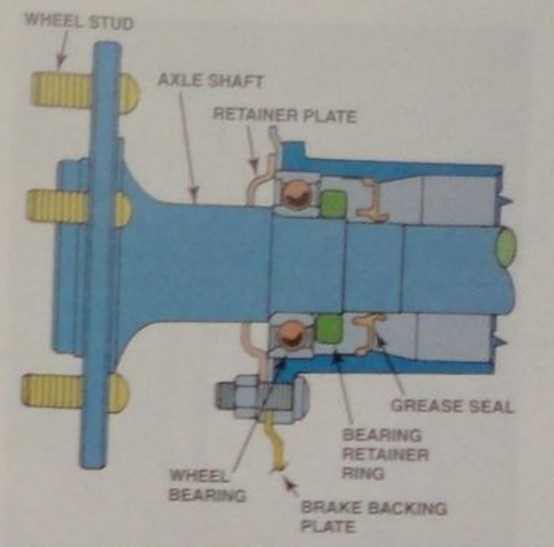


Figure 73–26 A retainer plate-type rear axle bearing. Access to the fasteners is through a hole in the axle flange.

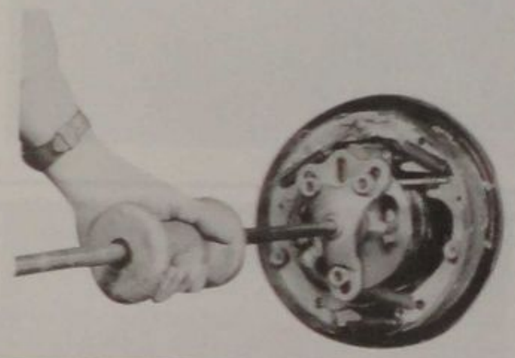
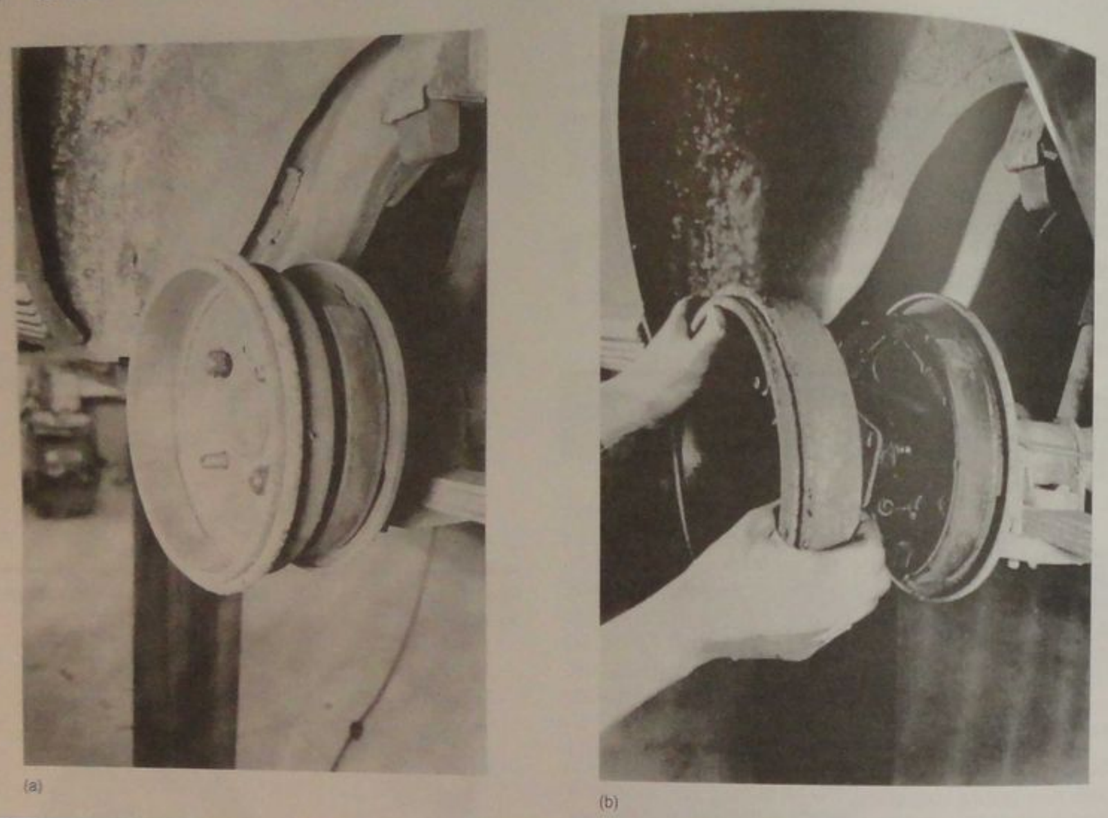


Figure 73–27 A slide hammer-type axle puller can also be used.



Figure 73–28 The ball bearings fell out onto the ground when this axle was pulled out of the axle housing. Diagnosing the cause of the noise and vibration was easy on this vehicle.

Once the C-lock has been removed, the axle simply is pulled out of the axle tube. Axle bearings with inner races are pressed onto the axle shaft and must be pressed off using a hydraulic press.



(a) (b)

Figure 73–29 (a) To remove the axle from this vehicle equipped with a retainer-plate rear axle, the brake drum was placed back onto the axle studs backward so that the drum itself can be used as a slide hammer to pull the axle out of the axle housing. (b) A couple of pulls and the rear axle is pulled out of the axle housing.

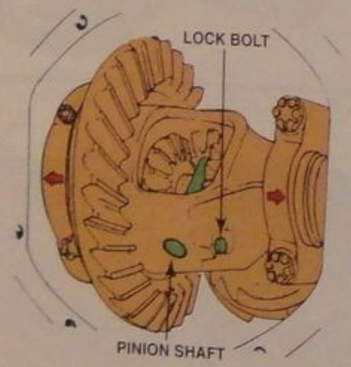


Figure 73–30 To remove the C-lock (clip), the lock bolt has to be moved before the pinion shaft.

A bearing retaining collar should be chiseled or drilled into to expand the collar, allowing it to be removed. See Figure 73–32.

Always follow the manufacturer's recommended bearing removal and replacement procedures. Always replace the rear axle seal whenever replacing a rear axle bearing. See Figure 73–33 for an example of seal removal.

Always check the differential vent to make sure it is clear. A clogged vent can cause excessive pressure to build up inside the differential and cause the rear axle seals to leak. If rear-end lubricant

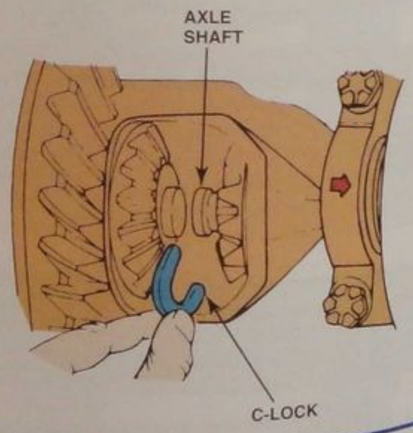


Figure 73–31 The axle must be pushed inward slightly to allow the C-lock to be removed. After the C-lock has been removed, the axle can be easily pulled out of the axle housing.

gets on the brake linings, the brakes will not have the proper friction and the linings themselves are ruined and must be replaced.

BEARING FAILURE ANALYSIS

Whenever a bearing is replaced, the old bearing must be inspected and the cause of the failure eliminated. See Figures 73–34 through 73–40 for examples of normal and abnormal bearing wear.

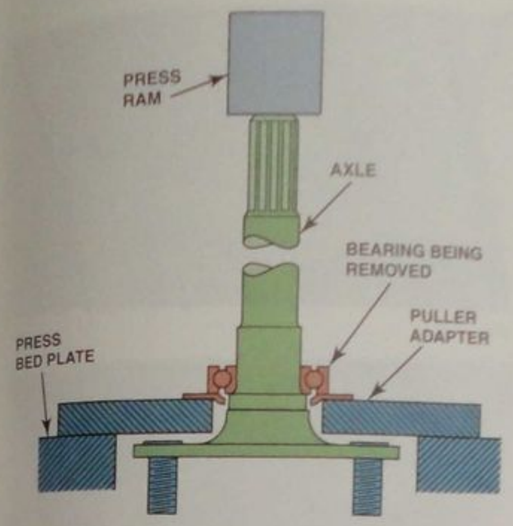


Figure 73–32 Using a hydraulic press to press an axle bearing from the axle. When pressing a new bearing back onto the axle, pressure should only be on the inner bearing race to prevent damaging the bearing.



Figure 73–33 Removing an axle seal using the axle shaft as the tool.

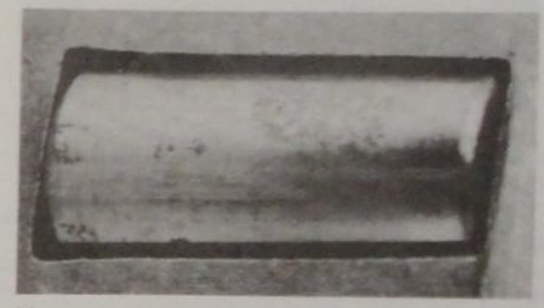
A wheel bearing may also fail for reasons, including the following:

Metal Fatigue. Long vehicle usage, even under normal driving conditions, causes metal to fatigue. Cracks often appear, and eventually these cracks expand downward into the metal from the surface. The metal between the cracks can break out into small chips, slabs, or scales of metal. This process of breaking up is called **spalling.** See Figure 73–41.

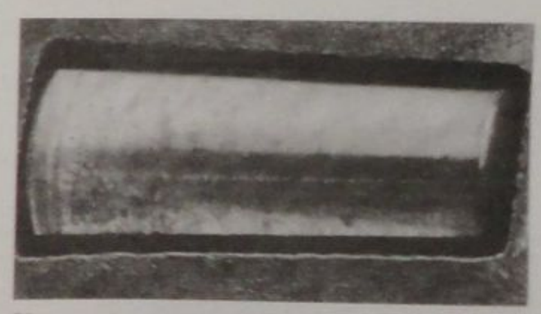
Shock Loading. Dents can be formed in the race of a bearing, which eventually leads to bearing failure. See the Tech Tip titled "What's That Sound" and Figure 73–42.



Figure 73–34 This is a normally worn bearing. If it does not have too much play, it can be reused. *(Courtesy SKF USA Inc.)*



(a)



(b)

Figure 73–35 (a) When corrosion etches into the surface of a roller or race, the bearing should be discarded. (b) If light corrosion stains can be removed with an oil-soaked cloth, the bearing can be reused. *(Courtesy SKF USA Inc.)*

TECH TIP ✓ **What's That Sound?**

Defective wheel bearings usually make noise. The noise most defective wheel bearings make sounds like noisy off-road or aggressive tread, or mud and snow tires. Wheel bearing noise will remain constant while driving over different types of road surfaces while tire tread noise usually changes with different road surfaces. In fact, many defective bearings have been ignored by the vehicle owners and technicians because it was thought that the source of the noise was the aggressive tread design of the mud and snow tires. Always suspect defective wheel bearings whenever you hear what seems to be extreme or unusually loud tire noise.

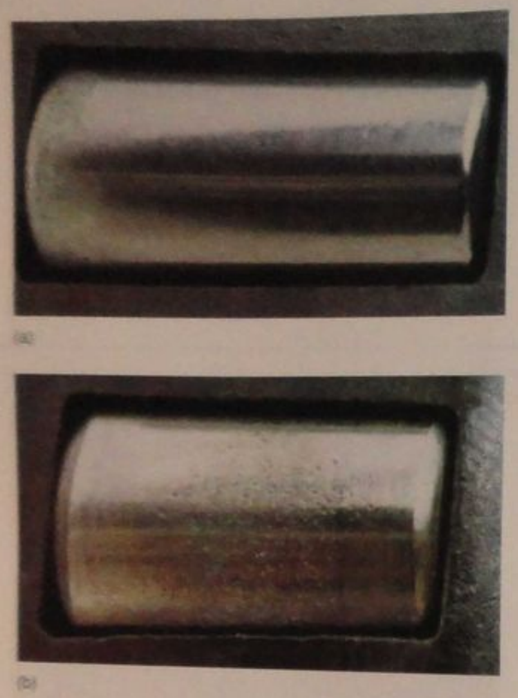


Figure 73–36 (a) When just the end of a roller is scored, it is because of excessive preload. Discard the bearing. (b) This is a more advanced case of pitting. Under load, it will rapidly lead to spalling. *(Courtesy SKF USA Inc.)*

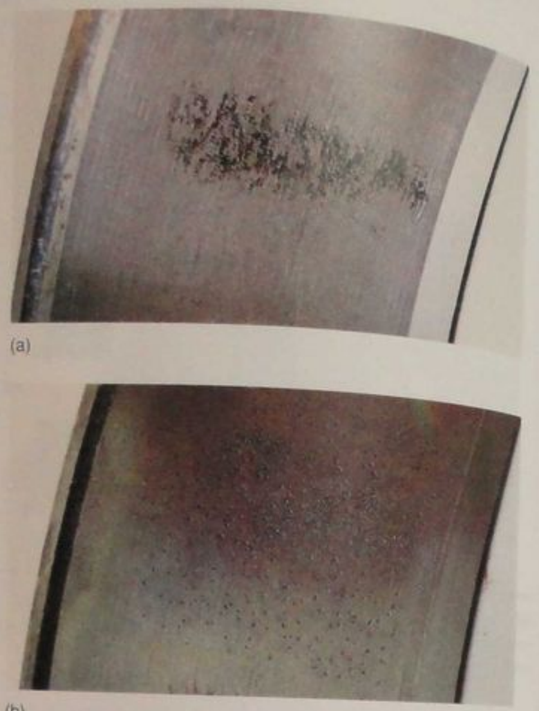


Figure 73–38 (a) Regular patterns of etching in the race are from corrosion. This bearing should be replaced. (b) Light pitting comes from contaminants being pressed into the race. Discard the bearing. *(Courtesy SKF USA Inc.)*



Figure 73–37 (a) Always check for faint grooves in the race. This bearing should not be reused. (b) Grooves like this are often matched by grooves in the race (above). Discard the bearing. *(Courtesy SKF USA Inc.)*

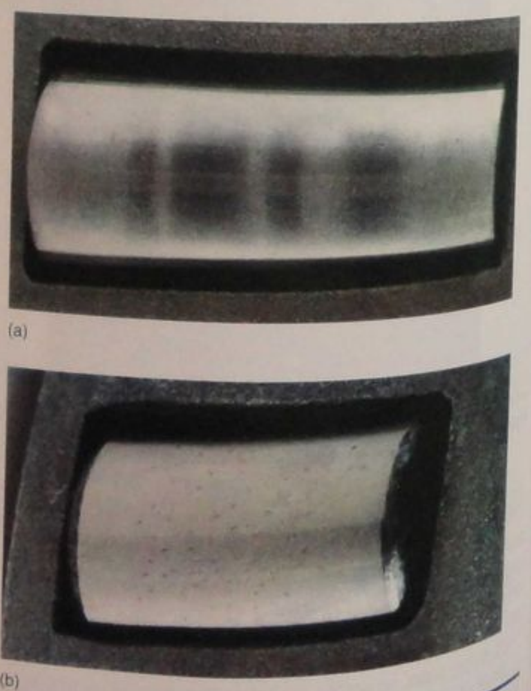


Figure 73–39 (a) This bearing is worn unevenly. Notice the stripes. It should not be reused. (b) Any damage that causes low spots in the metal renders the bearing useless. *(Courtesy SKF USA Inc.)*



Figure 73–40 (a) In this more advanced case of pitting, you can see how the race has been damaged. (b) Discoloration is a result of overheating. Even a lightly burned bearing should be replaced. *(Courtesy SKF USA Inc.)*



Figure 73–41 (a) Pitting eventually leads to spalling, a condition where the metal falls away in large chunks. (b) In this spalled roller, the metal has actually begun to flake away from the surface. *(Courtesy SKF USA Inc.)*



Figure 73–42 These dents resulted from the rollers "hammering" against the race, a condition called brinelling. *(Courtesy SKF USA Inc.)*

SUMMARY

1. Wheel bearings support the entire weight of a vehicle and are used to reduce rolling friction. Ball and straight roller-type bearings are nonadjustable while tapered roller-type bearings must be adjusted for proper clearance.
2. Most front-wheel-drive vehicles use sealed bearings, either two preloaded tapered roller bearings or double row ball bearings.
3. Most wheel bearings are standardized sizes.
4. A defective bearing can be caused by metal fatigue that leads to spalling, shock loads that cause brinelling, or damage from electrical arcing due to poor body ground wires or improper electrical welding on the vehicle.
5. Bearing grease is an oil with a thickener. The higher the NLGI number of the grease, the thicker or harder the grease consistency.
6. Tapered wheel bearings must be adjusted by hand tightening the spindle nut after properly seating the bearings. A new cotter key must always be used.
7. Defective wheel bearings usually make more noise while turning because more weight is applied to the bearing as the vehicle turns.
8. All bearings must be serviced, replaced, and/or adjusted using the vehicle manufacturer's recommended procedures as stated in the service manual.

REVIEW QUESTIONS

1. List three common types of automotive antifriction bearings.
2. Explain the adjustment procedure for a typical tapered roller wheel bearing.
3. List four symptoms of a defective wheel bearing.
4. Describe how the rear axle is removed from a C-lock-type axle.

CHAPTER QUIZ

1. Which type of automotive bearing can withstand radial and thrust loads, yet must be adjusted for proper clearance?
   a. Roller bearing
   b. Tapered roller bearing
   c. Ball bearings
   d. Needle roller bearing
2. Most sealed bearings used on the front wheels of front-wheel-drive vehicles are usually which type?
   a. Roller bearing
   b. Single tapered roller bearing
   c. Double row ball bearing
   d. Needle roller bearing
3. On a bearing that has been shock loaded, the race (cup) of the bearing can be dented. This type of bearing failure is called _____.
   a. Spalling
   b. Arcing
   c. Brinelling
   d. Fluting

PHOTO SEQUENCE Rear Axle Bearing



P73–1 After safely hoisting the vehicle, remove the rear wheels and brake drums.



P73–2 Remove the rear differential cover and inspect the magnet for metal particles that would indicate serious wear or damage.



P73–3 Remove the retaining bolt and allow the pinion shaft to be removed.



P73–4 Push the axle inward toward the center of the vehicle to free the axle clip.



P73–5 After removing the clip, the axle can then be removed. Note that the backing plate is wet indicating that the axle seal has been leaking.



P73–6 A seal removal tool being used to remove the axle seal.



P73–7 If a retainer-type axle is being serviced, the bearing and seal need to be pressed off of the axle.



P73–8 After installing a new bearing and seal, insert the axle and install the clip, then the pinion shaft.



P73–9 Clean the differential housing before installing the cover gasket and cover. Refill the differential with the specified fluid.

4. The bearing grease most often specified is rated NLGI _____.
   a. #00
   b. #0
   c. #1
   d. #2

5. A non-drive-wheel bearing adjustment procedure includes a final spindle nut tightening torque of _____.
   a. Finger tight
   b. 5 lb. in.
   c. 12 to 30 lb. ft.
   d. 12 to 15 lb. ft. plus 1/16 in. turn

6. After a non-drive-wheel bearing has been properly adjusted, the wheel should have how much end play?
   a. Zero
   b. 0.001 to 0.005 in.
   c. 0.10 to 0.30 in.
   d. 1/16 to 3/32 in.

7. The differential cover must be removed before removing the rear axle on which type of axle?
   a. Retainer plate
   b. C-lock
   c. Press fit
   d. Welded tube

8. What part(s) should be replaced when servicing a wheel bearing on a non-drive wheel?
   a. The bearing cup
   b. The grease seal
   c. The cotter key
   d. Both the grease seal and the cotter key

9. Technician A says that a defective wheel or axle bearing often makes a growling or rumbling noise. Technician B says that a defective wheel or axle bearing often makes a noise similar to a tire with an aggressive mud or snow design. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Two technicians are discussing differentials. Technician A says all differentials are vented. Technician B says that a clogged vent can cause the rear axle seal to leak. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 74 Drum Brake Parts and Operation

OBJECTIVES: **After studying Chapter 74, the reader will be able to:** Prepare for ASE Brakes (A5) certification test content area "B" (Drum Brake Diagnosis and Repair). • Identify drum brake component parts. • Describe the operation of non-servo brakes. • Explain the operation of dual-servo brakes. • Discuss drum brake adjusters.

KEY TERMS: anchor eyes • automatic adjusters • beehive holddown • bonded linings • brake fade • brake shoe holddown • brake shoe return springs • brake shoes • core charge • double-trailing brake • dual-servo brake • duo-servo • gas fade • labyrinth seal • leading shoe • leading-trailing brakes • ledges • lining edge codes • lining fade • lining table • mechanical fade • nibs • non-servo brakes • over-travel spring • pawl • piston stops • platform • primary shoe • riveted linings • secondary shoe • self-energizing action • servo brake • shoe anchors • shoe contact areas • shoe rim • shoe support pads • shoe web • trailing shoe • water fade

DRUM BRAKE ADVANTAGES

Drum brakes were the first type of brakes used on motor vehicles. Even today, over 100 years after the first "horseless carriages," drum brakes are still used on the rear of most vehicles, as shown in Figure 74–1.

The drum brake has been more widely used than any other automotive brake design. See Figure 74–2.

Although the disc brake has proven its superiority in extreme braking conditions, and has replaced the drum brake on the front axle of new vehicles, the drum brake continues to have a number of advantages that contribute to its widespread use on the rear axle of most automobiles.

Self-Energizing and Servo Action The primary advantage of drum brakes is that they can apply more stopping power for a given amount of force applied to the brake pedal than can disc brakes. This is possible because the drum brake design offers a self-energizing action that helps force the brake linings tightly against the drum. In addition, some drum brake designs use an effect called servo action that enables one brake shoe to help apply the other for increased stopping power. Both self-energizing and servo action are explained in detail later in the chapter.

Parking Brake Service One significant advantage that results from the superior banking power of drum brakes at low application forces is that they make excellent parking brakes. A simple linkage fitted to the brake assembly allows relatively low effort from the driver to hold a heavy vehicle in place when parked. Disc brakes, which do not benefit from self-energizing or servo action, require a complex set of extra parts to provide enough application force to work well as parking brakes.

DRUM BRAKE DISADVANTAGES

Drum brake disadvantages fall into three areas:

- Brake fade
- Brake adjustment
- Brake pull

Brake Fade The greatest drawback of drum brakes is that they are susceptible to fade. **Brake fade** is the loss of stopping power that occurs when excessive heat reduces the friction between the brake shoe linings and the drum.

Mechanical Fade Drum brakes are not very efficient at dissipating heat. The brake drum shrouds the linings, and most of the heat produced when braking must pass through the drum, from the inside out, before it can be carried away by the passing airflow. **Mechanical fade** occurs when the brake drum gets so hot it expands away from the brake linings. The brake shoes then move outward to maintain

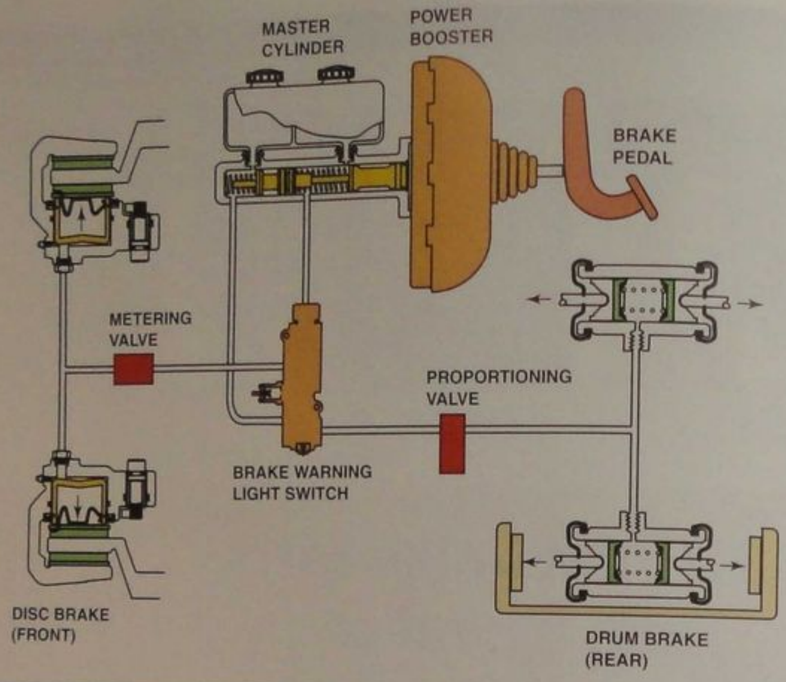


Figure 74–1 Typical brake system components showing disc brakes on the front and drum brakes on the rear.

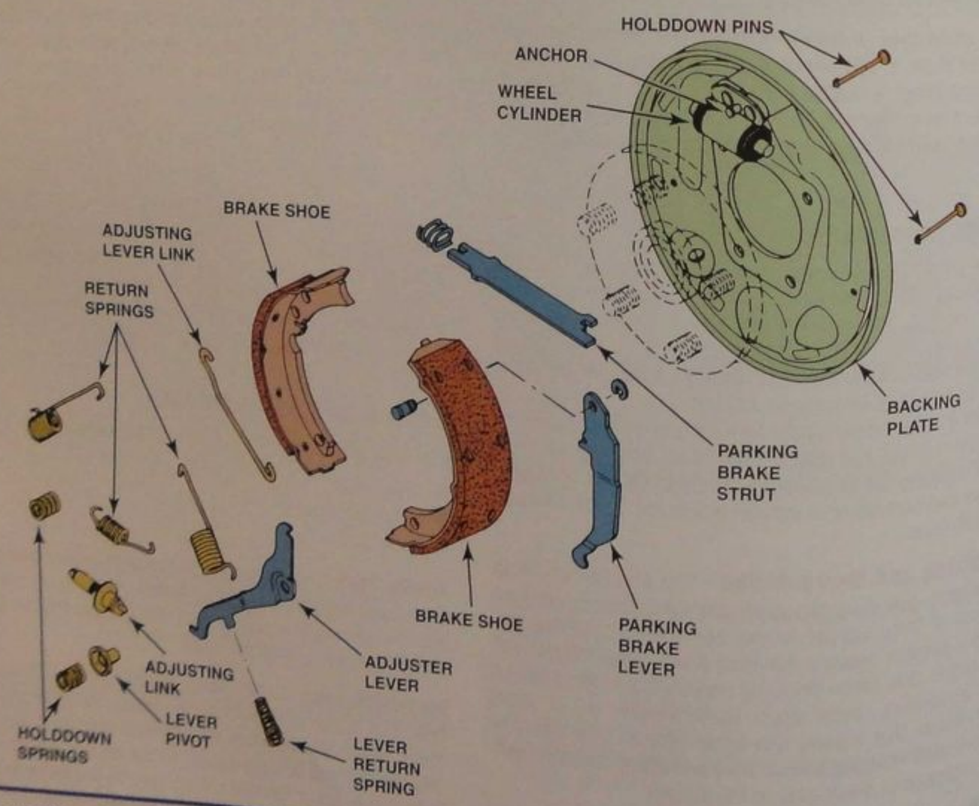


Figure 74–2 An exploded view of a typical drum brake assembly.

contact with the drum, causing the brake pedal to drop toward the floor as additional brake fluid moves into the hydraulic system.

Lining Fade **Lining fade** occurs when the friction coefficient of the brake lining material drops off sharply because intense heat makes it "slippery." Unlike mechanical fade, brake pedal travel does not increase when lining fade occurs. Instead, the pedal becomes hard and there is a noticeable loss of braking power. The portions of the linings that do remain in contact with the drum become extremely hot and mechanical fade of the drum soon results.

Gas Fade A relatively rare type of brake fade is called **gas fade.** Under extended hard braking from high speeds, a thin layer of hot gasses and dust particles can build up between the brake shoe linings and drum. The gas layer acts as a lubricant and reduces friction. As with the lining fade, the brake pedal becomes hard, and greater application force is required to maintain a constant level of stopping power.

Water Fade Drum brakes are also affected by a problem called **water fade.** A drum brake friction assembly cannot be made waterproof because clearance is necessary between the rotating drum and the fixed backing plate. This clearance allows a small amount of air circulation that helps combat heat fade, but it can also allow water to enter the friction assembly. Water fade occurs when moisture is trapped between the shoes and drum, where it acts as a lubricant. This lowers braking efficiency until friction creates enough heat to evaporate the water.

TECH TIP ✔ **Quick-and-Easy Drum Brake Adjustment Check**

Tap the brake drum lightly with a hammer or wrench. If the brake shoes are not contacting the drum, the drum will ring like a bell. If the shoes are contacting the drum, the sound will be muffled.

Brake Adjustment Another disadvantage of the drum brake design is its need for an adjusting mechanism. As the brake shoe lining material wears, the clearance between the linings and drum increases, resulting in longer brake pedal travel. To maintain a high brake pedal, a mechanism must be included in the friction assembly for periodic adjustment of the clearance between the shoe and drum. Most vehicles have automatic adjusters that maintain the proper clearance between the brake linings and the drum.

Brake Pull The final disadvantage of drum brakes is that they sometimes pull the vehicle to one side or the other during braking. Certain designs are more susceptible to this than others, but all drum brakes suffer from it to one degree or another. Brake pull occurs when the friction assemblies on opposite sides of the vehicle have different amounts of stopping power. These differences can be caused by brake fade or misadjustment of the clearance between the brake linings and drum.

DRUM BRAKE PARTS

A typical drum brake assembly consists of many parts, including the backing plate and springs, as well as the brake shoes and adjuster.

The foundation of every drum brake is the backing plate that mounts to the steering knuckle on the front brakes, or to the suspension or axle housing on the rear brakes. See Figure 74–3.

The backing plate serves as the mounting surface for all the other friction assembly parts. The backing plate also functions as a dust and water shield to keep contaminants out of the brake assembly. The edge of the backing plate curves outward to form a

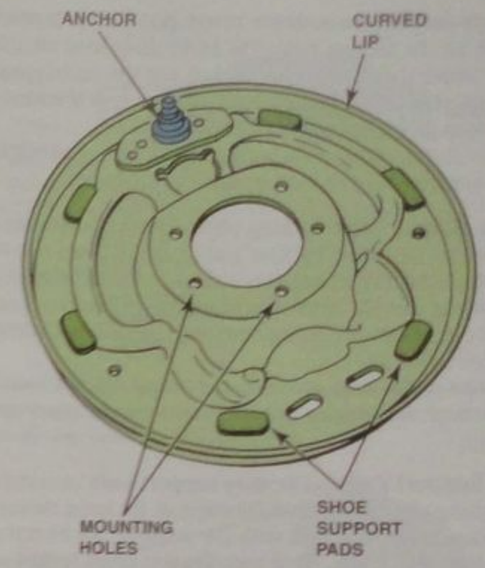


Figure 74–3 The backing plate is the foundation of every drum brake.

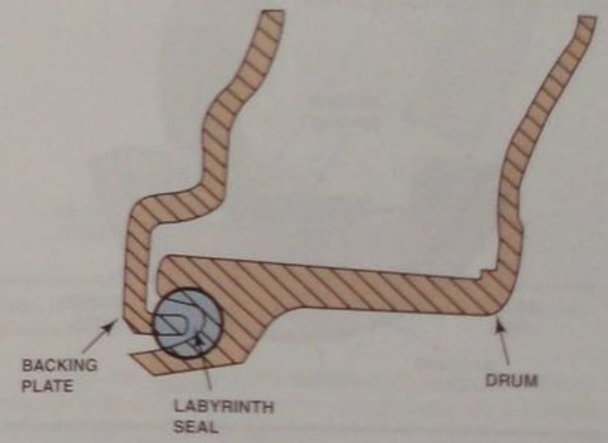


Figure 74–4 The flange on the backing plate is designed to come close to a notch or groove on the brake drum, forming a type of seal that helps prevent debris and water from getting onto the drum brake.

lip that strengthens the backing plate and fits inside the brake drum to help prevent water entry. The lip fits into a machined groove in the open edge of the brake drum to provide an even better water barrier or seal. This is called a **labyrinth seal.** See Figure 74–4.

In addition to mounting holes for the various brake parts, the backing plate may also have openings that are used to inspect the wear of the brake linings, or adjust the lining-to-drum clearance. These openings are sometimes sealed with metal plugs that must be punched out the first time inspection or adjustment is needed. Rubber plugs are available to seal the holes and prevent water entry once the metal plugs have been removed.

Shoe Anchors **Shoe anchors** prevent the brake shoes from rotating with the drum when the brakes are applied. The majority of drum brakes have a single anchor, but some drum brake designs use two or more.

Many anchors are a simple round post that is permanently mounted on the backing plate. The brake shoes have semicircular cutouts where they contact the anchor, and the anchor positively locates the shoe on the backing plate. Another type of anchor is the self-centering or keystone anchor. See Figure 74–5.

It is called a keystone anchor because of the angled shape similar to a keystone used on the top center of a stone arch.

Piston Stops Some backing plates incorporate **piston stops** that prevent the wheel cylinder pistons from coming out of their bores when the friction assembly is disassembled for servicing. The stops may be part of a reinforcing plate positioned under the anchor or they can be stamped directly into the shape of the backing plate itself. See Figure 74–6.

When piston stops are used, the wheel cylinder must be removed from the backing plate before it can be taken apart for servicing.

Shoe Support Pads The **shoe support pads** are stamped into the backing plate and contact the edges of the brake shoes to keep the linings properly aligned with the center of the friction surface inside the brake drum. These pads are also called **ledges** or **shoe contact areas.** The support pads are slightly coated with special high-temperature silicone brake grease to minimize wear, prevent rust, and eliminate squeaking that can occur when the shoes move slightly on the pads during a stop.

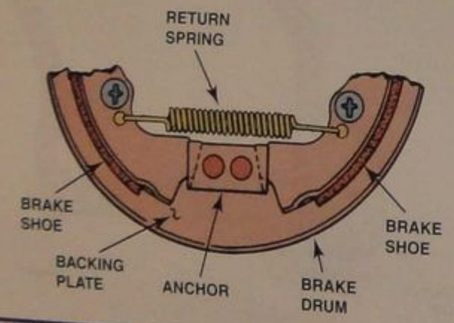


Figure 74–5 A keystone anchor allows the brake shoes to self-center in the drum.

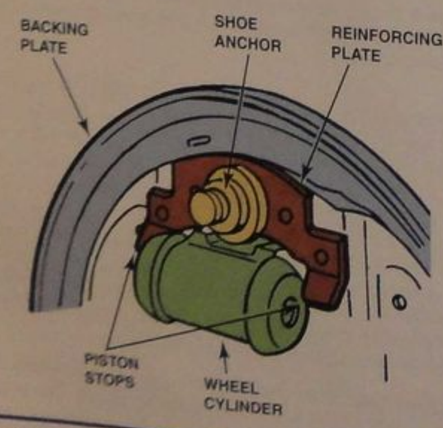


Figure 74–6 Piston stops prevent the wheel cylinder from coming apart.

Wheel Cylinders Hydraulic pressure is transferred from the master cylinder to each wheel cylinder through brake fluid. The force exerted on the brake fluid by the driver forces the piston inside the wheel cylinder to move outward. See Figure 74–7. Through pushrods or links, this movement acts on the brake shoes, forcing them outward against the brake drum. See Figure 74–8.

DRUM BRAKE SHOES

The linings of drum brakes are attached to curved metal assemblies called **brake shoes.** Most shoes are made of two pieces of sheet steel welded together in a T-shaped cross-section. See Figure 74–9.

While aluminum shoes are lighter than their steel counterparts, they are more expensive to make and not as durable at high temperatures. The outer edge is lined with a friction material that contacts the brake drum to generate the actual stopping power. The ends of the linings on most brake shoes are tapered to prevent vibration and brake noise as shown in Figure 74–10.

The curved metal piece on the outer portion of the shoe is called the **lining table,** the **shoe rim** or **platform.** The lining table supports the block of friction material that makes up the brake lining. On some shoes, the edge of the lining table contains small

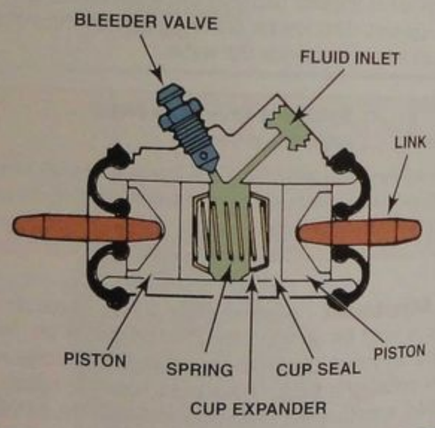


Figure 74–7 Cross-section of a wheel cylinder that shows all of its internal parts. The brake line attaches to the fluid inlet. The cup expander prevents the cup seal lip from collapsing when the brakes are released.

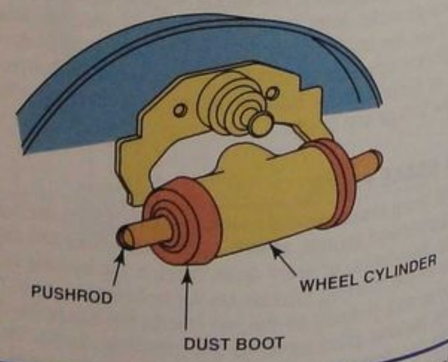


Figure 74–8 The pushrods are held in place by the rubber dust boots. As the wheel cylinder pistons move outward, the pushrods transfer the movement to the brake shoes.

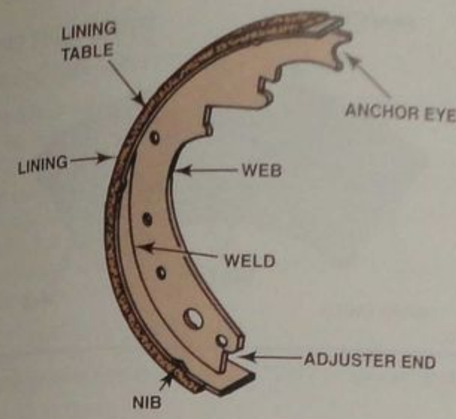


Figure 74–9 Steel brake shoes are made from two stampings welded together.

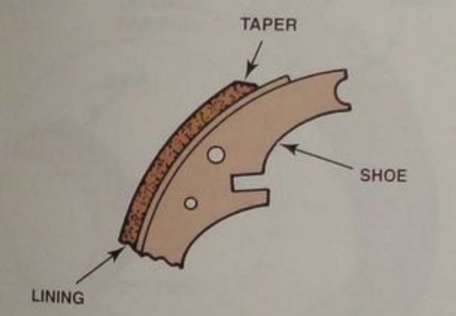


Figure 74–10 Tapered ends on the brake linings reduce noise.

V- or U-shaped notches called **nibs.** The nibs rest against the shoe support pads on the backing plate when the shoe is installed.

The metal piece of the shoe positioned under the lining table and welded to it is called the **shoe web.** All of the application force that actuates the shoe is transferred through the web to the lining table. The web usually contains a number of holes in various shapes and sizes for the shoe return springs, hold-down hardware, parking brake linkage, and self-adjusting mechanism.

One end of the web usually has a notch or protrusion where the wheel cylinder touches the shoe, while the other end commonly has a flat or curved surface where the shoe meets an anchor or adjusting link. The upper ends of the webs on dual-servo brake shoes have semicircular **anchor eyes.** See Figure 74–11.

Brake shoes are sturdy parts that can be relined and reused many times if the web and lining table are not damaged. Brake shoes for any given application are usually available in both "new" and "relined" versions from suppliers. Relined brake shoes are usually sold on an exchange basis. At the time of purchase, a **core charge** is added to the cost of the relined parts. This charge is refunded when the old shoes are returned in rebuildable condition.

Primary and Secondary Brake Shoes In many drum brake friction assemblies, the two shoes are interchangeable; one is a mirror image of the other. However, the shoes in a dual-servo brake perform very different jobs. The primary shoe (forward facing shoe) is self-energized by drum rotation to create a servo action that forces the secondary shoe more firmly against the drum. Because of this, the two shoes have definite physical differences and cannot be interchanged.

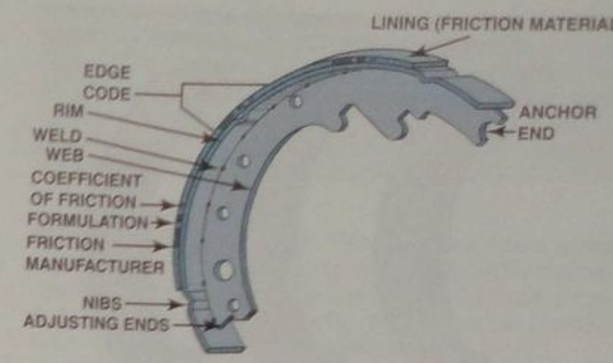


Figure 74–11 Typical drum brake shoe and the names of the parts. *(Courtesy of Allied Signal Automotive Aftermarket)*

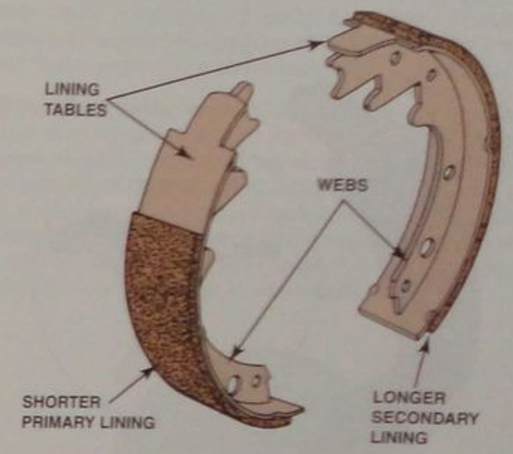


Figure 74–12 The primary (forward facing) brake shoe often has a shorter lining than the secondary shoe (rearward facing).

To help deal with the added friction, heat, and wear it undergoes, the lining of the secondary shoe extends nearly the full length of the shoe lining table. See Figure 74–12.

The secondary shoe lining material also has a high coefficient of friction to provide good stopping power. The primary shoe undergoes far less stress than the secondary shoe, and its lining is often shorter—sometimes less than half the length of the lining table. In addition, the lining material usually has a lower coefficient of friction. This prevents the shoe from engaging the drum too quickly or harshly, which could cause the brakes to grab or lock.

On most dual-servo brake primary shoes, the lining is positioned near the center of the lining table. However, in some cases, the lining may be positioned above or below the lining table centerline. Higher or lower lining positions provide better braking action, or prevent noise, in certain applications. See Figure 74–13.

Lining Assembly Methods Before any type of brake lining can do its job, it must be firmly attached to the lining table of a drum brake shoe or the backing plate of a disc brake pad. Several methods are used to mount brake linings; the most common are the following:

- Riveting
- Bonding
- Mold bonding

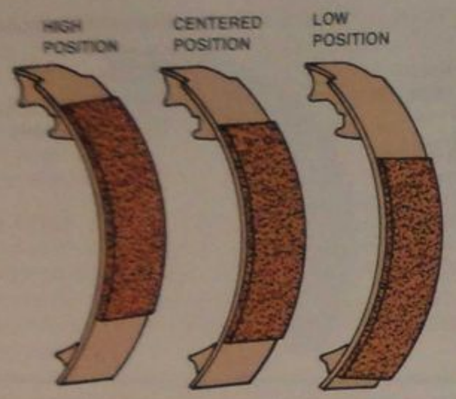


Figure 74–13 Primary shoe lining may vary depending on the application.

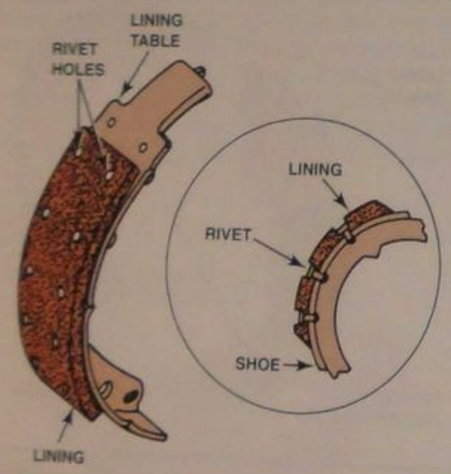


Figure 74–14 Riveted brake linings are quiet and reliable at high temperatures.

Riveting **Riveted linings** take advantage of the oldest method of lining attachment still in use. In this system, the brake block is attached to the lining table or backing plate with copper or aluminum rivets. See Figure 74–14.

The major advantage of riveting is that it allows a small amount of flex between the brake block and lining table or backing plate. This play enables the assembly to absorb vibration, and the result is that riveted linings operate more quietly than bonded linings. Rivets are also very reliable and will not loosen at high temperatures.

Despite the benefit of quiet operation, riveted linings present a number of problems. In order to leave sufficient friction material for the rivets to clamp the brake block securely against the lining table or backing plate, the rivet holes are countersunk only about two-thirds to three-quarters of the way through the lining. This reduces the service life of the assembly because the shoes must be replaced before the rivet heads contact and score the drum.

The rivet holes themselves also present some unique problems. First, they trap abrasive brake dust and other grit that can score the drum or rotor. Some rivets are hollow to allow these materials to escape.

Rivet holes also create stress points in the lining where cracks are likely to develop. Some riveted semimetallic brake pads have

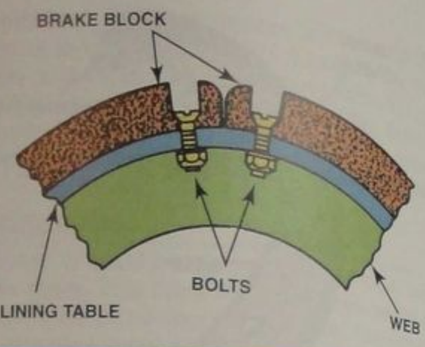


Figure 74–15 The brake line is bolted to the shoe on most heavy trucks and buses.

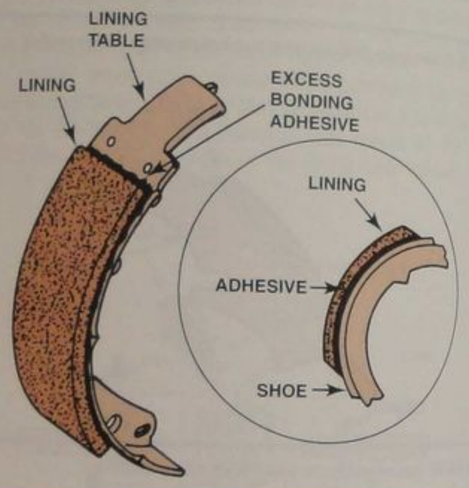


Figure 74–16 Many brake linings are bonded.

a thin layer of asbestos bonded to the back of the brake block to provide a more crack resistant mounting surface.

In a process similar to riveting, heavy-duty truck and trailer brake linings are often bolted in place. See Figure 74–15. The lining is countersunk as in riveting, but the rivet is replaced by a brass bolt, nut, and washer.

Bonding **Bonded linings** use high-temperature adhesive to glue the brake block directly to the shoe lining table or pad backing plate as shown in Figure 74–16.

Heat and pressure are then applied to cure the assembly. Bonding is a common form of shoe and pad assembly, and is most often used to mount organic friction materials.

Bonding offers several advantages. Without rivets, bonded linings can wear closer to the lining table or backing plate and provide a longer service life. If the linings wear too far, bonding adhesive is not as destructive to drums or rotors as rivets. Bonded linings also have fewer problems with cracking because they have no rivet holes to weaken the brake block.

The primary disadvantage of bonded linings is a limited ability to withstand high temperatures. If a bonded lining gets too hot, the bonding adhesive will fail and allow the brake block to separate from the lining table or backing plate. Bonded linings are also more prone to be noisy because they do not allow any vibration absorbing flex between the brake block and lining table or backing plate.

LINING EDGE CODES

The **lining edge codes** contain three groups of letters and numbers:

- The first group is a series of letters that identify the manufacturer of the lining.
- The second group is a series of numbers, letters, or both that identify the lining compound or formula. This code is usually known to the manufacturer of the lining material and helps identify the lining after manufacture.
- The third group is two letters that identify the coefficient of friction. See Figure 74–17.

The coefficient of friction is a pure number that indicates the amount of friction between two surfaces. A coefficient of friction will always be less than 1; the higher the number, the greater the amount of friction between two surfaces. (For example, a material with 0.55 coefficient of friction has more friction than a material with a coefficient of friction of 0.39.)

These codes were established by the SAE (Society of Automotive Engineers):

Code C	0.00 to 0.15
Code D	0.15 to 0.25
Code E	0.25 to 0.35
Code F	0.35 to 0.45
Code G	0.45 to 0.55
Code H	0.55 and above
Code Z	ungraded

The first letter, which is printed on the side of most linings, indicates its coefficient of friction when brakes are cold, and the second letter indicates the coefficient of friction of the brake lining when the brakes are hot. (For example, FF indicates that the brake lining material has a coefficient of friction between 0.35 and 0.45 when both cold and hot.)

These letters should not be interpreted to mean the relative quality of the lining material. Lining wear, fade resistance, tensile strength, heat recovery rate, wet friction, noise, and coefficient of friction must be considered when purchasing high-quality linings. Unfortunately, there are no standards that a purchaser can check regarding all of these other considerations. For best brake performance, always purchase the best-quality name-brand linings that you can afford.

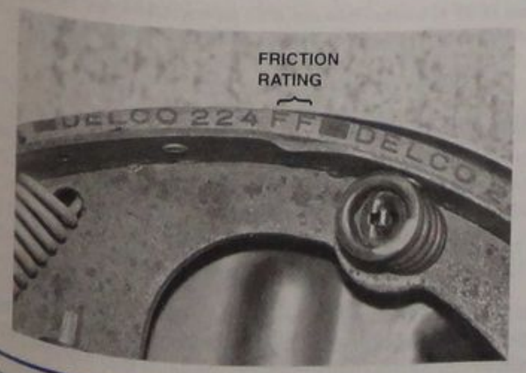


Figure 74–17 Typical drum brake lining edge codes.

NOTE: While many brands of replacement brake lining provide acceptable stopping power and long life, purchasing factory brake lining from a dealer is usually the best opportunity to get lining material that meets all vehicle requirements. Aftermarket linings are not required by federal law to meet performance or wear standards that are required of original factory brake linings.

Brake Shoe Return Springs The **brake shoe return springs** retract the shoes to their unapplied positions when the brake pedal is released. This helps prevent brake drag, and aids the return of brake fluid to the master cylinder reservoir. Most brakes use closed-coil return springs to retract the brake shoes. See Figure 74–18.

The coils on these springs are very tightly wound and contact one another when the spring is relaxed. Some vehicles have a single, large, horseshoe-shaped return spring. See Figure 74–19.

The type, location, and number of return springs vary from one brake design to the next. All springs are installed in one of two ways. Some connect directly from shoe to shoe, while others connect from one shoe to the anchor post.

Brake Shoe Holddowns While the return springs retract the brake shoes to their unapplied positions, the **brake shoe holddowns** keep the shoes securely against the support pads on the backing plate. The holddowns prevent noise, vibration, and wear, but still allow the shoes to move out and back as the brakes are applied and released. The holddowns also provide enough freedom of movement to allow adjustments of the shoes outward as the linings wear. Shoe holddowns take many forms, as shown in Figure 74–20.

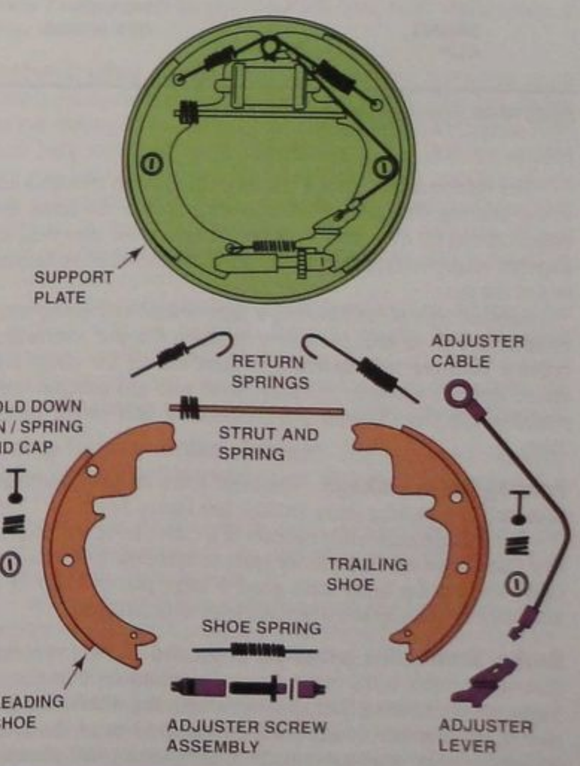


Figure 74–18 Typical drum brake showing support plate (backing plate), anchor pin, and shoe guide plate.

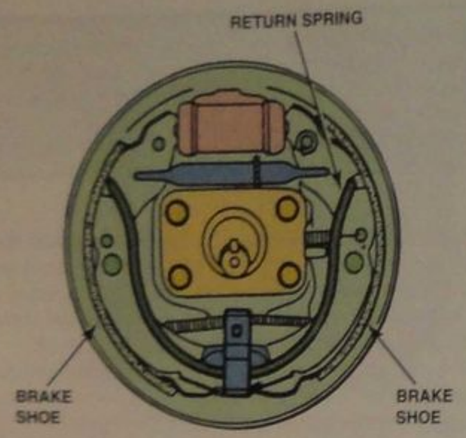


Figure 74–19 A single spring-steel return spring is used on some drum brakes.

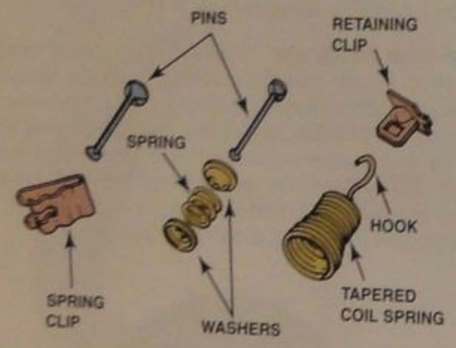


Figure 74–20 Various types and styles of hold-down springs.

The most common design is a steel pin installed through a hole in the backing plate and a corresponding hole in the brake shoe web. A spring fits over the end of the pin against the shoe web, and a special washer compresses the spring and locks onto the flattened end of the pin.

Another type of holddown is a taper-wound coil spring with a hook formed on its end. Because of its shape, this part is sometimes called a **beehive holddown.** The hook end of the spring is installed through a hole in the brake shoe web and attached into a retaining clip that fits into a corresponding hole in the backing plate.

Parking Brake Linkage Most rear drum brake friction assemblies include a parking brake linkage. See Figure 74–21.

The linkage commonly consists of a cable, lever, and strut system that spread the brake shoes apart to apply the brake mechanically. The parking brake strut plays a large part in many of the automatic brake adjusters described later in this chapter.

Brake Drum The last major component in a drum brake friction assembly is the brake drum. The brake drum is not connected to the backing plate, but turns with the wheel. The drum mounts on the hub or axle, and covers the rest of the friction assembly. Brake drums are made of cast iron or cast aluminum with a cast-iron liner. Many of these drum types may have ribs or fins on their outer edge to help dissipate heat. See Figure 74–22.

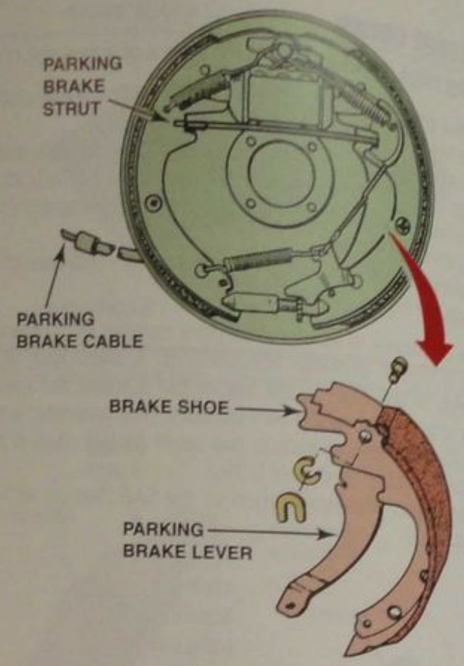


Figure 74–21 A mechanical parking brake linkage is part of most rear drum brakes.



Figure 74–22 An aluminum brake drum with a cast-iron friction surface. The cooling fins around the outside help dissipate the heat from the friction surface to the outside air.

DRUM BRAKE DESIGN

Drum brake designs are classified by the way in which the shoes are applied, and how they react when the linings make contact with the drum. All drum brakes fall into two basic categories:

- Non-servo brakes
- Servo brakes

Early automotive drum brake friction assemblies were non-servo designs, and non-servo brakes are still in many rear-wheel applications. The more powerful servo drum brakes were developed later and are still used on some vehicles.

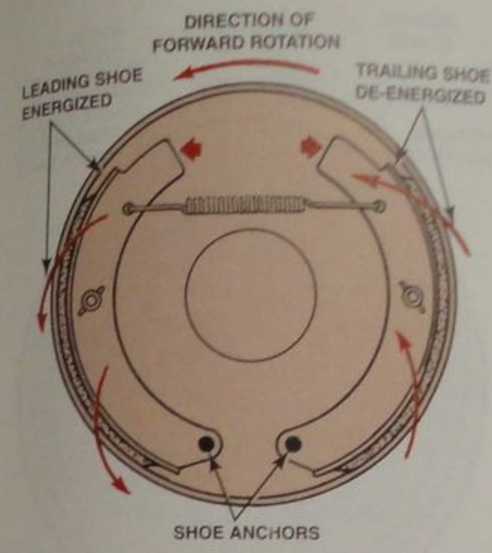


Figure 74–23 Self-energizing action can increase or decrease the stopping power of a brake shoe.

NON-SERVO BRAKES

The identifying feature of a **non-servo brake** is that each brake shoe is applied individually. The action of one shoe has no effect on the action of the other. Drum brakes have the advantage of a self-energizing action that can provide increased application force. Many non-servo drum brakes use this **self-energizing action** to improve their braking performance.

Self-Energizing Action The simple drum brake assembly shown in Figure 74–23 shows how the self-energizing process works.

As the forward or **leading shoe** contacts the drum, the drum attempts to rotate the shoe along with it. However, the shoe cannot rotate because its far end (relative to drum rotation) is fixed in place by an anchor. As a result, drum rotation *energizes* the shoe by forcing it outward and wedging it tightly against the brake drum.

The drum also attempts to rotate the reverse or **trailing shoe** as it contacts the drum. However, in this case, the far end of the shoe (relative to drum rotation) is not solidly anchored. As a result, drum rotation *de-energizes* the shoe by forcing it inward away from the brake drum.

When this type of brake is applied with the vehicle backing up, the roles of the forward and reverse shoes are switched. The reverse shoe becomes the leading shoe, which is self-energized by drum rotation, while the forward shoe becomes the trailing shoe, which is de-energized. *A leading shoe is always energized by drum rotation. A trailing shoe is always de-energized by drum rotation.*

To identify the leading shoe on a non-servo brake with only one wheel cylinder, the first shoe from the wheel cylinder in the direction of drum rotation is the leading shoe. If the piston of a wheel cylinder moves in the same direction as drum rotation when the brakes are applied, the shoe it actuates is a leading shoe. If the piston moves opposite the direction of drum rotation, the shoe actuated is the trailing shoe.

Leading shoes generally wear at a faster rate than trailing shoes because they are applied with greater force. Where a brake uses one leading and one trailing shoe, the leading shoe will sometimes have a thicker lining or one with a larger surface area than that of the trailing shoe. The thicker or larger lining balances the wear between the two shoes so that they will both need replacement at about the same time.

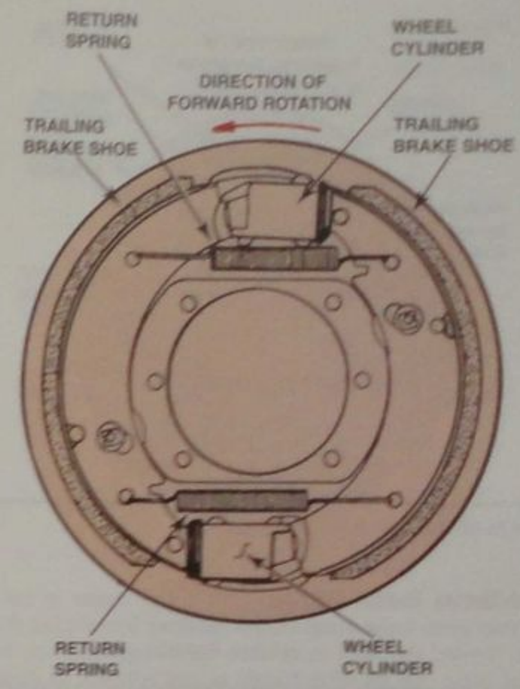


Figure 74–24 A double-trailing non-servo drum brake.

Double-Trailing Brake The least powerful non-servo drum brake is the **double-trailing brake.** See Figure 74–24. This design has two trailing shoes and does not use any self-energization. Both shoes have identically sized and shaped linings that are applied with equal force by a pair of single-piston wheel cylinders. Each shoe is anchored at the end opposite the wheel cylinder that applies it. In many double-trailing brakes, the backside of one wheel cylinder serves as the anchor for the brake shoe actuated by the other wheel cylinder.

The double-trailing brake is usually found only on the rear axles of vehicles with an extreme forward weight bias. In these applications its relative lack of stopping power aids brake balance and helps prevent rear lockup. Unfortunately, it also makes the double-trailing design a poor parking brake in the forward direction.

Leading-Trailing Brake Design The non-servo **leading-trailing brake** has one leading shoe and one trailing shoe. See Figure 74–25.

Typically, a single, two-piston wheel cylinder is mounted at the top of the backing plate and the two brake shoes are anchored at the bottom of the backing plate.

The brake design has one energized and one de-energized shoe regardless of whether it is applied while the vehicle is traveling forward or in reverse. This allows the leading-trailing brake to work equally well in either direction.

Leading-trailing brakes are popular on the rear wheels of many small and front-wheel-drive vehicles because, although they are not as powerful as a servo brake, they are also less prone to lockup. They have the further benefit of making a good parking brake in both directions.

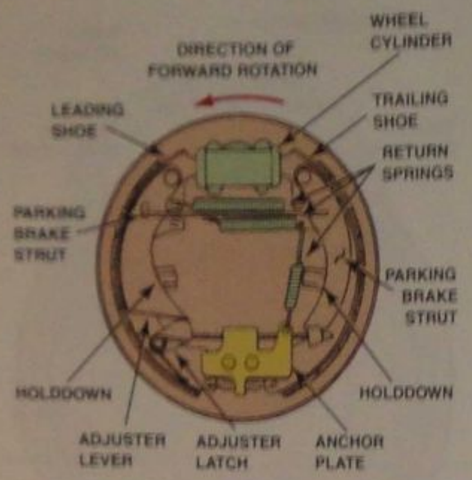


Figure 74–25 A leading-trailing non-servo drum brake.

Dual-Servo Brake Design The **servo brake** is the most common drum brake design. It gets its name from the fact that one shoe "serves" the other to increase application force. One version of this brake, the uni-servo design, is used primarily on trucks and supplies additional stopping power in the forward direction only. All servo brakes used on automobiles, however, are of the duo- or dual-servo design that works with equal force in both directions.

The primary advantage of the dual-servo brake is that it is more powerful than any of the non-servo designs. Another advantage of the dual-servo brake is that it makes a good parking brake. Dual-servo action not only makes the brake very powerful, it allows the brake to hold equally well in both directions.

Dual-servo brakes are more susceptible to pull than other brake designs, and their greater application force can lead to faster fade under extreme braking conditions.

NOTE: Dual-servo brakes are also called **Duo-Servo,** which is a brand name of the Bendix Corporation.

Dual-Servo Brake Construction The basic **dual-servo brake** uses one anchor and a single two-piston wheel cylinder. See Figure 74–26. The anchor is usually mounted at the top of the backing plate with the wheel cylinder directly beneath it. The tops of the brake shoes are held against the anchor by individual return springs. The bottoms of the shoes are spaced apart by an adjusting link held in position by a third return spring that connects the two shoes.

Adjusting Link The adjusting link consists of a starwheel that is part of an adjusting screw, a pivot nut that one end of the adjusting screw threads into, and a socket that rotates freely on the opposite end of the adjusting screw. See Figure 74–27.

The outer ends of the pivot nut and socket are notched to fit over the brake shoe webs. Some adjusting links have a steel thrust washer and/or spring washer installed between the socket and the starwheel. These washers allow easier rotation of the starwheel and help reduce brake squeal.

NOTE: Adjusting links generally have specific left- or right-hand threads, and must be installed on the correct side of the vehicle.

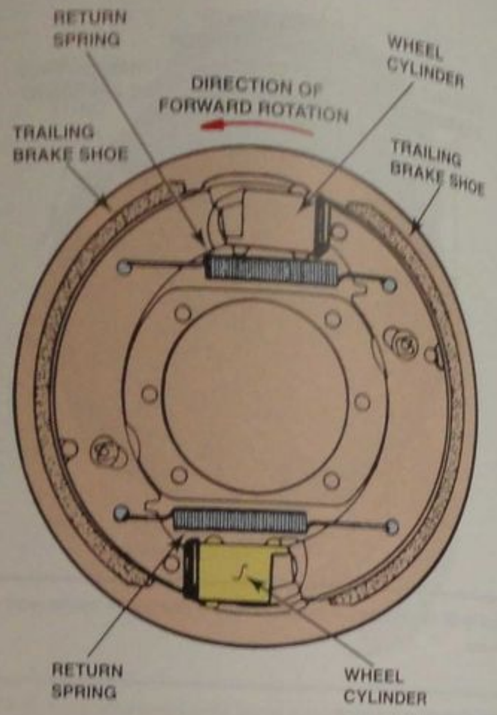


Figure 74–26 A typical dual-servo drum brake.

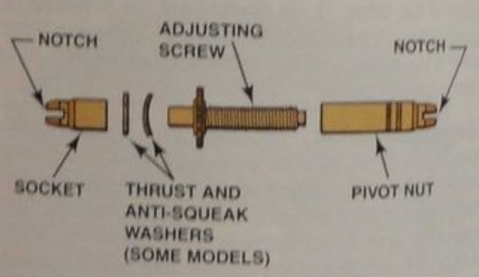


Figure 74–27 A dual-servo brake adjusting link.

Primary and Secondary Brake Shoes Although dual-servo brakes make use of self-energizing action to help provide servo action, the two brake shoes are not called leading and trailing parts as in non-servo brakes. Instead, they are identified as the **primary shoe** and the **secondary shoe.** To identify the primary shoe on a dual-servo brake with a single two-piston wheel cylinder, point to the wheel cylinder, and then move your finger in the direction of drum rotation. The first shoe reached is the primary shoe and the other shoe is the secondary shoe.

The secondary brake shoe provides approximately 70% of the total braking power in a dual-servo brake. For this reason, the lining is usually somewhat larger than that of the primary shoe. In addition, some manufacturers use different types of friction materials on the primary and secondary shoes to help equalize wear.

Dual-Servo Brake Operation When a dual-servo brake is applied, the wheel cylinder attempts to force the tops of both brake shoes outward against the drum. See Figure 74–28.

As the primary shoe makes contact it rotates with the drum because its far end (relative to the direction of drum rotation) is not directly anchored to the backing plate. As the primary shoe rotates, it forces the adjusting link and the secondary shoe to also rotate until the secondary shoe seats firmly against the anchor.

Although the wheel cylinder attempts to push the top of the secondary shoe outward, the rotational force developed by friction between the brake shoes and drum is much greater than the application force developed by hydraulic pressure in the wheel cylinder. As a result, the secondary shoe is held solidly against the anchor. In effect, only one-half of the wheel cylinder is used to apply the brakes.

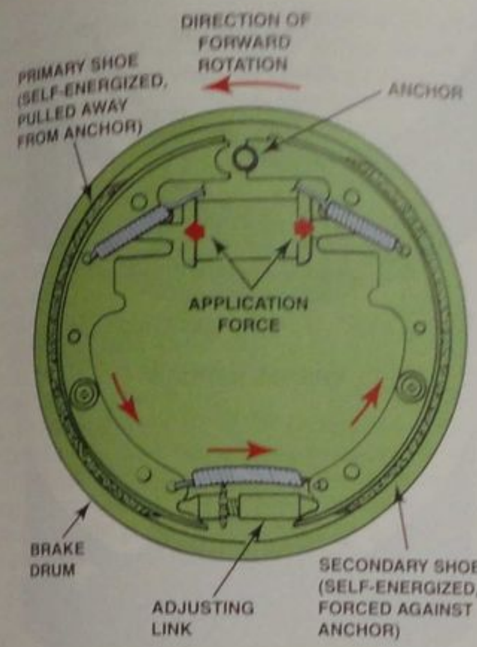


Figure 74–28 Dual-servo brake operation. The primary shoe on the left exerts a force on the secondary shoe on the right.

Servo-Action Once all slack is taken up between the brake shoes, adjusting link, and anchor, both brake shoes become self-energized like the leading shoes in a non-servo brake. The anchor pin prevents the secondary shoe from rotating, and the adjusting link (held in position by the secondary shoe) serves as the anchor for the primary shoe. Servo action then occurs as a portion of the braking force generated by the primary shoe is transferred through the adjusting link to help apply the secondary shoe. See Figure 74–29.

When a dual-servo brake is applied with the vehicle moving in reverse, the primary and secondary shoes switch roles. The primary shoe is forced against the anchor while the secondary shoe moves outward and rotates with the drum to apply the primary shoe with a greater force.

TECH TIP ✓ **Rear Wheel Lockup? Check the Adjustment**

Servo action enables a drum brake to provide increased stopping power, but it can also cause the brakes to grab and lock if they get too far out of adjustment. As clearance between the shoes and drum increases, the primary brake shoe is allowed a greater range of movement. The farther the shoe moves, the more speed it picks up from the rotating brake drum. At the moment the slack is taken up between the brake shoes, adjusting link, and anchor, the speed of the primary shoe is converted into application force by servo action. If the primary shoe is moving too quickly, it will apply the secondary shoe very hard and fast, causing the brakes to grab and possibly lock the wheels.

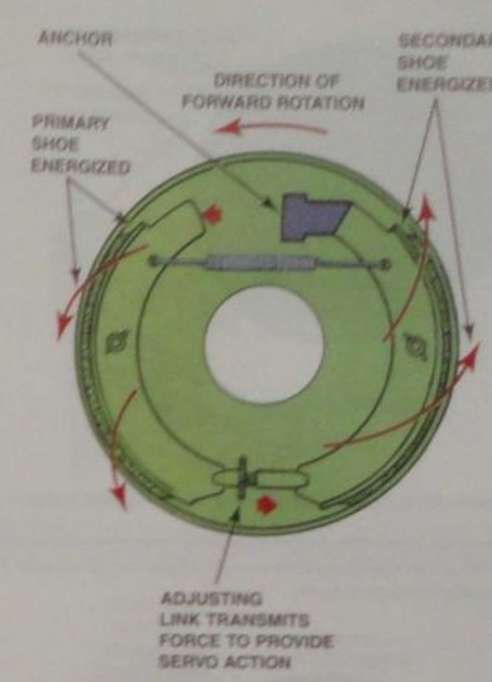


Figure 74–29 Servo action greatly increases the application force on the secondary shoe.

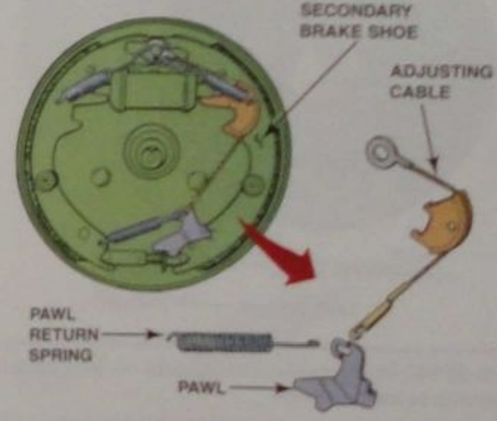


Figure 74–30 A cable-actuated starwheel automatic adjuster. This type of adjuster makes the adjustment as the brakes are released.

AUTOMATIC BRAKE ADJUSTERS

Automatic adjusters use the movement of the brake shoes to continually adjust lining-to-drum clearance as the brakes wear.

Servo Brake Starwheel Automatic Adjusters Servo brakes use three styles of starwheel adjusters:

- **Cable.** See Figure 74–30.
- **Lever.** See Figure 74–31.
- **Link.** See Figure 74–32.

All three adjusters mount on the secondary brake shoe and adjust only when the brakes are applied while the vehicle is moving in reverse.

As the brakes are applied on a vehicle with a cable or link automatic adjuster, the wheel cylinder and drum rotation combine

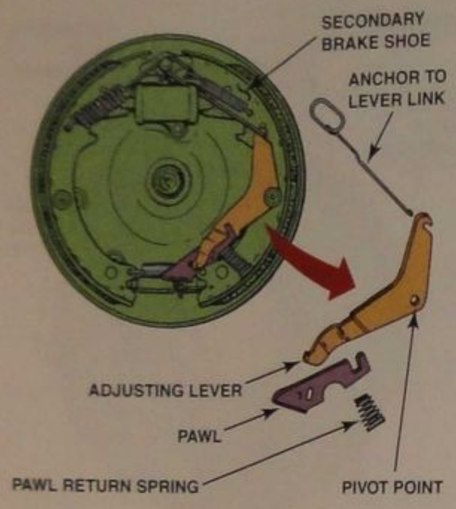


Figure 74–31 A lever-actuated starwheel automatic adjuster. This type of adjuster makes the adjustment as the brakes are applied.

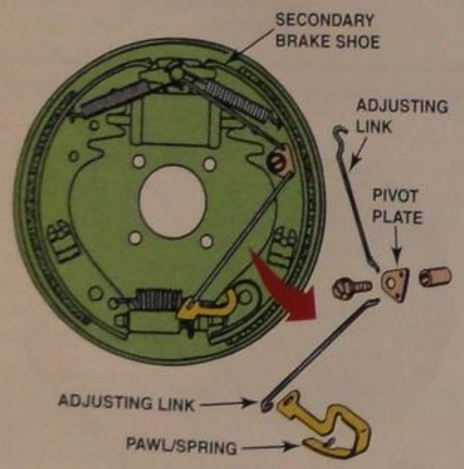


Figure 74–32 A link-activated starwheel automatic adjuster. This type of adjuster makes the adjustment as the brakes are released.

to move the secondary shoe away from the anchor. Movement of the shoe causes the cable or linkage to pull up on the adjuster **pawl.** See Figure 74–33.

If the brake lining has worn far enough, the pawl engages the next tooth on the starwheel. When the brakes are released, the pawl return spring pulls the pawl down, rotating the starwheel and moving the brake shoes apart to reduce the lining-to-drum clearance.

Some servo brakes with cable-actuated starwheel automatic adjusters have an **over-travel spring** assembly on the end of the cable. See Figure 74–34.

In this design, the adjuster pawl is mounted *under* the starwheel, and adjustment is made as the brakes are applied rather than released. The over-travel spring dampens the movements of the adjuster mechanism, and prevents over-adjustment if the brakes are applied very hard and fast. It also prevents damage to the adjusting mechanism if the starwheel seizes or is otherwise unable to rotate.

The lever starwheel adjuster makes the adjustment as the brakes are applied rather than released. As the secondary shoe

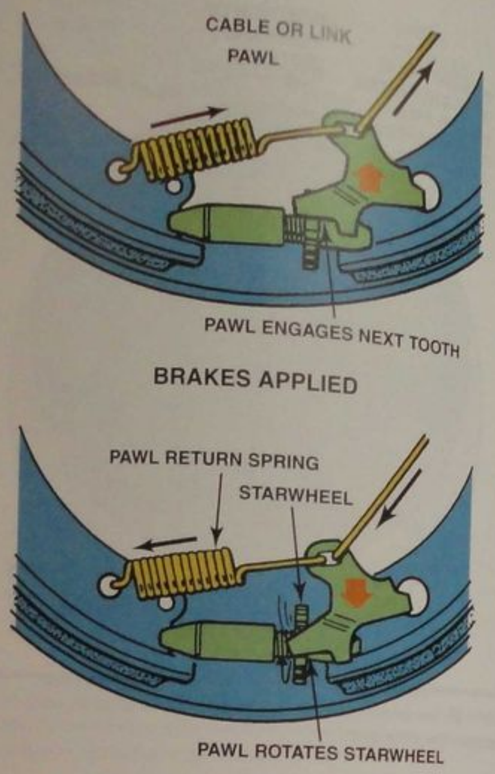


Figure 74–33 The operation of a typical self-adjuster. Notice that the adjuster actually moves the starwheel.

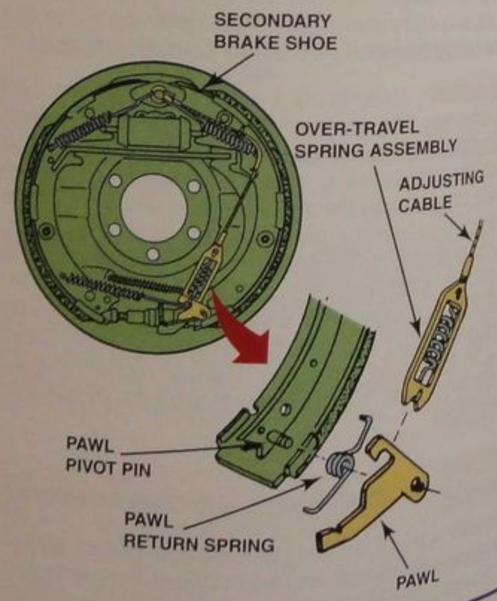


Figure 74–34 A cable-actuated starwheel automatic adjuster with an over-travel spring.

moves away from the anchor, the solid link between the anchor and the top of the adjuster lever forces the lever to rotate around the pivot point where it attaches to the brake shoe. This moves the bottom half of the lever downward, which causes the pawl to rotate the starwheel and make the adjustment. The separate pawl piece is free to pivot on the lever to prevent damage if the starwheel will not rotate. When the brakes are released, the return springs lift the lever. If the brakes have worn enough, the end of the lever engages the next tooth on the starwheel and additional adjustment will be made the next time the brakes are applied.

Non-Servo Starwheel Automatic Adjusters The starwheel automatic adjusters used on non-servo brakes may be mounted on either the leading or trailing shoe. These types of adjusters work whenever the brakes are applied—in either the forward or reverse direction. A leading-shoe design is shown in Figure 74–35.

When the brakes are not applied, the adjuster pawl is held in position by the parking brake strut. When the brakes are applied and the primary shoe moves out toward the brake drum (away from the parking brake strut), the pawl spring pivots the pawl downward where it mounts on the brake shoe and rotates the starwheel to adjust the brake. When the brakes are released, the return springs retract the shoes and the pawl is levered back into its resting position by the parking brake strut. If the linings have worn far enough, the lever engages the next tooth on the starwheel and further adjustment will occur the next time the brakes are applied.

The trailing-shoe non-servo starwheel adjuster shown in Figure 74–36 works somewhat like the leading-shoe design, but it makes the adjustment as the brakes are released rather than applied.

The upper shoe return spring in this design returns the brake shoes and operates the automatic adjuster. When the brakes are not applied, spring tension holds the trailing shoe and the adjuster pawl tightly against the parking brake strut. When the brakes are applied, the trailing shoe moves out toward the drum and away from the parking brake strut. This allows the adjuster pawl, which is restrained by the return spring, to pivot where it attaches to the brake shoe, causing the adjuster arm to move upward. If the brakes have worn far enough, the arm will engage the next tooth of the starwheel. When the brakes are released, the return spring pulls the brake shoes back together and the parking brake strut levers the adjuster pawl downward to rotate the starwheel and adjust the brakes.

TECH TIP ✔ **Cool the Brakes Before Backing**

Self-adjusters can over adjust the rear drum brakes if the brake drums are hot and have increased in diameter due to the heat. A typical example of how this can occur involves a pickup truck towing a boat down a long, steep grade to reach the lake and the boat ramp. If the brakes are used to slow the truck and trailer, the rear brake drums can become larger in diameter due to the heat created during braking. Then when the truck is backing the boat trailer down the ramp, the brakes can over adjust if the driver repeatedly depresses and releases the brake pedal while backing. Then after the boat has been removed from the trailer and the rear brakes have cooled, the drums will shrink and keep the rear brakes from releasing preventing the movement of the truck up the ramp.

NOTE: Some drum brakes are equipped with a bimetallic heat sensor that prevents the self-adjusters from working if the brakes are hot.

Ratchet Automatic Adjusters Most ratchet automatic adjusters use movement of the brake shoes to adjust the lining-to-drum clearance. The adjustment of a ratchet adjuster is carried out by two parts that have small interlocking teeth. As the adjustment is made, the two toothed elements ratchet across one another. Once adjustment is complete, the teeth lock together to hold the brake shoes in their new positions.

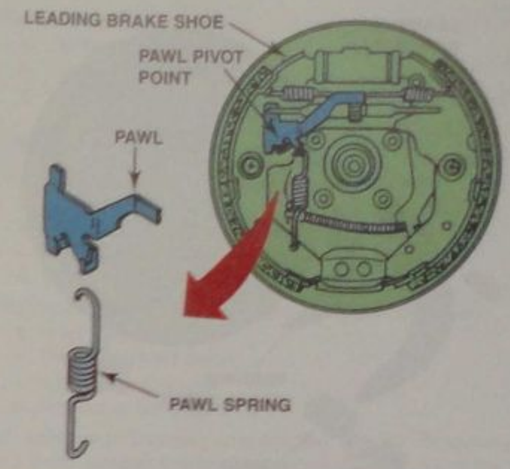


Figure 74–35 A non-servo brake with a lever-activated starwheel automatic adjuster on the leading shoe. This type of adjuster makes the adjustment as the brakes are applied.

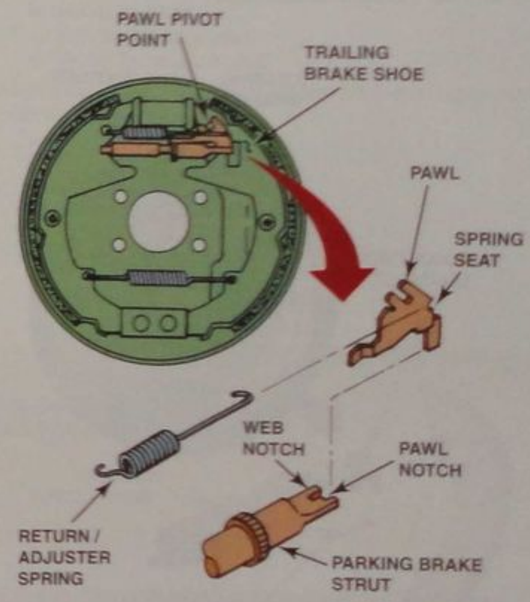


Figure 74–36 A non-servo brake with a lever-actuated starwheel automatic adjuster on the trailing shoe. This type of adjuster makes the adjustment as the brakes are released.

Lever-Latch Automatic Adjuster The lever-latch automatic adjuster installs on the leading shoe of a non-servo brake and operates whenever the brakes are applied. See Figure 74–37.

This design consists of a large lever and a smaller latch with interlocking teeth. A spring on the latch piece keeps it in contact with the lever to maintain the adjustment. One end of the parking brake strut hooks into an opening in the lever and the other end is held against the trailing brake shoe by a strong spring.

As the brakes are applied and the shoes move outward toward the drum, the parking brake strut pulls on the adjuster lever and forces it to pivot inward from where it attaches to the top of the leading shoe. If the brakes are sufficiently worn, the bottom of the lever will ratchet one or more teeth on the latch. When the brakes are released, the parking brake strut, which bottoms against the lever, will hold the shoes farther apart to reduce the lining-to-drum clearance.

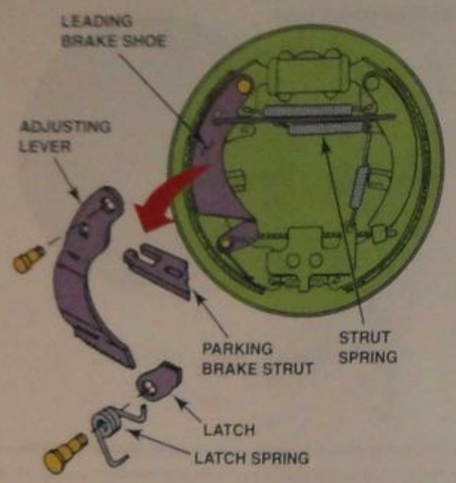


Figure 74–37 A lever-latch ratchet automatic adjuster.

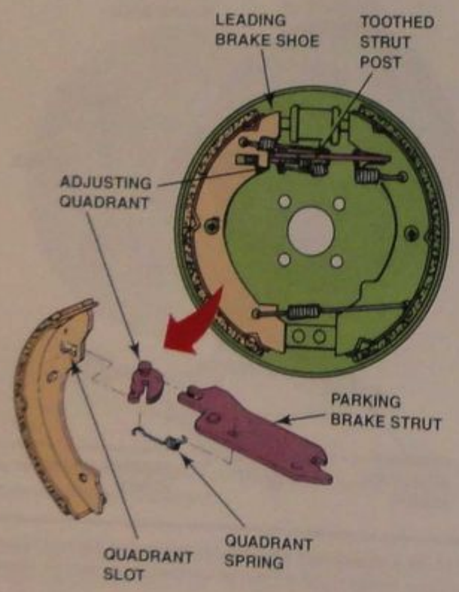


Figure 74–38 A strut-quadrant ratchet automatic adjuster.

Strut-Quadrant Automatic Adjuster The strut-quadrant automatic adjuster is used on some non-servo brakes. See Figure 74–38.

The strut-quadrant adjuster consists of three basic parts:

- The parking brake strut
- Adjusting quadrant
- A quadrant spring

The strut has a toothed post solidly mounted on its underside. The adjuster quadrant pivots on a pin that slips into a notch in the end of the strut, and the backside of the quadrant has a toothed, cam-shaped surface that interlocks with the toothed post on the strut. The quadrant also has an arm that extends through an opening in the web of the leading brake shoe. The outer side of this arm serves as the brake shoe stop when the brakes are released. The quadrant spring holds the quadrant in contact with the post to maintain the adjustment.

When the brakes are applied, the leading shoe moves out toward the brake drum. If there is sufficient wear of the brake lining, the edge of the slot in the shoe web contacts the inner side of the adjuster quadrant arm and pulls it outward. When this happens, the toothed section of the quadrant is lifted away from the post on the parking brake strut. The quadrant spring then rotates the quadrant until its pivot pin is bottomed in the slot in the parking brake strut. When the brakes are released, the quadrant returns inward with the leading shoe. The toothed section of the quadrant then engages the teeth on the strut post, causing the quadrant arm to remain in its new extended position that holds the shoes farther apart and reduces the lining-to-drum clearance.

SUMMARY

1. Drum brake shoes include the lining table, shoe web plus holes for the springs to attach, and semicircular anchor eyes.
2. Brake linings can be attached using rivets or bonding.
3. Lining edge codes identify the manufacturer and include two letters at the end, which identify the coefficient of friction of the material. The first letter indicates the coefficient when the lining is cold and the second indicates the coefficient when the lining is hot.
4. Brake shoes are forced outward against a brake drum by hydraulic action working on the brake shoes by the piston of a wheel cylinder.
5. The curved arch of the brake shoe causes a wedging action between the brake shoe and the rotating drum. This wedging action increases the amount of force applied to the drum.
6. Dual-servo brakes use primary and secondary brake shoes that are connected at one end. The wedge action on the front (primary) shoe forces the secondary shoe into the drum with even greater force. This action is called servo self-energizing.
7. Leading-trailing brakes use two brake shoes that are not connected. Leading-trailing brakes operate on a more linear basis and are therefore more suited than dual-servo for ABS.
8. Most self-adjusting mechanisms usually operate from the secondary or rearward facing brake shoe and adjust the brakes as the brakes are released.
9. Some self-adjusters operate on the primary shoe and adjust the brakes as they are being applied.

REVIEW QUESTIONS

1. Describe the difference between a dual-servo and a leading-trailing drum brake system.
2. List all the parts of a typical drum brake.
3. Explain how a self-adjusting brake mechanism works.
4. What is the meaning of the last two letters of the lining or pad edge code?

CHAPTER QUIZ

1. Two technicians are discussing drum brake shoes. Technician A says that forward and rear-facing shoes are the same and can be installed in either position on any drum brake system. Technician B says that the darker color lining should always be placed toward the front of the vehicle. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Two technicians are discussing brake lining edge codes. Technician A says that the code can identify the manufacturer. Technician B says that all friction material from the same manufacturer will have the same edge codes. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that starwheel adjusters use different threads (left- and right-handed) for the left and right sides of the vehicle. Technician B says that a pawl controls the teeth of the starwheel adjuster. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that drum brakes can fail to slow the vehicle if driven through deep water. Technician B says that when drum brakes get hot, the brake pedal will drop because the drum expands away from the shoes. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that self-adjusters used on most drum brakes work when the brakes are applied, then release while traveling in reverse. Technician B says that some adjusters can over adjust if the brake drums are hot. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Drum brake shoes _____.
   a. Can have riveted linings
   b. Can have bonded linings
   c. Can have one shoe that is longer than the other on the same wheel brake
   d. All of the above are possible
7. Which lining does most of the braking on a dual-servo brake?
   a. Front (forward facing)
   b. Rear (rearward facing)
   c. Both contribute equally
   d. Depends on the speed of the vehicle
8. Which lining does most of the braking on a leading-trailing brake?
   a. Leading (forward facing)
   b. Trailing (rearward facing)
   c. Both contribute equally
   d. Depends on the speed of the vehicle
9. Two technicians are discussing drum brake self-adjusters. Technician A says that a frozen starwheel adjuster can cause the brakes to lock up due to the adjusting lever being unable to move the adjuster causing the linkage to bind. Technician B says that some brakes self-adjust when the brakes are applied rather than when released. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A typical drum brake backing plate has how many shoe support pads (also called ledges)?
    a. 3
    b. 4
    c. 6
    d. 8

CHAPTER 75 Drum Brake Diagnosis and Service

OBJECTIVES: **After studying Chapter 75, the reader will be able to:** Prepare for ASE Brakes (A5) certification test content area "B" (Drum Brake Diagnosis and Repair). • Discuss the procedure recommended for brake drum removal. • Discuss the inspection and lubrication points of the backing plate. • Explain the importance of the proper drum brake hardware. • Disassemble and reassemble a drum brake assembly.

KEY TERMS: bearingized • brake hardware kits • core • speed nuts • tinnerman nuts

DRUM BRAKE DIAGNOSTIC PROCEDURE

Diagnosing brake concern includes the following steps:

Step #1 Verify the customer complaint (concern). For example, common drum brake concerns include:

- Low brake pedal
- Parking brake does not hold the vehicle on a hill
- Noise while braking
- Noise when the vehicle is moving, but the brakes are not applied

Step #2 Perform a visual inspection of the brakes and related parts, such as the wheels, tires, and suspension system.

Step #3 Determine the root cause. For example, this could include determining that the parking brake is corroded causing the brake shoes to wear. Replacing just the brake shoes will not correct the root cause.

Step #4 Restore the brake system to like-new operation, which is the purpose of any repair.

Step #5 Test drive the vehicle to verify that the service has corrected the customer's complaint.

Drum brake service usually involves the following steps:

Step #1 Removing the brake drums.

Step #2 Inspect the brake drums for damage and measure the inside diameter and compare to specifications.

Step #3 Inspect brake linings and hardware for wear or damage.

Step #4 Inspect the wheel cylinder and brake lines for leakage.

Step #5 Check the backing plate for excessive rust or wear.

BRAKE DRUM REMOVAL

The drum has to be removed before inspection or repair of a drum brake can begin. There are two basic types of drums, and the removal procedure depends on which type is being serviced. With either type it is usually recommended that the drums be marked with an "L" for left or an "R" for right so that they can be replaced in the same location.

CAUTION: Proper precaution should be taken to prevent any asbestos that may be present in the brake system from becoming airborne. Removal of the brake drum should occur inside a sealed vacuum enclosure equipped with a HEPA filter or washed with water or solvent. See Figure 75–1.

Hub or Fixed Drums A fixed or hub-mounted drum is often used on the rear of front-wheel-drive vehicles. The drum has a hub for inner and outer bearings and is retained by a spindle nut. To remove the brake drum, remove the dust cap and cotter key that is used to retain the spindle nut. Remove the spindle nut and washer and then the brake drum can be carefully pulled off the spindle.

Hubless or Floating Drums Floating or hubless drums are usually used on the rear of a rear-wheel-drive vehicle. The drums are secured to the axle flange by the wheel and lug nuts. New vehicles have **tinnerman nuts** (clips), also called **speed nuts,** on the stud when the vehicle is being assembled. These thin sheet-metal nuts keep the brake drum from falling off during shipping and handling prior to installation of the rear wheels. See Figure 75–2.



Figure 75–1 A liquid soaking solvent, such as brake cleaner, should be used to wet the linings. The purpose of wetting the lining material while the drum is still on the vehicle is to prevent the possibility of asbestos from the lining becoming airborne. Asbestos is only hazardous when asbestos dust is airborne and is breathed in during brake system service.

The tinnerman nuts can be discarded because they are not needed after the vehicle leaves the assembly plant. After removing the wheels, the drum *should* move freely on the hub and slip off over the brake shoes. Some drum brakes have two threaded holes in the drum that allow bolts to be installed. See Figure 75–3.

By tightening the bolts, the drum is forced off of the hub. Two situations that can prevent the drum from being removed include the following:

1. **The drum is rusted to the hub.** The fit between the drum and the hub is very close because it is this center pilot hole in the drum that centers the drum on the axle. Rust and corrosion often causes the drum to seize to the hub. Striking the area inside the wheel studs will usually break the drum loose from the hub. Sometimes a torch has to be used to expand the pilot hole.

NOTE: Use of an air hammer with a flat-headed driver against the hub also works well to break the drum loose from the hub.

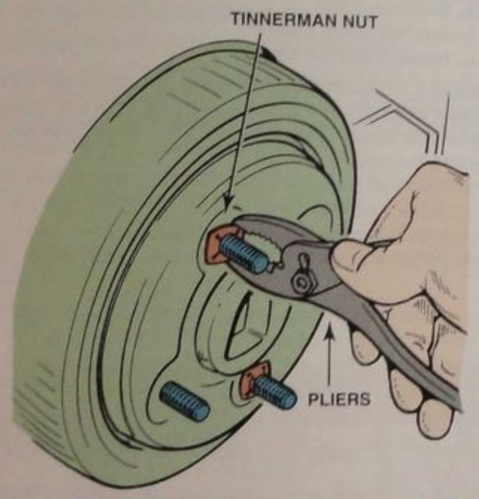


Figure 75–2 Tinnerman nuts are used at the vehicle assembly plant to prevent the brake drum falling off until the wheels can be installed. These sheet-metal retainers can be discarded after removal.

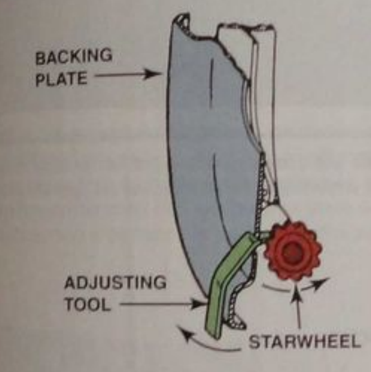


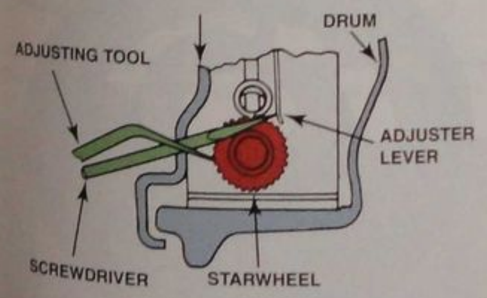
Figure 75–3 Turning the bolts that are threaded into the brake drum forces the drum off the hub.

CAUTION: Overheating or not allowing the drum to cool slowly can cause the brake drum to distort. Using a puller can also damage a drum.

2. **The brake shoes are worn into the drum.** Even if the pilot hole is loose, many brake drums cannot be removed because the inner edge of the brake drum catches on the lining. Pulling outward on the drum often bends the backing plate or breaks some of the mounting hardware. To prevent damage, remove the adjuster plug from the backing plate or drum and back off the adjuster. See Figure 75–4.

NOTE: Be sure to reinstall the adjuster opening plugs. These plugs help keep water and debris out of the brakes.





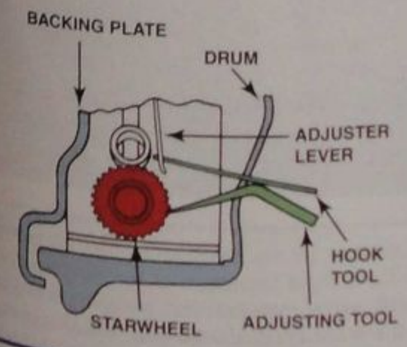


Figure 75–4 If the brake shoes have worn into the brake drum, the adjuster can be backed off after removing the access plug. After removing the plug, use another wire or screwdriver to move the adjusting lever away from the starwheel, then turn the starwheel with a brake adjusting tool, often called a brake "spoon." *(Courtesy of Allied Signal Automotive Aftermarket)*

After removing the brake drums, they should be cleaned, inspected, measured, and possibly machined before being returned to service.

DRUM BRAKE DISASSEMBLY

After removal of the brake drum, the brake shoes and other brake hardware should be wetted down with a solvent or enclosed in an approved evacuation system to prevent possible asbestos release into the air.

TECH TIP ✓ **Cutting the Nails Trick**

Many times a brake drum cannot be removed because the linings have worn a groove into the drum. Attempting to adjust the brakes inward is often a frustrating and time-consuming operation. The easy solution is to use a pair of diagonal side-cut pliers and cut the heads off the hold-down pins (nails) at the backing plate. This releases the brake shoes from the backing plate and allows enough movement of the shoes to permit removal of the brake drum without bending the backing plate.

The hold-down pins (nails) must obviously be replaced, but they are included in most drum brake hardware kits. Since most brake experts recommend replacing all drum brake hardware anyway, this solution does not cost any more than normal, may save the backing plate from damage, and saves the service technician lots of time. See Figure 75–5.

Usually, the first step in the disassembly of a drum brake system is removal of the return (retracting) springs. See Figure 75–6.

After the return springs have been removed, the hold-down springs and other brake hardware can be removed. See Figure 75–7.

NOTE: There are generally no "exact" disassembly or reassembly procedures specified by the manufacturer. The order in which the parts are disassembled or reinstalled is based on experience and the personal preference of the technician.

INSPECTING THE BACKING PLATE

The backing plate supports the parts of the drum brake and helps to keep water from getting onto the brake shoes. The backing plate bolts to the rear axle or spindle and is made from stamped steel. Backing



Figure 75–5 Using side-cut pliers to cut the heads off the hold-down spring pins (nails) from the backing plate to release the drum from the shoes.

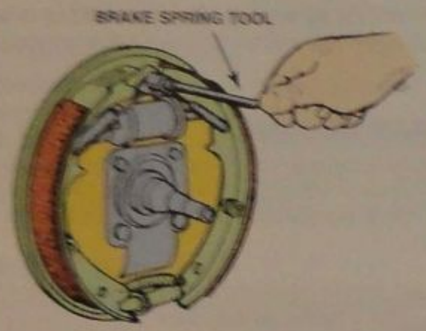


Figure 75–6 Using a brake spring tool to release a return (retracting) spring from the anchor pin.

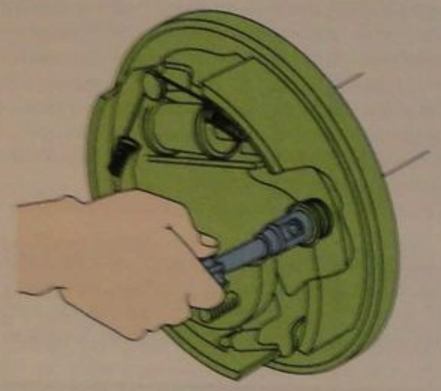


Figure 75–7 A special tool, called a hold-down spring tool, being used to depress and rotate the retainer.

plates are plated (usually cadmium) or painted to prevent rusting. When brakes are serviced, the six raised contact surfaces, called pads, ledges, or shoe contact areas, of the backing plate should be inspected because they rub against the sides of the shoes. See Figure 75–8.

If the pads are worn more than 1/16 in. (1.5 mm), the backing plate should be replaced. The backing plate must be inspected for looseness or bending.

The raised pads should be cleaned and lubricated. Lithium high-temperature brake grease, synthetic brake grease, silicone grease, or antiseize should be used to lubricate drum brake parts. See Figures 75–9 and 75–10.

DRUM BRAKE LINING INSPECTION

Both primary (front facing) and secondary (rear facing) lining material must be thicker than 0.060 in. (1.5 mm).

NOTE: Most vehicle and brake lining manufacturers recommend replacing worn brake lining when the thickness of the riveted lining reaches 0.060 in. or less. An American nickel is about 0.060 in. thick, so simply remember that you must always have at least "a nickel's worth of lining." See Figure 75–11.

The lining must be replaced if cracked, as shown in Figure 75–12.

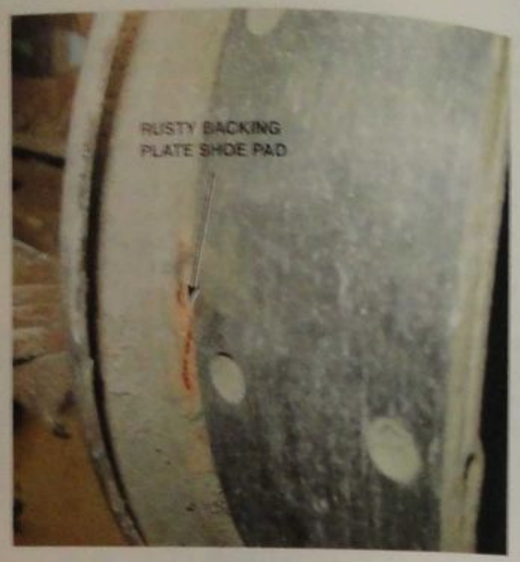


Figure 75–8 A typical rusting backing plate shoe pad. This can cause the brakes to squeak when the shoes move outward during a brake application and again when the brake pedal is released.

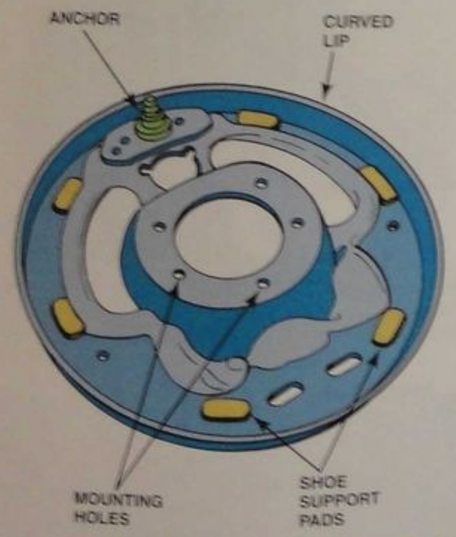


Figure 75–9 The backing plate is the foundation of every drum brake.

Some vehicles are equipped with holes in the backing plate that allow for a visual inspection of the thickness of the lining. Most experts agree that the best possible inspection involves removing the brake drum and making a thorough visual inspection of the entire brake instead of just looking at the thickness of the remaining lining. If a riveted brake lining is cracked between rivets, the lining should be replaced. Some brake manufacturers recommend riveted replacement linings because of reduced brake



Figure 75–10 Lithium high-temperature brake grease is used by many service technicians on metal-to-metal contact surfaces of a drum brake. A small metal-handled acid brush is stuck through a hole cut into the lid of this container of grease to make the application of grease easy and less messy. Avoid using too much grease. Excessive grease can get onto the friction surfaces of the brake shoes or drum and affect braking performance.



Figure 75–11 A rule of thumb is that the lining should be at least the thickness of a nickel.



Figure 75–12 Cracked brake lining must be replaced.

These manufacturers say that the recessed rivet holes allow dust to pocket away from the lining surface and thus help prevent the linings from glazing. Most experts agree that high-quality linings purchased from a known brake manufacturer will help ensure that the brake performance is returned to original equipment standards.



Figure 75–13 Brake lining worn at the top edge near the anchor pin is one indication that the return (retracting) springs are weak.

SPRING INSPECTION

Return Springs Each lining has a return spring (retracting spring) that returns the brake shoes back from the drums whenever the brakes are released. The springs are called primary and secondary return springs. The primary return spring attaches to the primary brake shoe and the secondary return spring attaches to the secondary brake shoe. These springs should be tested prior to a brake overhaul, especially when uneven lining wear is discovered, as shown in Figure 75–13.

Some drum brakes use a spring that connects the primary and secondary shoes and is commonly called a shoe-to-shoe spring. Return springs can get weak due to heat and time and can cause the linings to remain in contact with the drum.

Hold-down Springs Hold-down springs (one on each shoe) are springs used with a retainer and a hold-down spring pin (or nail) to keep the linings on the backing plate. Other types of hold-down springs include U-shape, flat spring steel type, and the combination return-and-hold spring. These springs still allow the freedom of movement necessary for proper braking operation.

TECH TIP ✓ **The Drop Test**

Brake return (retracting) springs can be tested by dropping them to the floor. A good spring should "thud" when the spring hits the ground. This noise indicates that the spring has not stretched and that all coils of the springs are touching each other. If the spring "rings" when dropped, the spring should be replaced because the coils are not touching each other. See Figure 75–14.

Although this drop test is often used, many experts recommend replacing all brake springs every time the brake linings are replaced. Heat generated by the brake system often weakens springs enough to affect their ability to retract brake shoes, especially when hot, yet not "ring" when dropped.

Connecting Spring (Adjusting Screw Spring) The connecting spring attaches to the lower portion and connects the two shoes together.

WHEEL CYLINDERS

Drum brake wheel cylinders are cast iron with a bore (hole) drilled and finished to provide a smooth finish for the wheel cylinder seals

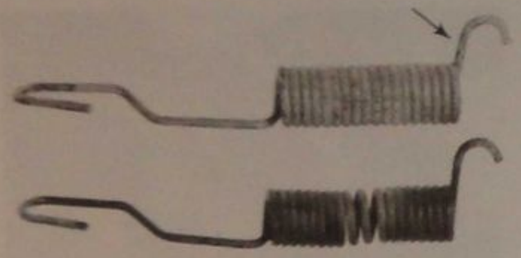


Figure 75–14 The top spring is a good-looking spring because all coils of the spring are touching each other. The bottom spring is stretched and should be discarded. The arrow points to the back side of the spring, which goes into a hole in the brake shoe. The open loop of the spring is not strong enough to keep from straightening out during use. Using the back side of the hook provides a strong, long-lasting hold in the brake shoe.

and pistons. This special finish is called **bearingized.** The final step in manufacture of the wheel cylinder is to force a hardened steel ball through the bore to bend over the "grain" of the metal and to smooth the inner surface. This process provides a smooth porous-free surface for the sealing caps to travel over. It is this bearingized surface finish on the inside of the wheel cylinder that is often destroyed when a wheel cylinder is honed. The hone stone used to refinish the inside bore of a wheel cylinder often opens up the end grain of the cast iron. As a result, the sealing cups do not seal as well. The brake fluid can penetrate the porous cast iron. This porous condition can cause the brake fluid to seep through the wheel cylinder, causing the outside of the wheel cylinder to become wet with brake fluid.

CAUTION: It is because of this bearingized surface finish that most vehicle manufacturers do not recommend that wheel cylinders be honed. Be sure to follow the vehicle manufacturer's recommended procedures. Some manufacturers state that the wheel cylinders can be overhauled using new (replacement) sealing cups and dust shields after cleaning the cylinder bore only.

Outside each wheel cylinder piston are dust boots installed to keep dirt out of the cylinder bore. Between both piston seals, there is a spring with piston seal expanders to keep the seals from collapsing toward each other and to keep pressure exerted on the lips of both seals to ensure proper sealing. See Figure 75–15.

On the back of each wheel cylinder there is a threaded hole for the brake line and a bleeder valve that can be loosened to remove (bleed) air from the hydraulic system. The wheel cylinder is bolted or clipped to the backing plate. See Figures 75–16 and 75–17.

TECH TIP ✔ **Wet Is Ok—Dripping Is Not Ok**

When inspecting a wheel cylinder, use a blunt nose tool and pry up the dust boot. If the inside of the seal is wet, this means that some seepage has occurred, which is normal. If, however, brake fluid drips from the dust seal, this indicates that the wheel cylinder sealing cups have failed and the wheel cylinder should be replaced.

Overhaul of the Wheel Cylinders If defective or leaking, wheel cylinders can be overhauled if recommended by the vehicle manufacturer. The following steps and procedures should be followed:

Step #1 Loosen the bleeder valve. If unable to loosen the bleeder valve without having it break off, a new replacement wheel cylinder is required. To help prevent broken bleeder valves, attempt to tighten the bleeder valve while tapping on the valve to loosen the rust before loosening the valve.

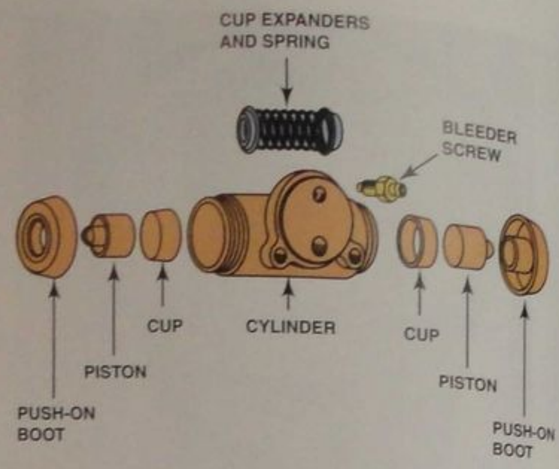


Figure 75–15 Exploded view of a typical wheel cylinder. Note how the flat part of the cups touch the flat part of the piston. The cup expander and spring go between the cups.

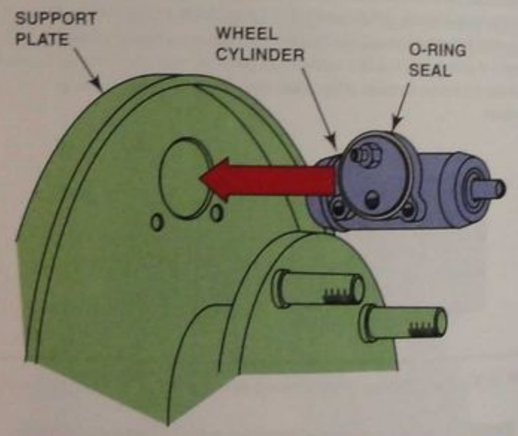


Figure 75–16 Many wheel cylinders are bolted to the support plate (backing plate). The O-ring seal helps keep water and dirt out of the drum brake.

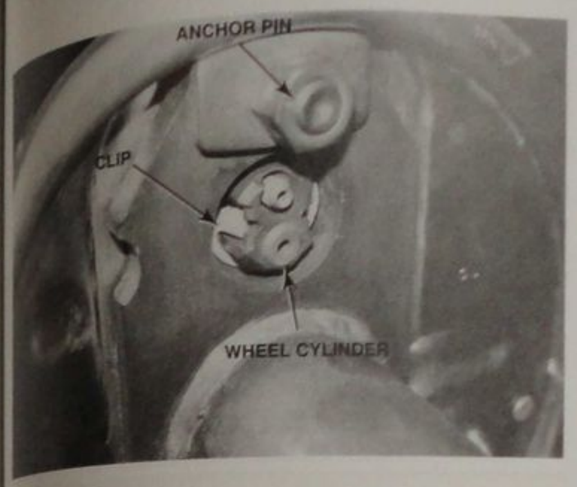
Step #2 To remove the wheel cylinder, the brake line must first be removed from the wheel cylinder. Unbolt or remove the wheel cylinder retainer clip. Be careful not to twist the brake line when removing the line from the wheel cylinder or the brake line will also require replacement.

Step #3 If the bleeder valve can be removed, remove all internal parts of the wheel cylinder.

NOTE: With some vehicles, the wheel cylinder must be unbolted from the backing plate to enable removal of the seals and piston.

Step #4 Clean and/or hone a wheel cylinder as specified by the manufacturer to remove any rust and corrosion.

Step #5 Install the pistons (usually not included in a wheel cylinder overhaul kit), seals, spring, and dust boots. Install on the vehicle and bleed the system.



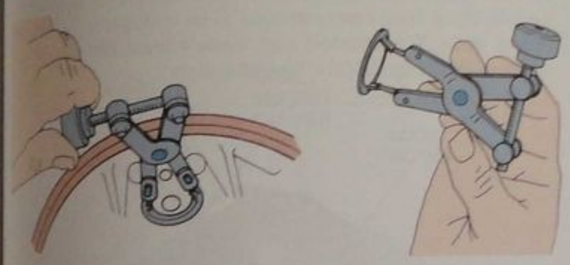


Figure 75–17 (a) Some wheel cylinders are simply clipped to the backing plate. (b) This special tool makes it a lot easier to remove the wheel cylinder clip. A socket (1 1/8 in., 28 mm) can be used to push the clip back onto the wheel cylinder.

NOTE: Even though the wheel cylinder is not leaking, many brake experts recommend replacing or rebuilding the wheel cylinder every time new replacement linings are installed. Any sludge build-up in the wheel cylinder can cause the wheel cylinder to start to leak shortly after a brake job. When the new thicker replacement linings are installed, the wheel cylinder piston may be pushed inward enough to cause the cup seals to ride on a pitted or corroded section of the wheel cylinder. As the cup seal moves over this rough area, the seal can lose its ability to maintain brake fluid pressure and an external brake fluid leak can occur. See Figure 75–18.

DRUM BRAKE HARDWARE KIT

If any spring is found to be defective, it is possible to purchase most parts individually or in pairs. However, for best results, many brake suppliers sell drum **brake hardware kits.** These kits usually include the items listed below for two drum brakes (axle set):

1. Primary and secondary return springs
2. Connecting spring
3. Hold-down springs
4. Hold-down spring retainers
5. Hold-down spring pins (nails)

Self-adjuster kits are available if needed. See Figure 75–19.

INSPECTING THE DRUM BRAKE SHOES

Carefully inspect the replacement brake shoes. Check all of the following:

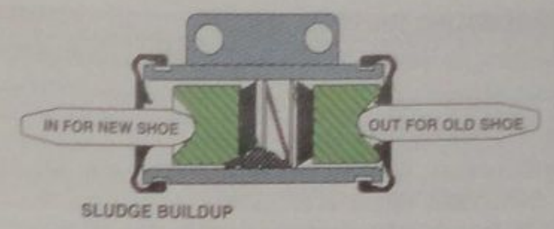


Figure 75–18 When new, thicker materials are installed, the pistons and cups are forced back into the wheel cylinder and pushed through the sludge that is present in every cylinder.



Figure 75–19 This starwheel adjuster is damaged and must be replaced. A lack of proper lubrication can cause the starwheel to become frozen in one place and not adjust properly.

1. Check that the replacements are exactly the same size (width and diameter) as the original. Hold the replacement shoes up against the old shoes to make the comparison.
2. Check for sound rivets (if rivet type). The friction material should also be snug against the metal brake shoe backing.

After checking that the replacement brake lining is okay, place the old shoes into the new linings' box. This helps ensure proper credit for the old shoes (called the **core**) as well as protection against asbestos contamination exposure.

TECH TIP ✔ **Time—Not Mileage—Is Important**

Many brake experts recommend rebuilding or replacing wheel cylinders at every other brake job. Some experts recommend that the wheel cylinders be overhauled or replaced every time the brake linings are replaced. If the wheel cylinders are found to be leaking, they must be replaced or overhauled. The most important factor is time, not mileage, when determining when to repair or replace hydraulic components.

The longer the time, the more moisture is absorbed by the brake fluid. The greater the amount of moisture absorbed by the brake fluid, the greater the corrosion to metal hydraulic components. For example, the brakes will probably wear out much sooner on a vehicle that is used all day every day than on a vehicle driven only a short distance every week. In this example the high-mileage vehicle may need replacement brake linings every year, whereas the short-distance vehicle will require several years before replacement brakes are needed. The service technician should try to determine the amount of time the brake fluid has been in the vehicle. The longer the brake fluid has been in the system, the greater the chances that the wheel cylinders need to be replaced or overhauled.

REASSEMBLING THE DRUM BRAKE

Reassembling the drum brake includes the following steps:

Step #1 Carefully clean the backing plate.

Step #2 Check the anchor pin for looseness.

Step #3 Lubricate the shoe contact surfaces (shoe pads) with anti-seize, brake grease, or synthetic grease.

Step #4 Reassemble the primary and secondary shoes and brake strut, along with all springs.

Step #5 Finish assembling the drum brake, being careful to note the correct location of all springs and parts.

NOTE: Many technicians preassemble the primary and secondary shoes with the connecting (lower retracting) spring as a unit before installing them onto the backing plate. See Figures 75–20 and 75–21.

TECH TIP ✔ **Brake Parts Cleaning Tips**

Denatured alcohol or "brake clean" should only be used to clean brake parts that are disassembled. When individual parts are cleaned, they can dry in the air before being assembled. Never clean or flush assembled brake components with denatured alcohol or brake clean. Often, the alcohol cannot evaporate entirely from an assembled component. This trapped alcohol will evaporate inside the brake system, causing contamination. The trapped alcohol vapors also act like trapped air in the braking system and can cause a spongy brake pedal. Always clean assembled brake components with brake fluid.

Most self-adjusters operate off the rear (secondary) shoe and should therefore be assembled toward the rear of the vehicle. See Figure 75–22.

ADJUSTING DRUM BRAKES

Most drum brakes are adjusted by rotating a starwheel or rotary adjuster. As the adjuster is moved, the brake shoes move toward the drum. If the brakes have been assembled correctly and with the parking brake fully released, both brake shoes should make contact with the anchor pin at the top. See Figure 75–23 for an example where one shoe does not make contact with the anchor pin.

If the clearance between the brake shoes and the brake drum is excessive, a low brake pedal results. The wheel cylinder travel may not be adequate to cause the lining to contact the drums. Often, the driver has to pump the brakes to force enough brake fluid into the wheel cylinder to move it enough for braking action to occur.

Many technicians use a brake shoe clearance gauge to adjust the brake shoes before installing the drum. See Figures 75–24 and 75–25.

CAUTION: Before installing the brake drum, be sure to clean any grease off the brake lining. Some experts warn not to use sandpaper on the lining to remove grease. The sandpaper may release asbestos fiber into the air. Grease on the linings can cause the brakes to grab.

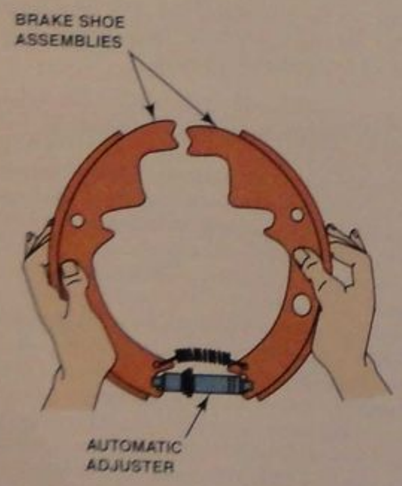


Figure 75–20 Preassembly of the starwheel adjuster with its connecting spring often helps when reassembling a drum brake.

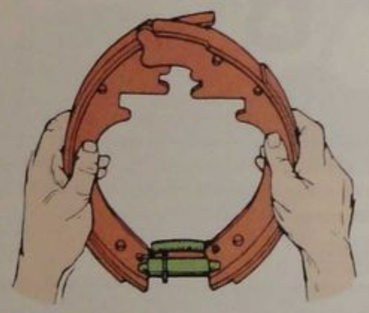


Figure 75–21 Sometimes it is necessary to cross the shoes when preassembling the starwheel adjuster and connecting spring. *(Courtesy of Allied Signal Automotive Aftermarket)*



Figure 75–22 Installing a shoe-to-shoe spring using brake spring pliers.



Figure 75–23 Notice that the brake shoe is not contacting the anchor pin. This often occurs when the parking brake cable is stuck or not adjusted properly.

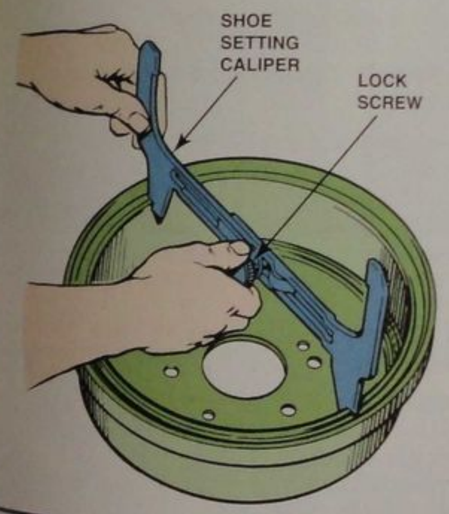


Figure 75–24 The first step in using a brake shoe clearance gauge is to adjust it to the drum inside diameter and tighten the lock screw.

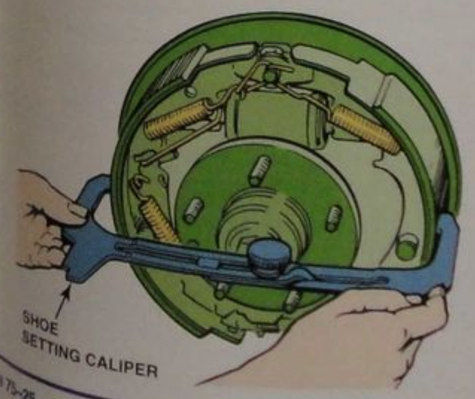


Figure 75–25 Place the gauge over the shoes and adjust the brakes until they contact the ends of the gauge.

TECH TIP ✔ **The Masking Tape Trick**

Some technicians cover the friction material with masking tape to prevent contaminating the linings with dirt or grease during installation. After everything has been installed and double-checked, the masking tape is removed and the brake drums are installed. See Figure 75–26.



Figure 75–26 To prevent getting grease on the lining, the wise service technician covers the friction material with masking tape. The tape is removed after the brake shoes have been installed.

LUBRICATION CHECKLIST

For proper operation, the following points should be lubricated with approved brake lubricant:

CAUTION: Do not use wheel bearing or chassis grease on a braking system. Use only approved brake lubricant such as molybdenum disulfide (moly) grease, synthetic grease, lithium-based brake grease, or antiseize compound.

1. The starwheel adjuster threads and under end caps
2. The backing plate contact areas (pads or ledges)
3. Anchor pins

Also, be sure to check and lubricate the parking brake cable, if necessary.

SYMPTOM-BASED TROUBLESHOOTING GUIDE

Low Pedal or the Pedal Goes to the Floor Possible causes for low pedal include the following:

1. Excessive clearance between the linings and drum
2. Automatic adjusters not working
3. Leaking wheel cylinder
4. Air in the system

Springy, Spongy Pedal Possible causes for springy, spongy pedal include the following:

1. Drums worn below specifications
2. Air in the system

Excessive Pedal Pressure Required to Stop the Vehicle Possible causes for excessive pedal pressure include the following:

1. Grease or fluid-soaked linings
2. Frozen wheel cylinder pistons
3. Linings installed on wrong shoes

Light Pedal Pressure—Brakes Too Sensitive Possible causes for light pedal pressure include the following:

1. Brake adjustment not correct
2. Loose backing plate
3. Lining loose on the shoe
4. Excessive dust and dirt in the drums
5. Scored, bell-mouthed, or barrel-shaped drum
6. Improper lining contact pattern

Brake Pedal Travel Decreasing Possible causes for brake pedal travel decreasing include the following:

1. Weak shoe retracting springs
2. Wheel cylinder pistons sticking

Pulsating Brake Pedal (Parking Brake Apply Pulsates Also) Possible cause for pulsating brake pedal include the following:

1. Drums out-of-round

Brakes Fade (Temporary Loss of Brake Effectiveness When Hot) Possible causes for brake fade include the following:

1. Poor lining contact
2. Drums worn below the discard dimension
3. Charred or glazed linings

Shoe Click Possible causes for shoe click include the following:

1. Shoes lift off the backing plate and snap back
2. Hold-down springs weak
3. Shoe bent
4. Grooves in the backing plate pads

Snapping Noise in the Front End Possible causes for snapping noise in the front end include the following:

1. Grooved backing plate pads
2. Loose backing plates

Thumping Noise When Brakes Are Applied Possible causes for thumping noise include the following:

1. Cracked drum; hard spots in the drum
2. Retractor springs unequal—weak

Grinding Noise Possible causes for grinding noise include the following:

1. Shoe hits the drum
2. Bent shoe web
3. Brake improperly assembled

One Wheel Drags Possible causes for one wheel dragging include the following:

1. Weak or broken shoe retracting springs
2. Brake-shoe-to-drum clearance too tight—brake shoes not adjusted properly
3. Brake assembled improperly
4. Wheel cylinder piston cups swollen and distorted
5. Pistons sticking in the wheel cylinder
6. Drum out-of-round
7. Loose anchor pin/plate
8. Parking brake cable not free
9. Parking brake not adjusted properly

Vehicle Pulls to One Side Possible causes for vehicle pulling to one side include the following:

1. Brake adjustment not correct
2. Loose backing plate
3. Linings not of specified kind; primary and secondary shoes reversed or not replaced in pairs
4. Water, mud, or other material in brakes
5. Wheel cylinder sticking
6. Weak or broken shoe retracting springs
7. Drums out-of-round
8. Wheel cylinder size different on opposite sides
9. Scored drum

Wet Weather: Brakes Grab or Will Not Hold Possible causes for brakes grabbing or not holding include the following:

1. Bent backing plate flange
2. Incorrect or abused shoe and linings

Brakes Squeak Possible causes for brakes squeaking include the following:

1. Backing plate is bent or shoes twisted
2. Shoes scraping on backing plate pads
3. Weak or broken hold-down springs
4. Loose backing plate, anchor, or wheel cylinder
5. Glazed linings
6. Dry shoe pads and hold-down pin surfaces

Brakes Chatter Possible causes for brake chattering include the following:

1. Incorrect lining-to-drum clearance
2. Loose backing plate
3. Weak or broken retractor spring
4. Drums out-of-round
5. Tapered or barrel-shaped drums
6. Improper lining contact pattern

SUMMARY

1. Care should be exercised when removing a brake drum so as not to damage the drum, backing plate, or other vehicle components.
2. After disassembly of the drum brake component, the backing plate should be inspected and cleaned.
3. Most experts recommend replacing the wheel cylinder as well as all brake springs as part of a thorough drum brake overhaul.
4. Measure the brake drum and adjust the brake shoes to fit the drum.
5. Use care to prevent getting grease on brake linings. It can cause the brake to grab.

REVIEW QUESTIONS

1. Explain how to remove a brake drum.
2. List all items that should be lubricated on a drum brake.
3. List the steps necessary to follow when replacing drum brake linings.
4. Explain why many vehicle manufacturers do not recommend the wheel cylinder be honed.

PHOTO SEQUENCE Drum Brake Service Step-by-Step



P75-1 Tools needed to service a drum brake assembly include brake tools, silicone grease, wheel lug nut sockets, and torque limiting adapters or a torque wrench.



P75–2 After safely hoisting the vehicle to chest height, remove the brake drum.



P75–3 Remove the primary (forward facing) shoe return spring, using a brake tool. Then, remove the secondary return spring.



P75-4 Remove the parking brake strut along with the anti-rattle spring.



P75–5 Use a brake tool to depress the hold-down spring, and then rotate it until the slot in the retainer lines up with the flattened part of the hold-down pin.



P75–6 Removing the primary brake shoe plus the starwheel adjuster and connecting spring.



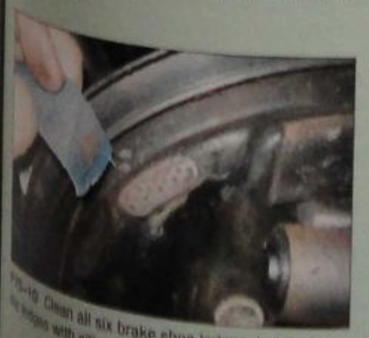
P75-7 When the secondary lining hold-down spring is removed, the adjusting lever and pawl return spring can be removed.



P75–8 The parking brake lever can now be disconnected from the secondary brake shoe.



P75–9 Check the wheel cylinder for leakage. This wheel cylinder is relatively new and not leaking.



P75–10 Clean all six brake shoe ledges. Lubricate the ledges with silicone brake grease.



P75–11 Many technicians prefer to assemble the connecting spring and starwheel adjuster to both shoes to help in the reinstallation.



P75–12 Attaching the parking brake lines to the secondary shoe. The assembled parts at the bottom help keep everything together.

(continued)

PHOTO SEQUENCE Drum Brake Service Step-by-Step—continued



P75–13 Installing the secondary shoe hold-down spring.



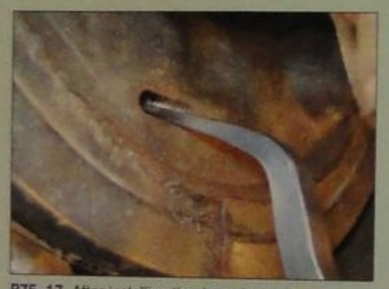
P75–14 Installing the secondary shoe return spring. Note that the primary return spring has already been installed.



P75–15 After installing the brake shoes and springs, use a drum/shoe clearance gauge and set it to the inside diameter of the drum.



P75–16 Adjust the starwheel adjuster until the linings contact the drum brake shoe clearance gauge.



P75–17 After installing the drum, it may be necessary to make the final adjustment using a brake adjusting tool (spoon).



P75–18 After completing the brake service, be sure to cover the brake adjustment opening to prevent water from getting into the brake.

CHAPTER QUIZ

1. Technician A says that the tinnerman nuts are used to hold the brake drum on and should be reinstalled when the drum is replaced. Technician B says that a drum should be removed inside a sealed vacuum enclosure or washed with water or solvent to prevent possible asbestos dust from being released into the air. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. The backing plate should be replaced if the shoe contact areas (pads or ledges) are worn more than _____.
   a. 1/2 in. (13 mm)
   b. 1/4 in. (7 mm)
   c. 1/8 in. (4 mm)
   d. 1/16 in. (2 mm)
3. Technician A says that silicone brake grease can be used to lubricate the shoe contact ledges. Technician B says that synthetic brake grease, lithium brake grease, or antiseize compound can be used as a brake lubricant. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Most brake experts and vehicle manufacturers recommend replacing brake lining when the lining thickness is _____.
   a. 0.030 in. (0.8 mm)
   b. 0.040 in. (1.0 mm)
   c. 0.050 in. (1.3 mm)
   d. 0.060 in. (1.5 mm)
5. Technician A says that starwheel adjusters use different threads (left- and right-handed) for the left and right sides of the vehicle. Technician B says that the threads and end caps of the adjusters should be lubricated with brake grease before being installed. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Technician A says that many vehicle manufacturers recommend that wheel cylinders not be honed because of the special surface finish inside the bore. Technician B says that seal expanders are used to help prevent the lip of the cup seal from collapsing when the brakes are released. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Most manufacturers recommend that brake parts should be cleaned with _____.
   a. Clean water only
   b. Denatured alcohol
   c. Stoddard solvent
   d. Detergent and water
8. Old brake shoes are often returned to the manufacturer when new friction material is installed. These old shoes are usually called the _____.
   a. Core
   b. Web
   c. Rim
   d. Nib
9. After assembling a drum brake, it is discovered that the brake drums will not fit over the new brake shoes. Technician A says that the parking brake cable may not have been fully released. Technician B says to check to see if both shoes are contacting the anchor pin. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Technician A says to use masking tape temporarily over the lining material to help prevent getting grease on the lining. Technician B says that grease on the brake lining can cause the brakes to grab. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 76

Disc Brake Parts and Operation

OBJECTIVES: After studying Chapter 76, the reader will be able to: Prepare for ASE Brakes (A5) certification test content area "C" (Disc Brake Diagnosis and Repair). • Describe how disc brakes function. • Name the parts of a typical disc brake system. • Describe the construction of disc brake pads. • Describe the difference between fixed caliper and floating or sliding caliper. • Explain the difference between a standard caliper and a low-drag caliper.

KEY TERMS: anchor plate • antirattle clips • aramid fiber • bonded linings • brake block • brake pad • carbon fiber-reinforced carbon (CFRC) • fixed brake caliper • floating caliper • gas fade • integrally molded • Kevlar • lining fade • low-drag caliper • mechanical fade • molded lining • NAO • NAS • natural frequency • nonasbestos • pad wear indicators • pin-slider caliper • riveted linings • semimets • sintered metal • sintering • sliding caliper • swept area • water fade • ways

DISC BRAKES

Disc brakes use a piston(s) to squeeze friction material (pads) on both sides of a rotating disc (rotor). Disc may be spelled *disk* by some manufacturers, but *disc* is the SAE (Society of Automotive Engineers) term and the most commonly used spelling in the industry. The rotor is attached to and stops the wheel.

Disc brakes are used on the front wheels of late-model vehicles, and on the rear wheels of an increasing number of automobiles. Disc brakes were adopted primarily because they can supply greater stopping power than drum brakes with less likelihood of fade. This makes disc brakes especially well suited for use as front brakes, which must provide 60% to 80% of the vehicle's total stopping power.

DISC BRAKE ADVANTAGES

Although increased federal brake performance standards hastened the switch to disc brakes, the front drum brakes would eventually have been eliminated anyway because disc brakes are superior in almost every respect. The disc brake friction assembly has several significant strong points, and only a few relatively minor weak points. See Figure 76–1.

The main advantages of the disc brake include the following:

- Fade resistance
- Self-adjustment
- Freedom from pull

Fade Resistance When a disc brake is compared with a drum brake of similar diameter, its biggest advantage is a much greater ability to resist fade. In fact, disc brakes are more resistant to all kinds of fade, including the following:

- Mechanical fade
- Lining fade
- Gas fade
- Water fade

The main design features that help disc brakes avoid heat-induced fade is their cooling ability because all of the major parts of a disc brake are exposed to the air flowing over the friction assembly. Many brake rotors also have cooling passages cast into them to further reduce operating temperatures.

Another reason disc brakes have greater fade resistance than drum brakes is that they have greater **swept area**. Swept area is the amount of brake drum or rotor friction surface that moves past the brake linings every time the drum or rotor completes a rotation. A larger swept area allows the heat generated in braking to be transferred more rapidly into the rotor for better cooling. A disc brake has swept area on both sides of the rotor. A drum brake has swept area only on the inside of the drum. Large diameter rotors, however, require larger diameter wheels to provide the necessary clearance. This is one of the major reasons why high-performance vehicles use 17-inch diameter and larger wheels.

Mechanical Fade **Mechanical fade** is not a problem with disc brakes because, unlike a brake drum, the disc brake rotor expands *toward* the brake linings as it heats up rather than *away* from them. This fundamental design difference makes it physically impossible for heat to cause the rotor to expand out of contact with the brake linings. Because of this, there is never the need to move the brake linings out to keep them in contact with the rotor, so brake pedal travel does not increase. If the brake pedal on a vehicle with disc brakes drops toward the floor, it is almost always a sign of vapor lock, a fluid leak, fluid bypassing the seals in the master cylinder, or mechanical fade of the rear drum brakes.

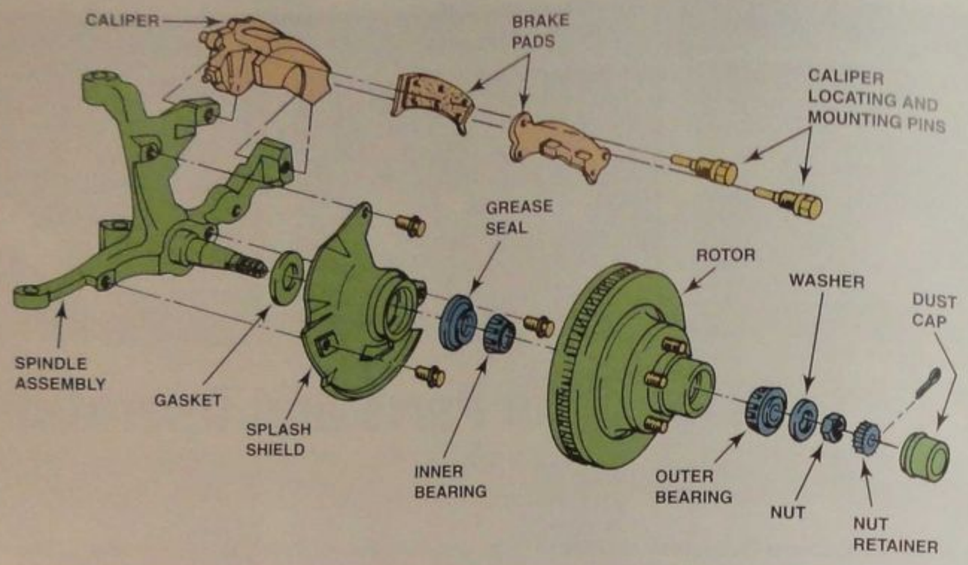


Figure 76–1 A typical disc brake assembly.

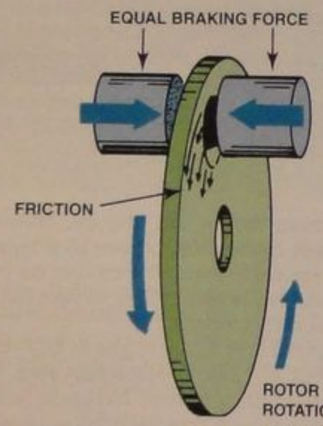


Figure 76–2 Braking force is applied equally to both sides of the brake rotor.



Figure 76–3 Disc brakes can absorb and dissipate a great deal of heat. During this demonstration, the brakes were gently applied as the engine drove the front wheels until the rotor became cherry red. During normal braking, the rotor temperature can exceed 350°F (180°C), and about 1500°F (800°C) on a race vehicle.

Lining Fade **Lining fade** can and does occur if the brakes become overheated. A little bit of heat brings the brake pads to their operating temperature and actually increases the friction coefficient of the lining material. A warm brake performs better than a cold brake. However, when too much heat is generated by braking, the lining material overheats. Its friction coefficient drops, and lining fade occurs.

The primary symptom of lining fade is a hard brake pedal that requires the driver to apply greater force to maintain stopping power. Unlike the similar situation in a drum brake, however, increased application force will not distort the brake rotor because the caliper applies equal force to both sides. See Figure 76–2.

Increased pressure will, however, create even more heat, and if brake lining temperatures continue to increase, gas fade and vapor lock of the hydraulic system can occur.

If the pads are overheated to the point where the lining material is physically damaged, the brakes will not recover their full stopping power until the pads are replaced. See Figure 76–3.

Gas Fade **Gas fade** is a problem only under severe braking conditions when hot gasses and dust particles from the linings are trapped between the brake linings and rotor, where they act as lubricants. The symptoms of gas fade are the same as those for lining fade. The pedal becomes hard and increased force is required to maintain stopping power.

Even though disc brakes operate at higher temperatures than drum brakes, they have fewer problems with gas fade for a number of reasons.

1. Disc brakes do not have a drum to contain gasses and particles in the area around the brake linings.

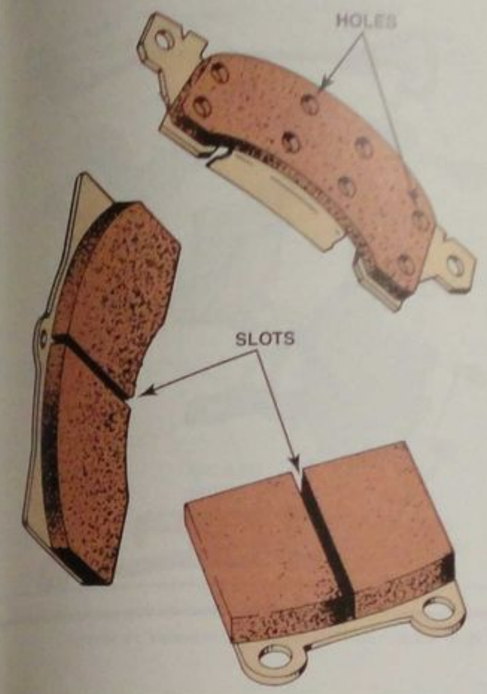


Figure 76–4 Slots and holes in the brake linings help prevent gas and water fade.

2. The constant flow of air over the brake carries away contaminants that might otherwise build up.
3. The surface area of the brake lining material in a disc brake is smaller than that of a comparable drum brake and this allows gasses and particles to escape more easily.

To help prevent gas fade, many brake pads have slots cut in the lining material. These slots allow gasses and dust particles to escape. See Figure 76–4.

The holes required in riveted linings also perform this function. For even greater protection against gas fade, high-performance vehicles and motorcycles sometimes have holes or slots cut into the rotor. These openings allow gasses and water to escape, and their sharp edges continually wipe loose particles off the linings.

Water Fade **Water fade** is not a big problem with disc brakes because centrifugal force created by the spinning rotor throws off most moisture, and the brake pads positioned only a few thousandths of an inch away from the rotor continuously wipe it clean. When the brakes are applied, the leading edge of the brake pad lining material wipes the last bit of water from the rotor. Once good lining-to-rotor contact is established, water is unable to enter the space between the linings and rotor until the brakes are released.

Although far more resistant to water fade than drum brakes, disc brakes are not entirely free from its effects. Splash shields and the vehicle's wheels help keep water off of the rotor, and the brake lining materials specified for most vehicles minimize the effects of water fade.

Self-Adjusting Ability Disc brakes are self-adjusting because any wear of the linings is automatically compensated for by the action of the brake caliper.

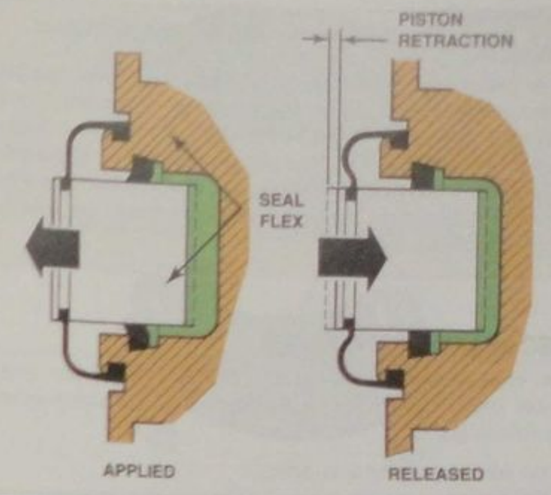


Figure 76–5 The square-cut O-ring not only seals hydraulic brake fluid, but also retracts the caliper piston when the brake pedal is released.

When the brakes are applied the caliper pistons move out as far as needed to force the brake pads into contact with the rotor. When the brakes are released, the piston retracts only the small distance dictated by rotor runout and piston seal flex.

The surface finish on the piston must be clean to allow the piston to slide past this seal. Moisture accumulation inside the caliper often causes the piston to rust. These rust pits can cut or groove the caliper seal. Excessive friction between the caliper piston and the caliper bore can prevent the piston from retracting. If the force of the caliper seal is not strong enough, the piston stays in the applied position. Because the brake pads are still in contact with the rotor, one or both pads will show excessive wear.

Normal Operation The piston moves just enough to distort the caliper seal and returns to the original position when the brake pedal is released.

Wear Compensation The piston moves more than the caliper seal can distort. The piston moves through the seal until the pad contacts the rotor. The caliper piston returns to the released position by the seal distortion, the same as during normal operation, except now in a different, more applied position. See Figure 76–5.

As the wear occurs and the piston moves, additional brake fluid is needed behind the piston. This additional brake fluid comes from the master cylinder and the brake fluid level drops as the disc brake pads wear.

Freedom from Pull A disc brake will stop straighter under a wider range of conditions than will a drum brake. A disc brake is self-cleaning, will throw off most water, and is less likely to pull.

Disc brakes do not have self-energizing or servo action. These actions increase the power of drum brakes, but depend on friction between the linings and drum for their effect. This means that even a small loss of lining-to-drum friction causes a large loss of braking power and a significant side-to-side variation in the amount of braking force. Since disc brakes do not use friction between the linings and rotor to increase their braking power, the effects of a loss of friction on one side of the vehicle are far less pronounced than with drum brakes.

TECH TIP ✓ **Check the Tire Size for a Pulling Problem**

If an unequal braking problem is being diagnosed, check that the front tires match and that the rear tires match. Brakes slow and stop wheels. Unequal diameter tires create an unequal braking force. The result may be a pulling toward one side while braking. Tire diameter can vary from one tire manufacturer to another even though the size designation is the same. Even slight differences in the wear of tires can cause a different tire diameter and, therefore, a different braking force.

DISC BRAKE DISADVANTAGES

The most notable fact about the disadvantages of disc brakes is that there are so few. The weaknesses of disc brakes include the following:

- No self-energizing or servo action
- Brake noise
- Brake dust
- Poor parking brake performance

No Self-Energizing or Servo Action The disc brake's lack of self-energizing or servo action is a disadvantage for two reasons. It contributes to poor parking brake performance and requires the driver to push harder on the brake pedal for a given stop. However, the problem of high pedal pressures has been virtually eliminated through the use of brake power boosters, since the disc brake responds more directly to pressure on the brake pedal. This makes it easier to modulate the brakes for the exact amount of stopping power desired.

Brake Noise Probably the biggest complaint about disc brakes is that they sometimes make various squeaks and squeals during a brake application. As long as the brake linings are not worn down to the backing plate, these noises are usually caused by high-frequency rattling or vibration of the brake pads.

Several methods are used to quiet noisy disc brakes. Manufacturers use specific lining materials that damp vibrations, and most calipers have **antirattle clips** or springs that hold the pads in the caliper under tension to help prevent vibration. See Figure 76–6.

Some calipers use special shims between the brake pad backing plate and the caliper piston to damp vibrations. See Figure 76–7. These shims may be made of metal or fiber.

Antinoise sprays and brush-on liquids are available and provide a cushion layer between the pad and the caliper piston. The bond lowers the **natural frequency** of the pad, and the cushion layer damps any vibration that may still occur.

Brake Dust Because the lining is exposed on a disc brake, rather than being enclosed on a drum brake, some brake dust can accumulate on the wheels. This brake dust is often dark brown or black and can stain wheels if not cleaned often or protected from the dust.

TECH TIP ✓ **Wax the Wheels**

Brake dust from semimetallic brake pads often discolors the front wheels. Customers often complain to service technicians about this problem, but it is normal for the front wheels to become dirty because the iron and other metallic and nonmetallic components wear off the front disc brake pads and adhere to the wheel covers. A coat of wax on the wheels or wheel covers helps prevent damage and makes it easier to wash off the brake dust.

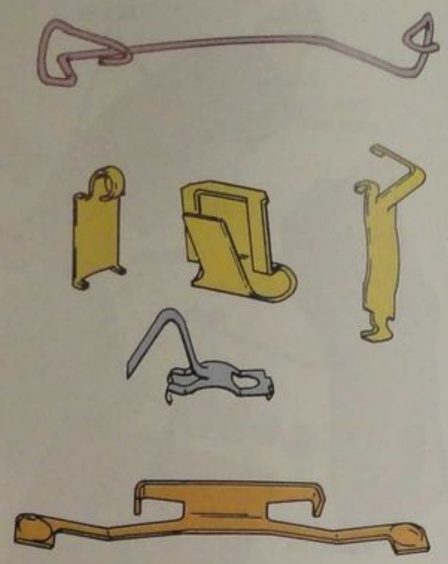


Figure 76–6 Antirattle clips reduce brake pad movement and vibration.

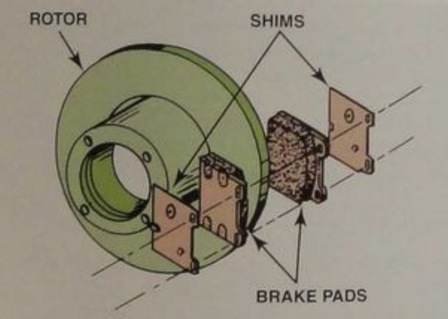


Figure 76–7 Antivibration shims are used behind the pads on many disc brake caliper designs.

Poor Parking Brake Performance The lack of self-energizing and servo action plays a large part in poor disc brake parking brake performance. The lining-to-rotor contact area of a disc brake is somewhat smaller than the lining-to-drum contact area of a drum brake. This causes the disc brake to have a lower static coefficient of friction, and therefore less holding power when the vehicle is stopped.

DISC BRAKE CONSTRUCTION

A disc brake is relatively simple compared with a drum brake. The major disc brake friction assembly components include the following:

- Caliper
- Splash shield
- Brake pads
- Brake rotor

Caliper With the exception of the rotor, the caliper is the largest part of a disc brake friction assembly. The brake caliper uses hydraulic pressure to create the mechanical force required to move the brake pads into contact with the brake rotor. At the front axle, the caliper mounts to the spindle or steering knuckle. See Figure 76–8.

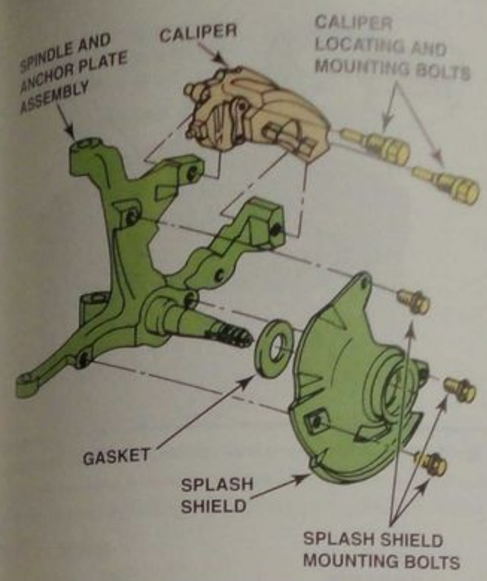


Figure 76–8 This brake caliper attaches to the front spindle.

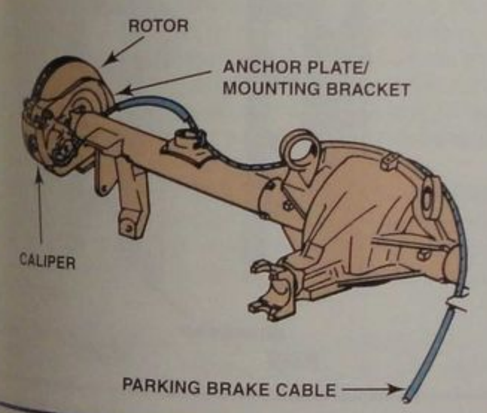


Figure 76–9 This brake caliper attaches to a mounting bracket on the rear axle housing.

Rear disc brake calipers mount to a support bracket on the axle flange or suspension. See Figure 76–9.

Splash Shield The splash shield bolts to the front spindle or steering knuckle, or in rear disc brake applications, to the axle flange or a suspension adapter plate. The job of the splash shield is to protect the inner side of the brake rotor from water and other contaminants, whereas the outer side of the rotor is protected by the wheel. Most splash shields are made of stamped steel or plastic.

DISC BRAKE PADS

The lining of a disc brake is part of an assembly called the **brake pad**. See Figure 76–10.

Compared to a brake shoe, a brake pad is a relatively simple unit that consists of a block of friction material attached to a stamped steel backing plate. Some pad backing plates have tabs that bend over the caliper to hold the pad tightly in place and help prevent brake noise. See Figure 76–11.

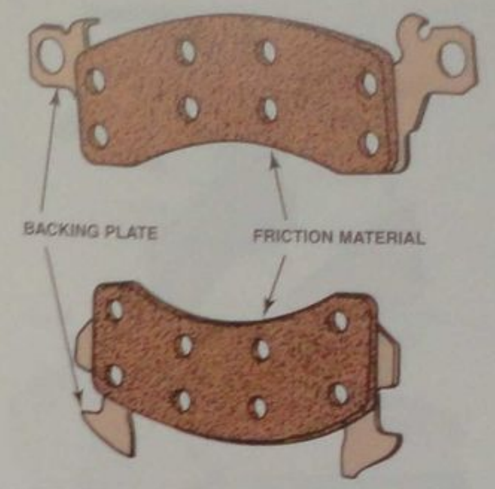


Figure 76–10 A typical disc brake pad.

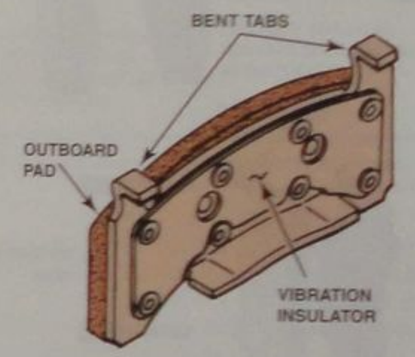


Figure 76–11 To prevent noise, bent tabs on the backing plate hold some brake pads to the caliper housing.

Other pad backing plates have tabs with holes in them as shown in Figure 76–12.

A pin slips through the holes and fastens to the caliper body to hold the pads in position. Still other pad backing plates have a retainer spring attached that locates the pad in the caliper by locking it to the caliper piston. See Figure 76–13.

As with brake shoes, the lining material of a disc pad can be any one of a number of products that can be fastened to the backing plate in several ways. The edges of the lining material on a brake pad are usually perpendicular to the rotor surface, although a few larger pads do have tapered edges to help combat vibration and noise. See Figure 76–14.

Pad Wear Indicators Although not required by law, a growing number of vehicle manufacturers are fitting **pad wear indicators** to their brakes for safety reasons. Pad wear indicators are either mechanical or electrical, and signal the driver when the lining material has worn to the point where pad replacement is necessary.

A mechanical wear indicator is a small spring-steel tab riveted to the pad backing plate. When the friction material wears to a predetermined thickness, the tab contacts the rotor and makes a squealing or chirping noise (when the brakes are not applied) that alerts the driver to the need for service. See Figure 76–15.

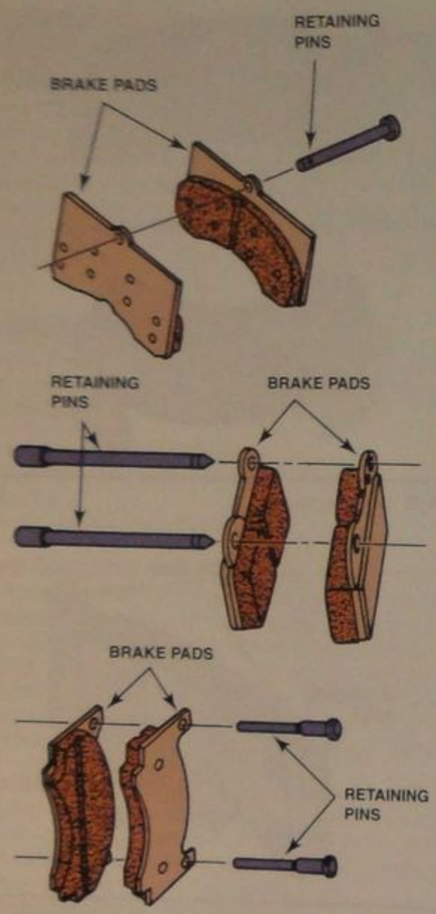


Figure 76–12 Holes in the backing plate are a common method of locating a pad in the caliper.

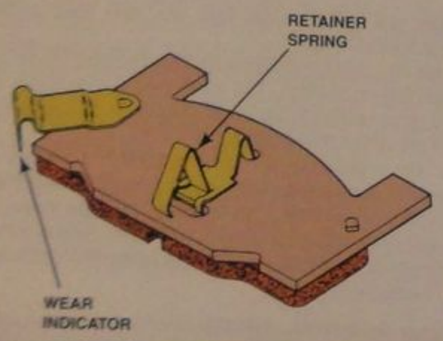


Figure 76–13 Retainer springs lock the pad to the caliper piston to prevent brake noise.

Electrical wear indicators, such as those shown in Figure 76–16, use a coated electrode imbedded in the lining material to generate the warning signal.

The electrode is wired to a warning light in the instrument panel and when the lining wears sufficiently, the electrode grounds against the rotor to complete the circuit and turn on the warning light.

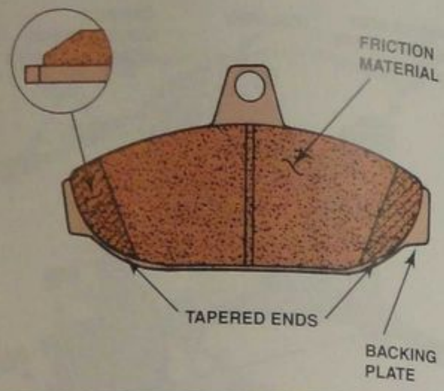


Figure 76–14 The lining edges of some brake pads are tapered to help prevent vibration.

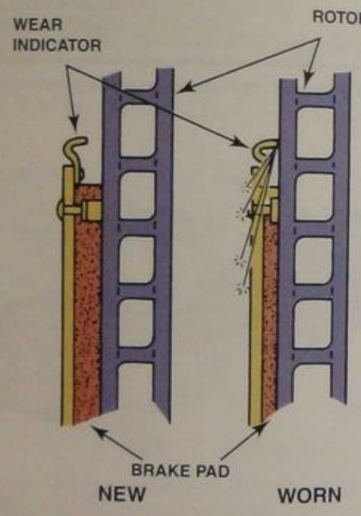


Figure 76–15 Typical pad wear sensor operation. It is very important that the disc brake pads are installed on the correct side of the vehicle to be assured that the wear sensor will make a noise when the pads are worn. If the pads with a sensor are installed on the opposite side of the vehicle, the sensor tab is turned so that the rotor touches it going the opposite direction. Usually the correct direction is where the rotor contacts the sensor before contacting the pads when the wheels are being rotated in the forward direction.

Pad Assembly Methods

As mentioned in Chapter 74, there are several methods used to mount brake linings, including:

- Riveting
- Bonding
- Mold bonding

Riveting **Riveted linings** take advantage of the oldest method of lining attachment still in use. In this system, the brake block is attached to the backing plate with copper or aluminum rivets.

The major advantage of riveting is that it allows a small amount of flex between the brake block backing plate. This play

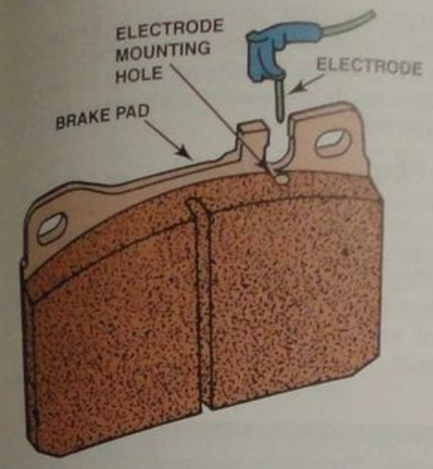


Figure 76–16 Electrical wear indicators ground a warning light circuit when the pads need replacement.

enables the assembly to absorb vibration, and the result is that riveted linings operate more quietly than bonded linings. Rivets are also very reliable and will not loosen at high temperatures.

Despite the benefit of quiet operation, riveted pads present a number of problems. In order to leave sufficient friction material for the rivets to clamp the brake block securely against the backing plate, the rivet holes are countersunk only about two-thirds to three-quarters of the way through the lining. This reduces the service life of the assembly because the shoes must be replaced before the rivet heads contact and score the rotor.

The rivet holes themselves also present some unique problems. First, they trap abrasive brake dust and other grit that can score the rotor. Some rivets are hollow to allow these materials to escape. The rivet holes also create stress points in the lining where cracks are likely to develop.

Bonding **Bonded linings** use high-temperature adhesive to glue the brake block directly to the shoe pad backing plate. Heat and pressure are then applied to cure the assembly. Bonding is a common form of shoe and pad assembly, and is most often used to bond organic friction materials.

Bonding offers several advantages. Without rivets, bonded linings can wear closer to the backing plate and provide a longer service life. If the linings wear too far, bonding adhesive is not as destructive to rotors as rivets. Bonded linings also have fewer problems with cracking because they have no rivet holes to weaken the brake block.

The primary disadvantage of bonded linings is a limited ability to withstand high temperatures. If a bonded lining gets too hot, the bonding adhesive will fail and allow the brake block to separate from the backing plate. Bonded linings are also more prone to be noisy because they do not allow any vibration absorbing flex between the brake block and backing plate.

Mold Bonding **Mold-bonded linings** are found on some disc brake pads. Mold bonding is a manufacturing process that combines the advantages of bonding with some of the mechanical strength of riveting. Instead of riveting and/or bonding a cured brake block to a separate backing plate, the friction material in a powdered pad is cured on the backing plate during manufacture. This process is also called **integrally molded.** Most high-performance disc brake pads are made in this way.

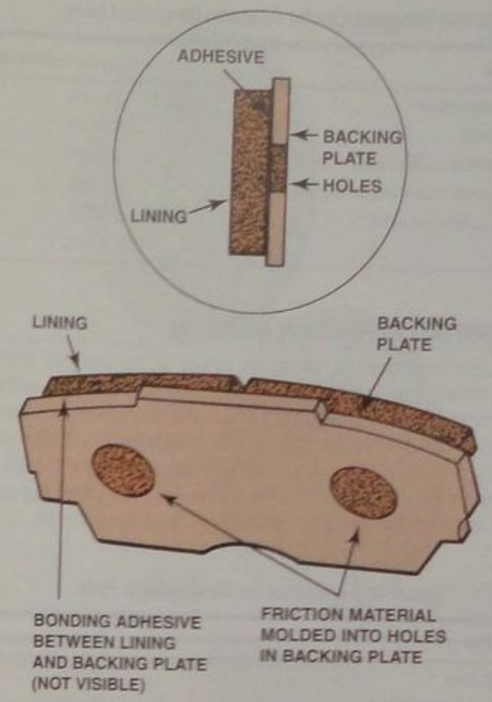


Figure 76–17 Mold-bonded linings are commonly used in many applications.

To make a mold-bonded pad, one or more holes are punched in the pad backing plate, and a high-temperature adhesive is applied to it. The backing plate is then installed in a molding machine where uncured friction material is formed onto the plate and forced into the holes. See Figure 76–17.

Once the pad is cured under heat and pressure, the bonding adhesive combines with the portions of the lining that extend into the backing plate holes to solidly lock the brake block in place.

Brake Lining Composition

Shoes and pads operate under the most extreme conditions in the entire brake system and are subject to a great deal of wear. The replacement of worn brake shoes and pads is a common part of brake service.

Although they appear to be simple parts, brake shoes and pads are the result of years of engineering development. Often, two shoes or pads that look identical will not perform the same because different friction materials are used for their linings. When a brake system is designed, engineers test the performance characteristics of many friction materials and then specify those that will work best in the particular application.

Friction materials such as disc brake pads or drum brake shoes contain a mixture of ingredients. These materials include a binder such as a thermosetting resin, fibers for reinforcement, and friction modifiers to obtain a desired coefficient of friction (abbreviated μ—Greek letter mu). The various ingredients in brake lining are mixed and molded into the shape of the finished product. The fibers in the material are the only thing holding this mixture together. A large press is used to force the ingredients together to form a **brake block,** which eventually becomes the brake lining.

Typical Compositions for Asbestos (Organic) Lining

Ingredient	Typical Formula Range
Phenolic resin (binder)	9–15%
Asbestos fiber	30–50%
Organic friction modifiers (rubber scrap)	8–19%
Inorganic friction modifiers (barites, talc, whiting)	12–26%
Abrasive particles (alumina)	4–20%
Carbon	4–20%

SEMIMETALLIC FRICTION MATERIAL

The term *semimetallic* refers to brake lining material that uses metal rather than asbestos in its formulation. It still uses resins and binders and is, therefore, not 100% metal, but rather, semimetallic. Semimetallics are commonly called **semimets.** The metal in most metallic linings is made from metal particles that have been fused together without melting. This process is called **sintering** and the result is called **sintered metal** linings. See Figure 76–18.

Typical Compositions for Semimetallic Pads

Ingredient	Formula Range
Phenolic resin	15–40%
Graphite or carbon particles	15–40%
Steel fibers	0–25%
Ceramic powders	2–10%
Steel, copper, brass metal powders	15–40%
Other modifiers (rubber scrap)	0–20%

Most semimetallic linings do not contain asbestos. Semimetallic linings require a very smooth finish on the rotor because the metal in the lining does not conform to the surface of the rotor, as does asbestos lining.

Nonasbestos Friction Material Brake pads and linings that use synthetic material such as aramid fibers instead of steel are usually referred to as **nonasbestos, nonasbestos organic (NAO),** or **nonasbestos synthetic (NAS).** Linings are called "synthetic" because synthetic (man-made) fibers are used. These linings use **aramid fiber** instead of metal as the base material. Aramid is the generic name for aromatic polyamide fibers. **Kevlar** is the Dupont brand name of aramid and a registered trademark of E.I. Dupont de Nemours and Company. Nonasbestos linings are often quieter than semimetallics and do not cause as much wear to brake rotors as do semimetallic pads.

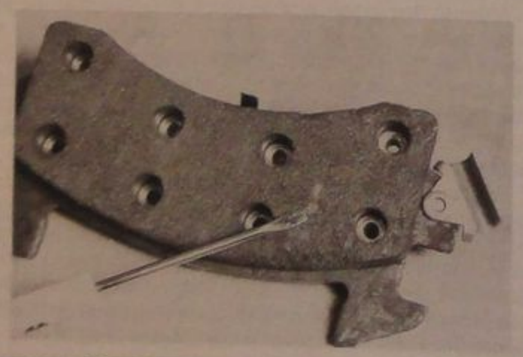


Figure 76–18 Poor-quality semimetallic disc brake pad. The screwdriver is pointing to large chunks of steel embedded in the lining.

Carbon Fiber Friction Material Carbon fiber brake lining is the newest and most expensive of the lining materials. Carbon fiber material is often called CFRC **(carbon fiber-reinforced carbon).** It is composed of a carbon mix into which reinforcing carbon fibers are embedded. CFRC is commonly used in the brakes of jet aircraft and racing cars. CFRC brakes provide constant friction coefficient whether cold or hot, low wear rates, and low noise development.

FREQUENTLY ASKED QUESTION ???

What Does "D³EA" Mean?

Original equipment brake pads and shoes are required to comply with the Federal Motor Vehicle Safety Standard (FMVSS) 135, which specifies maximum stopping distances. There is also a requirement for fade resistance, but no standard for noise or wear. Aftermarket (replacement) brake pads and shoes are not required to meet the FMVSS standard. However, several manufacturers of replacement brake pads and shoes are using a standardized test that closely matches the FMVSS standard and is called the "Dual Dynamometer Differential Effectiveness Analysis" or D³EA. This test is currently voluntary and linings that pass the test can have a "D³EA certified" seal placed on the product package.

FREQUENTLY ASKED QUESTION ???

What Is a Brake Pad Recipe?

The actual amount of each ingredient in a typical brake lining is varied for each application. Each vehicle has its own "recipe" based on vehicle weight and options. For example, a Chevrolet with a light four-cylinder engine and no air conditioning may use a different brake lining recipe than the same vehicle, but with the heavier V-6 engine, air conditioning, and other options that increase the vehicle weight. Both of these brake linings (shoes or pads) may physically fit other similar vehicles, yet their brake lining recipe is different.

Replacement linings are usually a compromise "generic" recipe that will give acceptable service. The brake lining recipe is just one of many factors that results in the fact that new brakes always seem to last longer than any replacement lining. Replacement lining should have the same friction code as the original. Although this will not guarantee the same braking performance, this edge code rating does help assure the service technician that the replacement brakes will give "as-new" performance.

Ceramic Friction Material Some vehicle manufacturers use friction materials that contain ceramic fibers. These ceramic fibers are usually potassium titanite. Some vehicle manufacturers do not recommend the use of ceramic friction material because they tend to wear the rotors more than NAO or semimetallic friction materials.

LINING EDGE CODES

As explained in Chapter 74, the lining edge codes help identify the coefficient of friction.

These codes were established by the SAE (Society of Automotive Engineers):

	0.00 to 0.15
	0.15 to 0.25
	0.25 to 0.35
	0.35 to 0.45
	0.45 to 0.55
	0.55 and above
	ungraded

TECH TIP **Competitively Priced Brakes**

The term *competitively priced* means lower cost. Most brake manufacturers offer "premium" as well as lower-price linings, to remain competitive with other manufacturers or with importers of brake lining material produced overseas by U.S. or foreign companies. Organic asbestos brake lining is inexpensive to manufacture. In fact, according to warehouse distributors and importers, the box often costs more than the brake lining inside!

Professional brake service technicians should only install brake linings and pads that will give braking performance equal to that of the original factory brakes. "Competitive" asbestos linings should never be substituted for semimetallic or NAO original linings or pads. For best results, always purchase high-quality brake parts from a known brand-name manufacturer.

The first letter, which is printed on the side of most linings, indicates its coefficient of friction when brakes are cold, and the second letter indicates the coefficient of friction of the brake lining when the brakes are hot. (For example, FF indicates that the brake lining material has a coefficient of friction between 0.35 and 0.45 when both cold and hot.)

BRAKE ROTORS

The brake rotor provides the friction surfaces for the brake pads to clamp against. The rotor, the largest and heaviest part of a disc brake, is usually made of cast iron because that metal has excellent friction and wear properties. There are two basic types of rotors: solid and vented. See Figure 76–19.

Vented rotors have radial cooling passages cast between the friction surfaces, whereas solid rotors are most often used on the rear of vehicles equipped with four-wheel disc brakes.

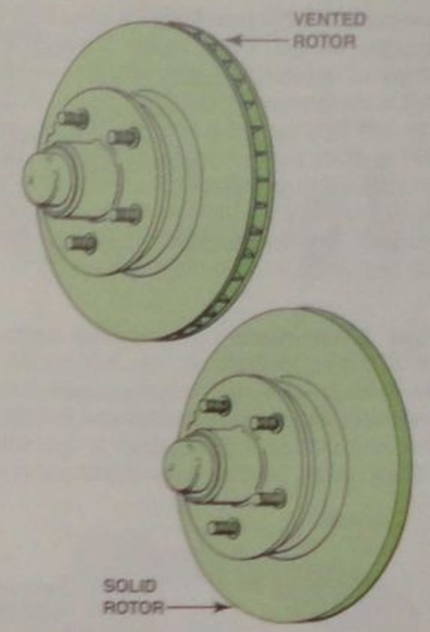


Figure 76–19 Disc brake rotors can be either solid or vented.

DISC BRAKE DESIGN

While the hydraulic operation of all brake calipers is similar, calipers differ in two important areas: how they attach to the vehicle and how they apply the brake pads to the rotor. The manners in which these tasks are performed determine the design of a disc brake friction assembly. There are basically three types of calipers:

- Fixed
- Floating
- Sliding

Fixed calipers have several unique features, but sliding and floating calipers share similar features.

Fixed Caliper Design The **fixed brake caliper** is the earliest design. See Figure 76–20. The fixed caliper has a body manufactured in two halves, and uses two, three, or four pistons to apply the brake pads. The fixed caliper gets its name from the fact that the caliper is rigidly mounted to the suspension. When the brakes are applied, the pistons extend from the caliper bores and apply the brake pads with equal force from both sides of the rotor. No part of the caliper body moves when the brakes are applied.



Figure 76–20 Four-piston fixed caliper assembly on a race vehicle.

Fixed Caliper Advantages Fixed calipers are relatively large and heavy, which enables them to absorb and dissipate great amounts of heat. This allows the brake rotor and pads to run cooler, and

reduce the amount of heat transferred to the brake fluid. Compared with other caliper designs, a fixed caliper is able to withstand a greater number of repeated hard stops without heat-induced fade or vapor lock of the hydraulic system.

The size and rigid mounting of a fixed caliper also means it does not flex as much as other designs. A caliper that is flexing is usually felt by the driver as a spongy brake pedal. Fixed calipers are very strong and provide a firm and linear brake pedal feel.

The strength and heat-dissipating abilities of fixed calipers make them best suited for heavy-duty use such as in most race vehicles.

Fixed Caliper Disadvantages The size and weight of fixed calipers are advantages in heavy-duty use, but they add weight to the vehicle. To obtain better fuel economy, manufacturers want to eliminate as much weight as possible from new vehicles.

Another disadvantage of fixed calipers is that, with multiple pistons and split bodies, service is more difficult and allows greater opportunity for leaks. The drilled passages that route fluid through the inside of the caliper body also contribute to cracking as miles accumulate and the caliper goes through hundreds of thousands of heating and cooling cycles. See Figure 76–21.

Fixed Caliper Alignment Because the caliper body is locked in position, a fixed caliper must be centered over the rotor and aligned so the pistons contact the brake pad backing plates parallel to the friction surface of the rotor. See Figure 76–22.

If the caliper is not properly aligned, the pistons will contact the pads at an angle and cause tapered wear of the brake linings. If the misalignment is bad enough, the pistons will cock into their bores, suffer increased wear, and possibly crack.

Whenever a fixed caliper is unbolted from its mounts, care should be taken to note the location and quantity of any shims so they can be replaced in the same positions during reassembly. If a different caliper is installed, its alignment must be checked and adjusted as necessary.

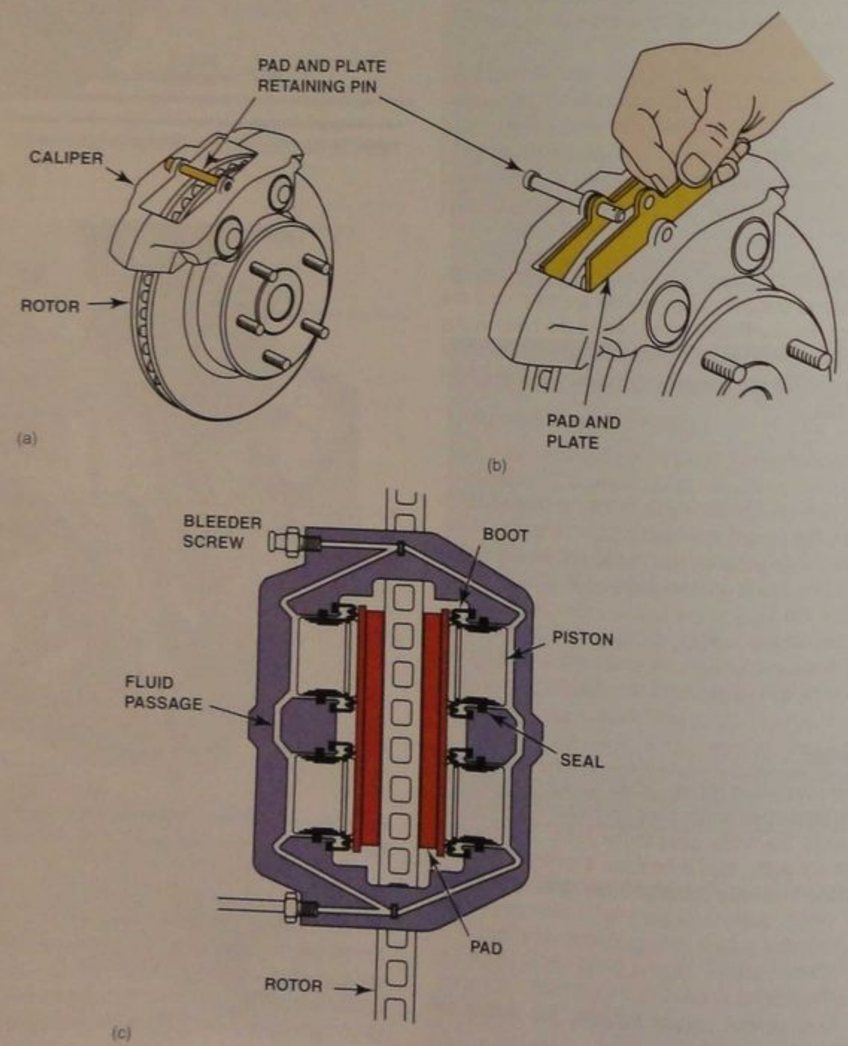
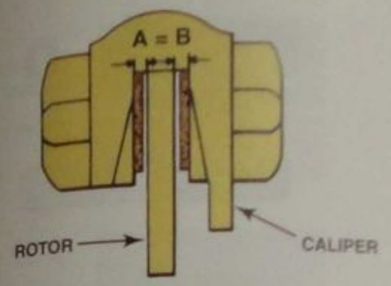


Figure 76–21 (a) Many fixed caliper disc brakes use a simple retaining pin to hold the disc brake pads. (b) Removing the retainer pads allows the brake pads to be removed. (c) Notice the cross-over hydraulic passage that connects both sides of the caliper.



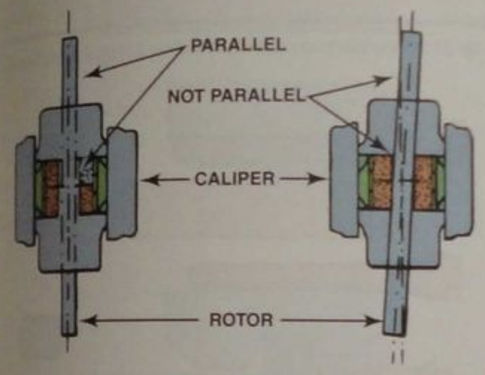


Figure 76–22 Fixed brake calipers must be centered over the rotor with their pistons parallel to the rotor friction surfaces.

Floating and Sliding Caliper Design The front brakes of most vehicles are fitted with either floating or sliding calipers, which are *not* rigidly mounted. The caliper is free to move within a limited range on an **anchor plate** that *is* solidly mounted to the vehicle suspension. The anchor plate may be cast into a suspension member (often the front spindle) or it can be a separate piece that bolts to the suspension. See Figure 76–23.

When the brakes are applied the caliper piston moves out of its bore and applies the inner brake pad. At the same time, the caliper body moves in the opposite direction on the anchor plate and applies the outer brake pad. With a floating or sliding caliper, the caliper body moves every time the brakes are applied. See Figure 76–24.

Floating and Sliding Caliper Advantages The biggest advantages of floating and sliding calipers are lower cost, simple construction, and compact size. Most floating and sliding calipers are single-piston designs. Because they have fewer pieces, floating and sliding calipers are cheaper to build and service, and have fewer places where leaks can develop.

The smaller size of floating and sliding calipers also allows easier packaging of the caliper on the vehicle. A single-piston caliper with the piston located on the inboard side of the brake rotor fits easily within the diameter of a small wheel. The inboard location of the caliper piston also contributes to better cooling because the bulk of the caliper body is exposed to the passing airflow.

Like any disc brake, floating and sliding calipers have poor parking brake performance. Unlike a fixed caliper, a floating or sliding caliper can be mechanically actuated by applying the single piston with a cable and lever mechanism.

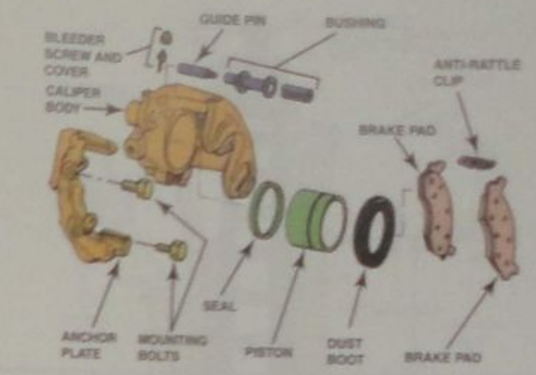


Figure 76–23 This floating caliper mounts on a separate anchor plate that bolts to the vehicle suspension.

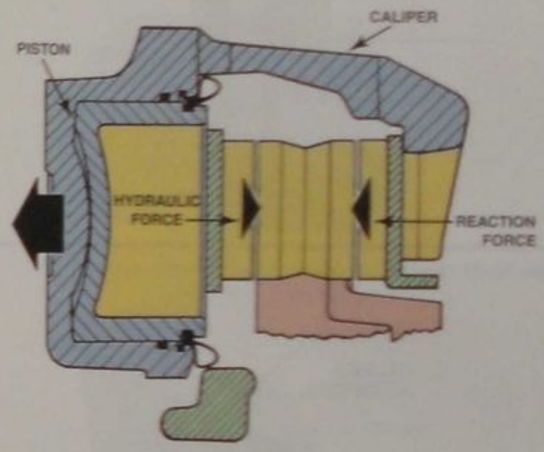


Figure 76–24 Hydraulic force on the piston (left) is applied to the inboard pad and the caliper housing itself. The reaction of the piston pushing against the rotor causes the entire caliper to move toward the inside of the vehicle (large arrow). Since the outboard pad is retained by the caliper, the reaction of the moving caliper applies the force of the outboard pad against the outboard surface of the rotor.

Floating and Sliding Caliper Disadvantages The movable caliper body allows a certain degree of flex, which can contribute to a spongy brake pedal. Caliper flex also allows the caliper body to twist slightly when the brakes are applied, causing tapered wear of the brake pad lining material. See Figure 76–25.

Although the inboard piston location of floating and sliding calipers provides good cooling, these designs can never absorb as much heat (and therefore have the fade resistance) as a fixed caliper with similar stopping power. Floating and sliding calipers simply do not have the mass of fixed calipers, and their flexible mounting systems slow the transfer of heat from the caliper body to the anchor plate and other suspension components that aid in the cooling process.

Floating Calipers The body of a **floating caliper** does not make direct metal-to-metal contact with the anchor plate. See Figure 76–26.

Instead, the caliper body is supported by bushings and/or O-rings that allow it to "float" or slide on metal guide pins or locating sleeves attached to the anchor plate. For this reason, some automakers call the floating caliper a **pin-slider caliper.**

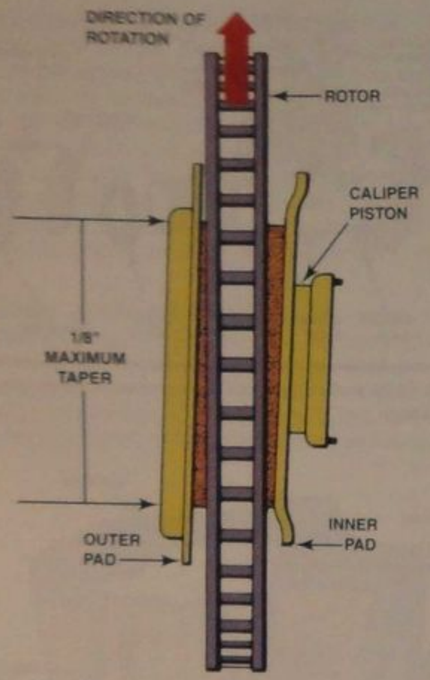


Figure 76–25 Caliper flex can cause tapered wear of the brake lining.

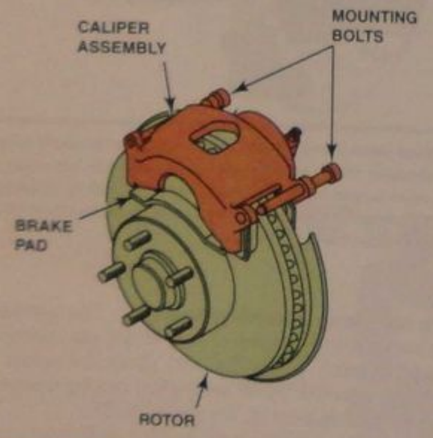


Figure 76–26 A typical single-piston floating caliper. In this type of design, the entire caliper moves when the single piston is pushed out of the caliper during a brake application. When the caliper moves, the outboard pad is pushed against the rotor.

The bushings that support floating calipers are made from a number of materials including rubber, Teflon, and nylon. O-rings are generally made from high-temperature synthetic rubber. See Figure 76–27.

The guide pins and sleeves are made of steel and come in a variety of shapes and sizes for different caliper designs. See Figure 76–28.

Floating calipers depend on proper lubrication of their pins, sleeves, bushings, and O-rings for smooth operation. If these parts become rusted or corroded, the caliper will bind and stick, causing loss of braking power that is usually accompanied by rapid and unusual wear of brake pads. Special high-temperature brake grease must be used to lubricate these parts any time the caliper is disassembled. Many manufacturers recommend that floating caliper pins, sleeves, bushings, and O-rings be replaced whenever the caliper is serviced. These parts come in a "small parts kit" available from brake part suppliers.

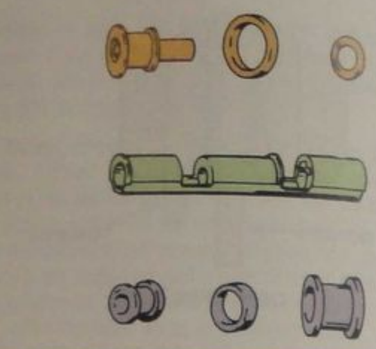


Figure 76–27 Floating calipers are supported by rubber O-rings or plastic bushings.

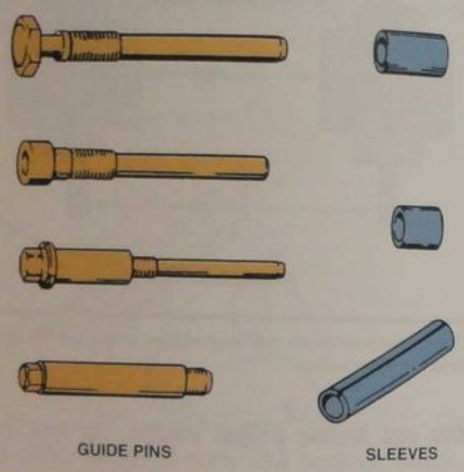


Figure 76–28 Metal guide pins and sleeves are used to retain and locate floating calipers.

FREQUENTLY ASKED QUESTION ???

What Is a Low-Drag Caliper?

A **low-drag caliper** differs from a standard caliper in the area of the square-cut O-ring. A V-shaped cutout allows the O-ring to deflect more and, as a result, is able to pull the caliper piston back into the bore when the brakes are released. Because of this further movement, the brake pads are pulled further from the rotor and are less likely to drag. The negative aspect of this design is that greater volume of brake fluid is needed to achieve a brake application. To compensate for this need for greater brake fluid volume, a quick-take-up master cylinder was designed and is used whenever low-drag calipers are used. See Figure 76–29.

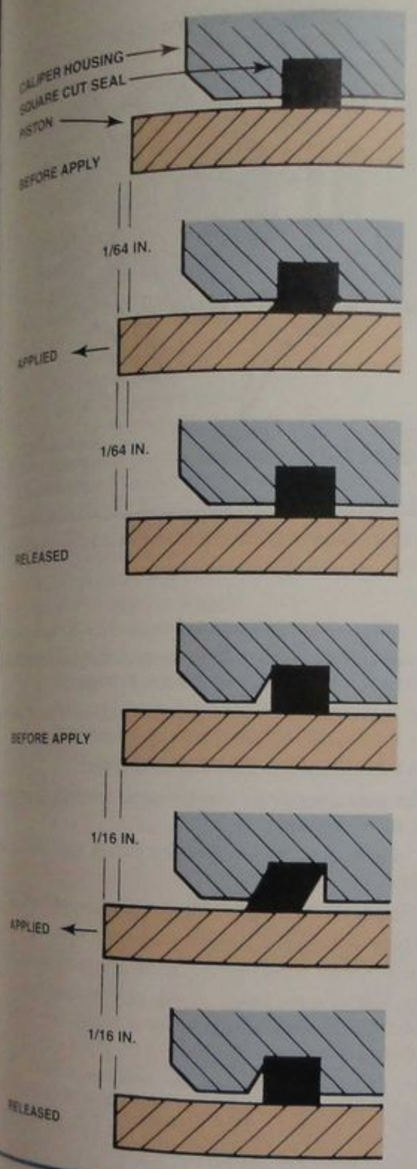


Figure 76–29 In a standard disc brake caliper, the square-cut O-ring deforms when the brakes are applied and returns the piston to its original (released) position due to the elastic properties of the rubber seal. In a low-drag caliper design, the groove for the square-cut ring is V-shaped, allowing for more retraction. When the brake pedal is released, the piston is moved away from the rotor, further resulting in less friction between the disc brake pads and the rotor when the brakes are released.

Sliding Calipers Unlike a floating caliper, the body of a **sliding caliper** mounts in direct metal-to-metal contact with the anchor plate. See Figure 76–30.

Instead of pins and bushings, sliding calipers move on **ways** that are machined into the caliper body and anchor plate. See Figure 76–31.

Retaining clips and the design of the caliper prevent the body from coming out of the ways once the caliper is assembled. On some calipers, the ways may have to be filed for proper clearance between the caliper body and anchor plate if the caliper is replaced.

Like floating calipers, sliding calipers depend on good lubrication of their ways for proper operation. If not properly coated with high-temperature brake grease, the ways can rust or corrode, causing the caliper to drag or seize.

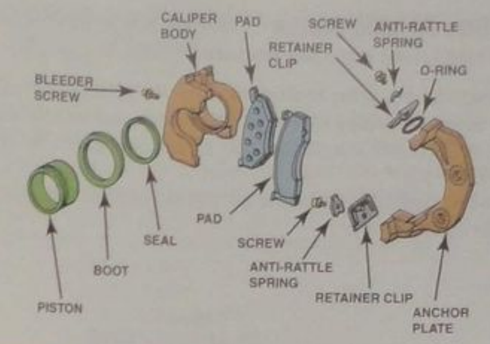


Figure 76–30 Exploded view of a typical sliding brake caliper.

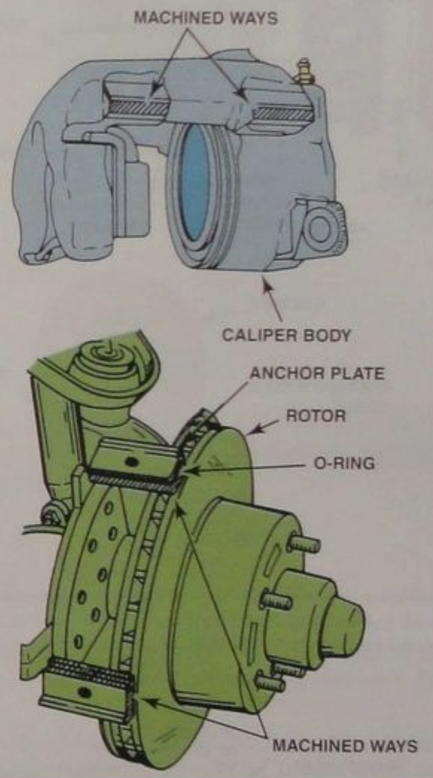


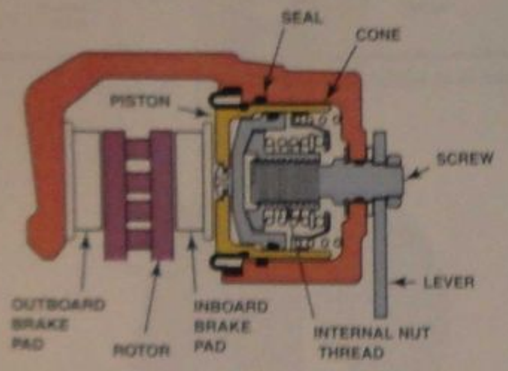
Figure 76–31 Sliding calipers move on machined ways.

REAR DISC BRAKES

In recent years, four-wheel disc brake systems have become more common. In most rear-wheel applications, drum brakes are adequate to provide the relatively small portion of a vehicle's total braking power required of them. Because rear drum brakes are lightly loaded, fade is a problem only in extreme conditions when the front brakes fade and force the rear brakes to take on a larger part of the braking load. The automatic adjusting ability of disc brakes is also less of an advantage in slow-wearing rear brakes.

Rear Disc Parking Brakes There are two methods of providing parking brakes when rear discs are installed on a vehicle.

1. Adapt the disc brake to also function as the parking brake. This is done by installing a series of cables, levers, and internal parts to mechanically actuate the brake caliper. See Figures 76–32 and 76–33.
2. Use mechanically actuated drum brakes inside the rear rotors. See Figure 76–34.



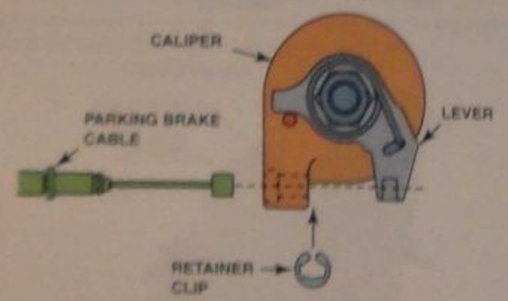


Figure 76–32 Exploded view of a typical rear disc brake with an integral parking brake. The parking brake lever mechanically pushes the caliper piston against the rotor.

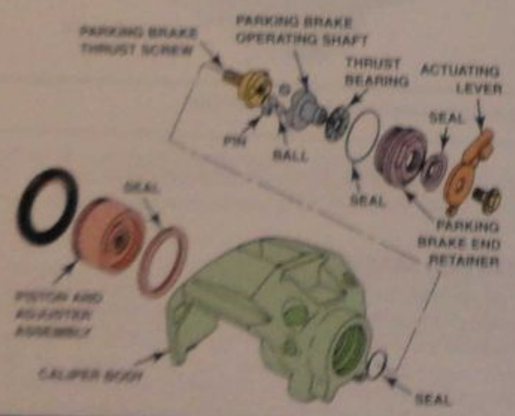


Figure 76–33 This single-piston brake caliper is mechanically actuated to serve as a parking brake.

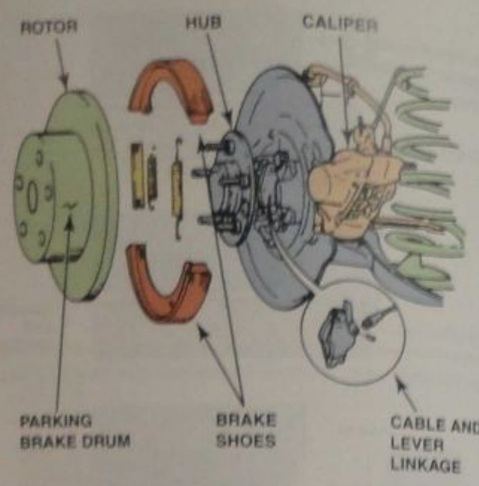


Figure 76–34 Drum parking brakes are fitted inside the rotors on this vehicle equipped with rear disc brakes.

SUMMARY

1. Disc brakes are superior to drum brakes because they are fade-resistant, self-adjusting, and are less likely to pull during braking.
2. Disc brakes, however, lack self-energization requiring greater force be applied to the brake pedal compared with the drum brakes.
3. Disc brakes are more prone to noise than drum brakes.
4. A typical disc brake assembly includes the caliper assembly, splash shield, brake pads, and brake rotor.
5. The three basic types of disc brake calipers include fixed, floating, and sliding designs.
6. A low-drag caliper requires the use of a quick-take-up master cylinder.
7. Some disc brakes are equipped with integral parking brakes.
8. Brake pads can be attached using rivets, bonding, or integrally molded.
9. Typical semimetallic brake linings contain phenolic resin, graphite or carbon particles, steel fibers, ceramic and metal powders plus other modifiers such as rubber scraps.
10. Other types of friction material include nonasbestos organic (NAO), nonasbestos synthetic (NAS), and carbon fiber-reinforced carbon (CFRC).
11. Lining edge codes identify the manufacturer and include two letters at the end, which identify the coefficient of friction of the material. The first letter indicates the coefficient when the lining is cold and the second indicates the coefficient when the lining is hot.

REVIEW QUESTIONS

1. What are the advantages and disadvantages of disc brakes?
2. What parts are included in a typical disc brake?
3. How does a low-drag caliper work?
4. What mechanism is used to apply the parking brake on a vehicle equipped with rear disc brakes?
5. What do the abbreviations NAO, NAS, and CFRC mean?

CHAPTER QUIZ

1. What part causes the disc brake caliper piston to retract when the brakes are released?
   a. Return (retracting) spring
   b. The rotating rotor (disc) that pushes the piston back
   c. The square-cut O-ring
   d. The caliper bushings
2. Two technicians are discussing the reason that the brake fluid level in the master cylinder drops. Technician A says that it may be normal due to the wear of the disc brake pads. Technician B says that a low brake fluid level may indicate a hydraulic leak somewhere in the system. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Two technicians are discussing a floating-type disc brake caliper. Technician A says that if the caliper slides are corroded, one pad may wear more than the other pad on the same wheel brake. Technician B says that if a caliper slide is corroded, reduced braking may occur. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that disc brakes are self-adjusting and the brake pedal height should not become lower as the disc brake pads wear. Technician B says that as the disc brake pads wear, the level of brake fluid in the master cylinder reservoir drops. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Which type of disc brake caliper may require alignment for proper operation?
   a. Sliding
   b. Fixed
   c. Floating
   d. Single piston
6. A quick-take-up master cylinder is required when what type of caliper design is used on a vehicle?
   a. Fixed
   b. Two-piston
   c. Sliding
   d. Low-drag
7. Technician A says that all vehicles equipped with rear disc brakes use a parking brake that is integrated in the caliper. Technician B says that all vehicles equipped with rear disc brakes use a small drum brake inside the rear rotor for a parking brake. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. The brake pad edge code letters "FF" mean _____.
   a. Brand name
   b. Coefficient of friction rating
   c. Quality factor
   d. Noise level rating
9. Semimetallic brake pads are made by a process called _____.
   a. Sintering
   b. Melting
   c. Grating
   d. Composition
10. The major ingredient in most brake lining is _____.
    a. Carbon
    b. Graphite
    c. Ceramic powders
    d. Phenolic resin

CHAPTER 77

Disc Brake Diagnosis and Service

OBJECTIVES: After studying Chapter 77, the reader will be able to: Prepare for ASE Brakes (A5) certification test content area "C" (Disc Brake Diagnosis and Repair). • List the items that should be checked during a visual inspection. • Describe the caliper disassembly procedure. • Describe the caliper assembly procedure. • List the steps necessary to reduce brake noise.

KEY TERMS: abutments • antiseize compound • bedded-in • brake assembly fluid • burnished • constrained layer shims (CLS) • lithium-based wheel grease • loaded calipers • minimum thickness • MOS_2 (molybdenum disulfide) grease • polyalphaolefin (PAO) • phenolic caliper pistons • rotation pads • silicone grease • synthetic grease • ways

DISC BRAKE DIAGNOSTIC PROCEDURE

When diagnosing disc brake concerns, the first step is to verify the customer complaint. This step usually includes test driving the vehicle to see if the complaint can be duplicated. If the problem cannot be duplicated, then the repair or service cannot be verified.

CAUTION: Do not test-drive the vehicle on public roads if the red brake warning light is on.

After verifying the customer concern, the brake system should be carefully inspected and all parts and systems checked for proper operation. These steps include:

Step #1 Check the brake pedal height and verify proper operation. If the brake pedal is low, check the parking brake and count the number of "clicks." There should be 3 to 7 clicks. If there are over 10 clicks, check the rear brakes.

Step #2 Safely hoist the vehicle and remove the wheels. Visually check the following:

- Flexible brake lines for wear or damage
- Disc brake rotors for excessive rust or scoring
- Disc brake calipers for leakage or damage

Step #3 Remove disc brake calipers and check the disc brake pads for proper lining thickness and check for cracks or other damage.

Step #4 Replace all components that do not meet factory specifications.

Step #5 Test-drive the vehicle to verify that the repairs did correct the customer concern.

TECH TIP **Let the Owner Drive**

When verifying the customer complaint, ask the owner or driver of the vehicle to drive. Often, the problem is best discovered if the vehicle is being driven exactly the same way as when the complaint first occurred. For example, the technician may brake harder or softer than the driver so the problem may not be detected.

VISUAL INSPECTION

Even with operating wear-indicating sensors, a thorough visual inspection is very important. See Figure 77–1.

A lining thickness check alone should not be the only inspection performed on a disc brake. *A thorough visual inspection can only be accomplished by removing the friction pads.* See Figure 77–2 for an example of a disc brake pad that shows usable lining thickness, but is severely cracked and *must* be replaced.

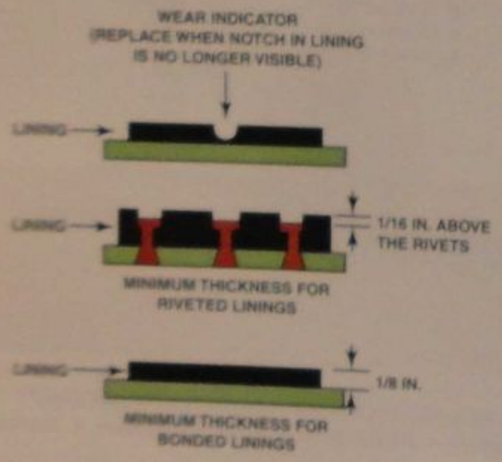


Figure 77–1 Minimum thickness for various types of disc brake pads. Disc brake pads can, of course, be replaced before they wear down to the factory-recommended **minimum** thickness.

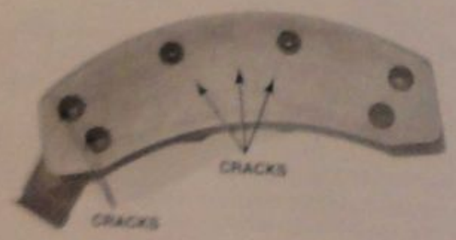


Figure 77–2 This cracked disc brake pad must be replaced even though it is thicker than the minimum allowed by the vehicle manufacturer.

NOTE: Some disc brake pads use a heat barrier (thermo) layer between the steel backing plate and the friction material. The purpose of the heat barrier is to prevent heat from transferring into the caliper piston where it may cause the brake fluid to boil. Do not confuse the thickness of the barrier as part of the thickness of the friction lining material. The barrier material is usually a different color and usually can be distinguished from the lining material.

Some disc brake pads may show more wear on the end of the pad that first contacts the rotor as compared to the trailing end of the pad. This uneven wear is caused by the force between the pad and the abutment (slide area). In designs that place the caliper piston exactly in the center of the leading edge of the pad that first contacts the rotor as it is revolving through the caliper, pressures are often one-third higher than the average pressure exerted on the entire pad. The result of this higher pressure is greater wear.

Brake engineers design brakes to minimize or eliminate tapered pad wear by offsetting the piston more toward the trailing edge of the shoe or by other caliper/pad mounting designs.

One method used to help reduce tapered pad wear is the design that offsets the friction material off center. Be certain to position the pads correctly or severe tapered pad wear will occur. See Figures 77–3 and 77–4.

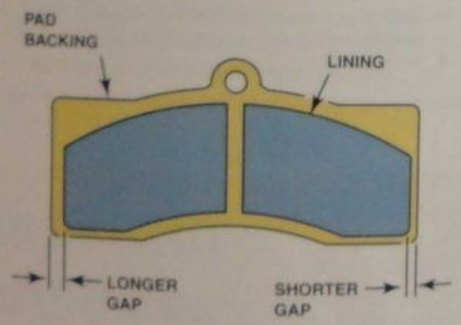


Figure 77–3 Be careful to observe the direction in which replacement linings are facing. Some vehicle manufacturers offset the friction material on the steel backing to help prevent or minimize tapered pad wear.

TECH TIP **The Bleed and Squirt Test**

If you suspect a brake is not being fully released, simply loosen the bleeder valve. If brake fluid squirts out under pressure, then the brake is being kept applied. Look for a defective flexible brake hose.

If the vehicle is off the ground, the wheels should be able to be rotated with the brakes off. If a wheel is difficult or hard to turn by hand and is easy to turn after opening the bleeder valve, then there is a brake fluid restriction between the master cylinder and the brake.

DISC BRAKE CALIPER SERVICE

Removal Hoist the vehicle and remove the wheel(s). Note the caliper mount position as shown in Figure 77–5 before removing the caliper.

Knowing whether the caliper is "rear mount" position or "forward mount" position is often needed when purchasing replacement calipers.

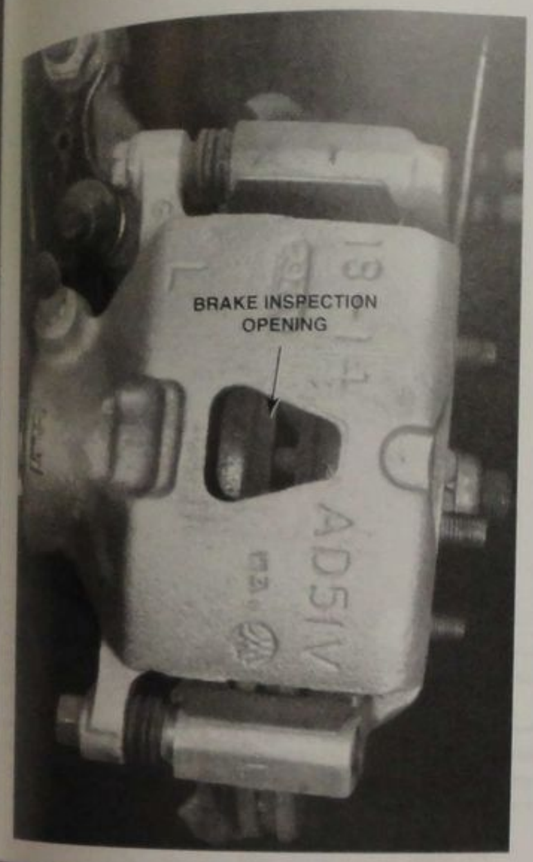


Figure 77–4 Most disc brake calipers have a brake inspection opening. For a thorough inspection, however, the caliper should be removed and the entire braking system thoroughly inspected.

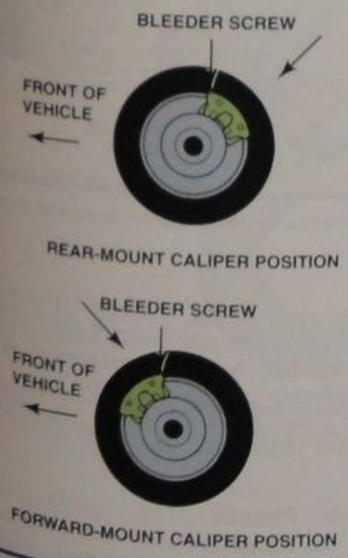


Figure 77–5 Both rear- and forward-mounted calipers have the bleeder valve at the top. Such calipers will fit on the wrong side of the vehicle, yet not be able to be bled correctly because the bleeder valve would point down, allowing trapped air to remain inside the caliper. Also, if both calipers are being removed at the same time, mark them "left" and "right."

Remove the caliper following the steps in Figures 77–6 through 77–10.

Inspection and Disassembly Check for brake fluid in and around the piston boot area. If the boot is damaged or a fluid leak is visible, then a caliper assembly repair or replacement is required. See Figures 77–11 and 77–12.

Phenolic Caliper Pistons **Phenolic caliper pistons** are made from a phenol-formaldehyde resin combined with various reinforcing fibers. When phenolic brake caliper pistons were first

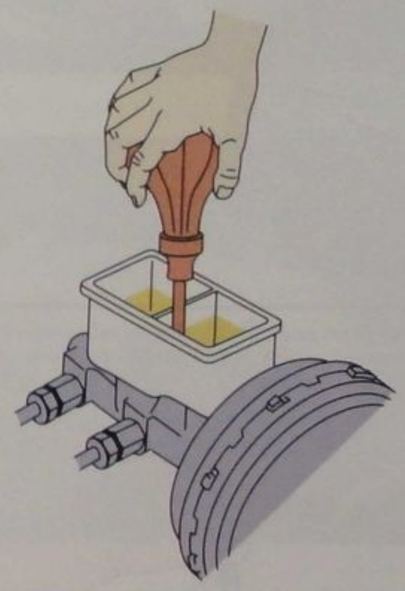


Figure 77–6 Many manufacturers recommend removing one-half of the brake fluid from the master cylinder before servicing disc brakes. Use a squeeze bulb and dispose of the used brake fluid correctly.

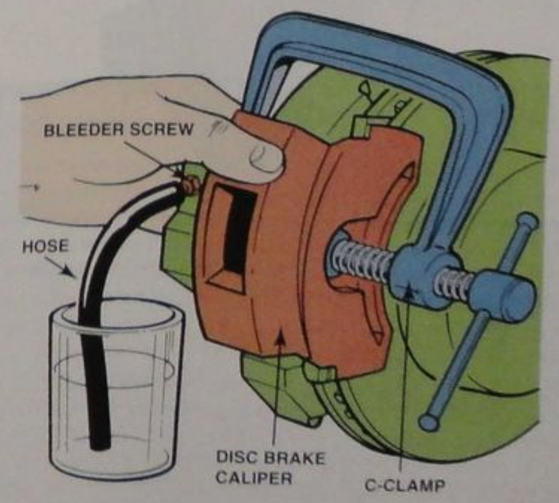


Figure 77–7 Most manufacturers recommend that the bleeder valve be opened and the brake fluid forced into a container rather than back into the master cylinder reservoir. This helps prevent contaminated brake fluid from being forced into the master cylinder where the dirt and contamination could cause problems.

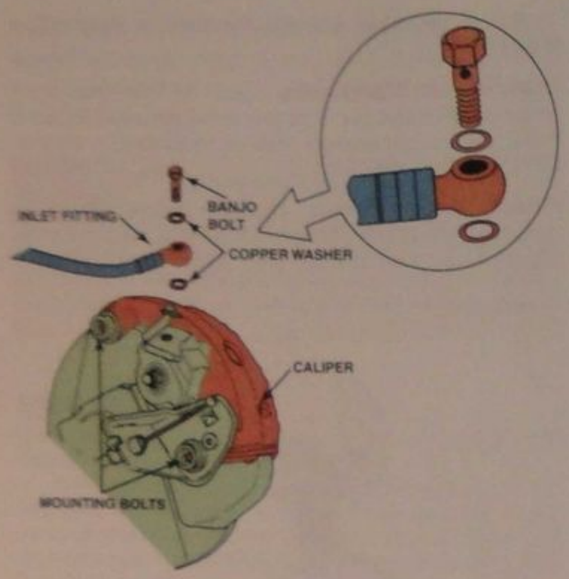


Figure 77–8 Many calipers use a hollow "banjo bolt" to retain the flexible brake line to the caliper housing. The fitting is usually round like a banjo. The copper washers should always be replaced and not reused.

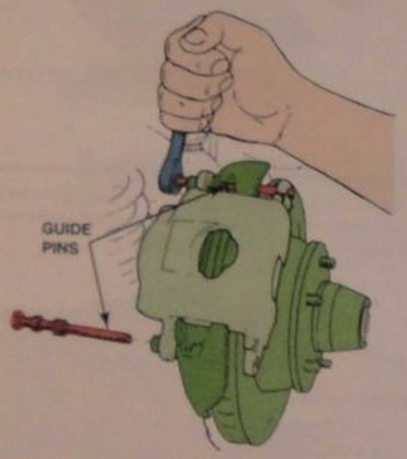


Figure 77–9 Caliper retaining bolts are often called guide pins. These guide pins are used to retain the caliper to the steering knuckle. These pins also slide through metal bushings and rubber O-rings. *(Courtesy of EIS Brake Parts)*

used, the results were not good and the problem was blamed on "three dam plastic pistons." What was happening was that the pistons were becoming stuck in the caliper, which caused the brake pads to remain applied. This caused the brake pads to wear out very rapidly. The problem occurred because the phenolic pistons absorbed moisture and swelled in size.

By reducing the diameter of the pistons 0.001 to 0.002 in. (0.025 to 0.050 mm) and improving the caliper boot seal, the sticking problem has been solved. Since the mid-1980s, phenolic caliper pistons have been used as original equipment by many

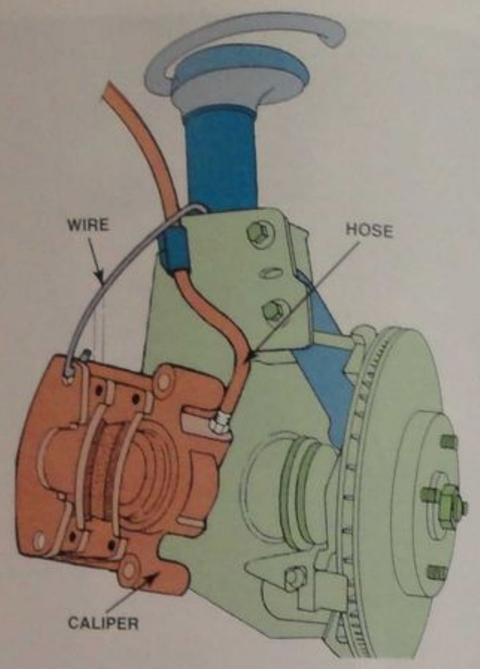


Figure 77–10 If the caliper is not being removed, it must be supported properly so that the weight of the caliper is not pulling on the flexible rubber brake line. A suitable piece of wire, such as a coat hanger, may be used.

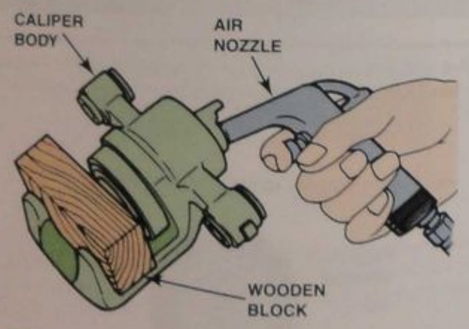


Figure 77–11 A wooden block or a folded shop cloth helps prevent damage when caliper pistons are removed.

vehicle manufacturers. Phenolic caliper pistons are natural thermal insulators and help keep heat generated by the disc brake pads from transferring through the caliper piston to the brake fluid. Phenolic brake caliper pistons are also lighter in weight than steel caliper pistons and are usually brown in color. See Figure 77–13.

Steel Caliper Pistons Many manufacturers still use steel pistons. The stamped steel pistons are plated first with nickel, then chrome to achieve the desired surface finish. See Figure 77–14.

Unlike phenolic caliper pistons, steel pistons can transfer heat from the brake pads to the brake fluid. The surface finish on a steel piston is critical. Steel can rust and corrode. Any surface pitting can cause the piston to stick.

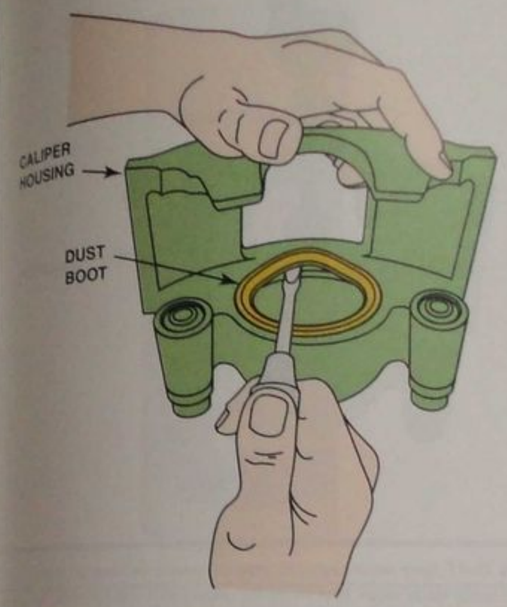


Figure 77–12 After the piston is removed from the caliper housing, the dust boot can often be removed using a straight-blade screwdriver.

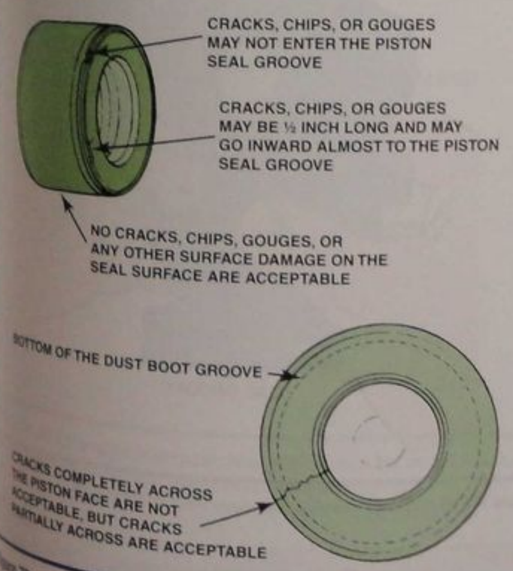


Figure 77–13 Phenolic (plastic) pistons should be carefully inspected.

Note: Care should be taken when cleaning steel pistons. Use crocus cloth to remove any surface staining. Do not use sandpaper, emery cloth, or any other substance that may remove or damage the chrome surface finish.



(a)



(b)

Figure 77–14 (a) The outside surface of caliper pistons should be carefully inspected. The square-cut O-ring inside the caliper rides on this outside surface of the piston. Sometimes dirty pistons can be cleaned and reused. (b) If there are any surface flaws such as rust pits on the piston, it should be replaced.

REAL WORLD FIX — **Three Brake Jobs in 40,000 Miles**

A service technician was asked to replace the front disc brake pads on a Pontiac Grand Am because the sensors were touching the rotors and making a squealing sound. This was the third time that the front brakes needed to be replaced. Previous brake repairs had been limited to replacement of the front disc brake pads only.

When the caliper was removed and the pads inspected, it was discovered that a part of one pad had broken and a piece of the lining was missing. See Figure 77–15.

Then the technician spotted something at the rear of the vehicle that told the whole story—a trailer hitch.

The owner confirmed that a heavy jet ski was towed in hilly terrain. The technician recommended overhauling the front disc brake calipers to prevent the possibility of the front pads dragging. The technician also recommended an inspection of the rear brakes. The rear brakes were glazed and out-of-adjustment. The technician received permission to replace the rear brakes, overhaul both front calipers, and install quality disc brake pads. When the customer returned, the technician advised the customer to use the transmission on long downhill roads to help keep the brakes from overheating and failing prematurely.

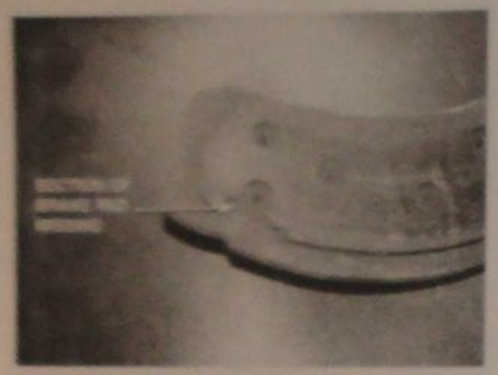


Figure 77–16 These pads were found to be cracked and a section was missing from a part of one pad.

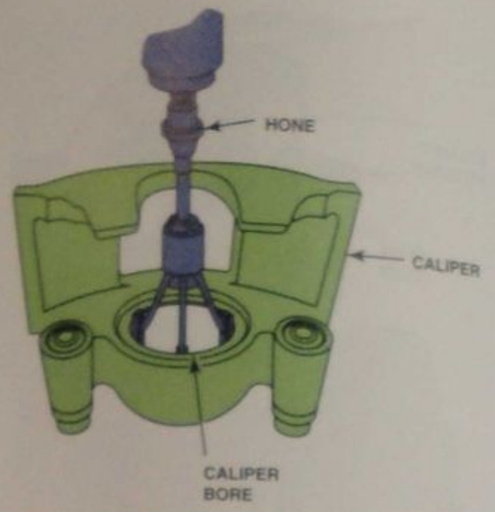


Figure 77–17 Some manufacturers recommend cleaning the inside of the caliper bore using a honing tool as shown. Even though the caliper piston does not contact the inside of this bore, removing any surface rust or corrosion is important to prevent future problems. If the honing process cannot remove any pits or scored areas, the caliper should be replaced.

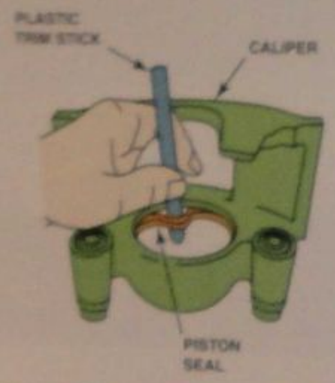


Figure 77–18 Removing the square-cut O-ring seal from the caliper bore. Use a wooden or plastic tool to prevent damage to the seal groove.

REASSEMBLING DISC BRAKE CALIPERS

After disassembly, the caliper should be thoroughly cleaned in denatured alcohol and closely examined. See Figure 77–16.

If the caliper bore is rusted or pitted, some manufacturers recommend that a special hone be used, as shown in Figure 77–17.

Some manufacturers do not recommend honing the caliper bore because the actual sealing surface in the caliper is between the piston seal and the piston itself. This is the reason why the surface condition of the piston is so important.

To assemble the disc brake caliper, perform the following steps:

Step #1 Carefully clean the caliper bore with clean brake fluid from a sealed container. Coat a new piston seal with clean brake fluid and install it in the groove inside the caliper bore, as shown in Figure 77–18.

Step #2 Check the piston-to-caliper bore clearance. Typical piston-to-caliper bore clearance is as follows:

steel piston 0.002–0.005 in. clearance (0.05–0.13 mm)
phenolic piston 0.005–0.010 in. clearance (0.13–0.25 mm)

Step #3 Coat a new piston boot with brake fluid or **brake assembly fluid.** See Figure 77–19. Brake assembly fluid is similar to brake fluid but has antiwear additives.

Step #4 Install the piston into the caliper piston, as shown in Figures 77–20 and 77–21.



Figure 77–18 Installing a new piston seal. Never reuse old rubber parts.

Step #5 Some caliper boots require a special boot-seating tool, as shown in Figure 77–22.

Step #6 Always lubricate caliper bushings, shims, and other brake hardware as instructed by the manufacturer. See Figure 77–23.

Step #7 The pads should also be securely attached to the caliper as shown in Figures 77–24 and 77–25.

CAUTION: Installing disc brake pads on the wrong side of the vehicle (left versus right) will often prevent the sensor from making noise when the pads are worn down.



Figure 77–19 Brake assembly fluid or clean brake fluid from a sealed container can be used to lubricate the caliper seal and caliper pistons before assembly.

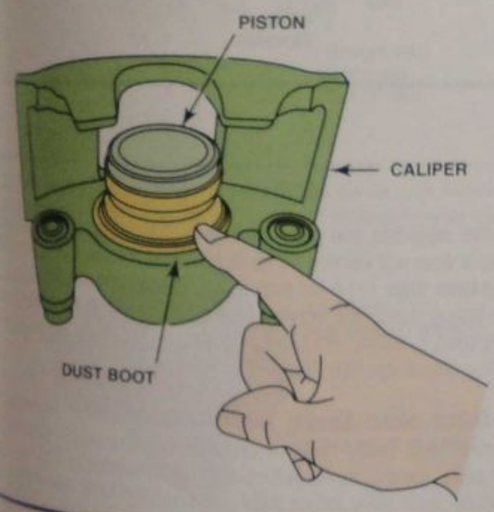


Figure 77–20 Installing the caliper piston. Many calipers require that the dust boot be seated in the groove of the piston and/or caliper before installing the piston.

TIP **Using "Loaded Calipers" Saves Time**

Many technicians find that disassembly, cleaning, and rebuilding calipers can take a lot of time. Often the bleeder valve breaks off or the caliper piston is too corroded to reuse. This means that the technician has to get a replacement piston, caliper overhaul kit (piston seal and boot), plus the replacement friction pads and hardware kit.

To save time (and sometimes money), many technicians are simply replacing the old used calipers with "loaded calipers." **Loaded calipers** are remanufactured calipers that include (come loaded) with the correct replacement friction pads and all the necessary hardware. See Figure 77–26.

Therefore, only one part number is needed for each side of the vehicle for complete disc brake overhaul.

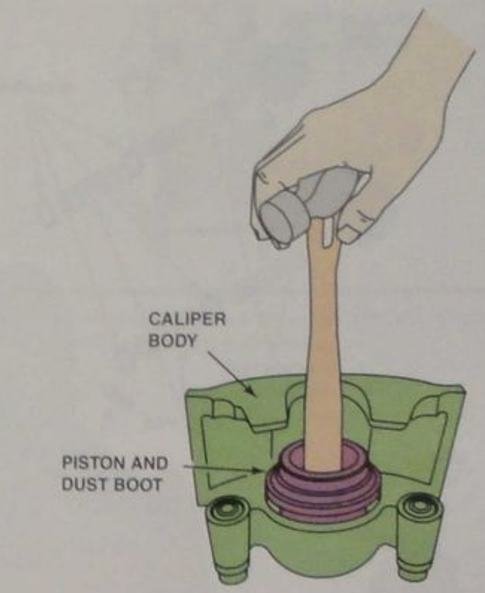


Figure 77–21 Installing a piston into a caliper. Sometimes a C-clamp is needed to install the piston. Both the piston and the piston seal should be coated in clean brake fluid before assembly.

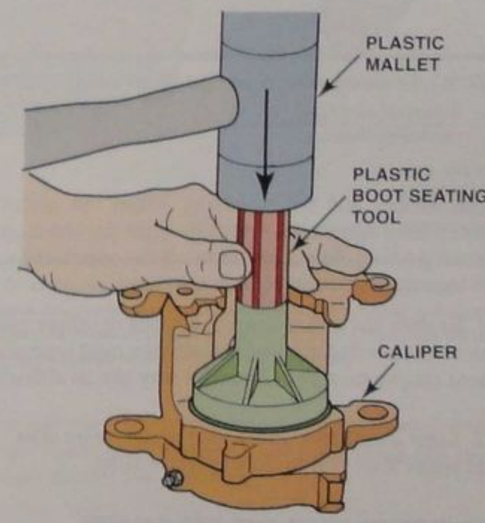


Figure 77–22 Seating the dust boot into the caliper housing using a special plastic seating tool.

Caliper Mounts When the hydraulic force from the master cylinder applies pressure to the disc brake pads, the entire caliper tends to be forced in the direction of rotation of the rotor. All calipers are mounted to the steering knuckle or axle housing. See Figure 77–27.

All braking force is transferred through the caliper to the mount. The places where the caliper contacts the caliper mount are called the **abutments, reaction pads,** or **ways.** The sliding surfaces of the caliper support should be cleaned with a wire brush and coated with a synthetic grease or antiseize compound according to manufacturer's recommendations. See Figure 77–28.

As the vehicle ages and the brakes are used thousands of times, these abutments (pads) can wear, causing too much clearance

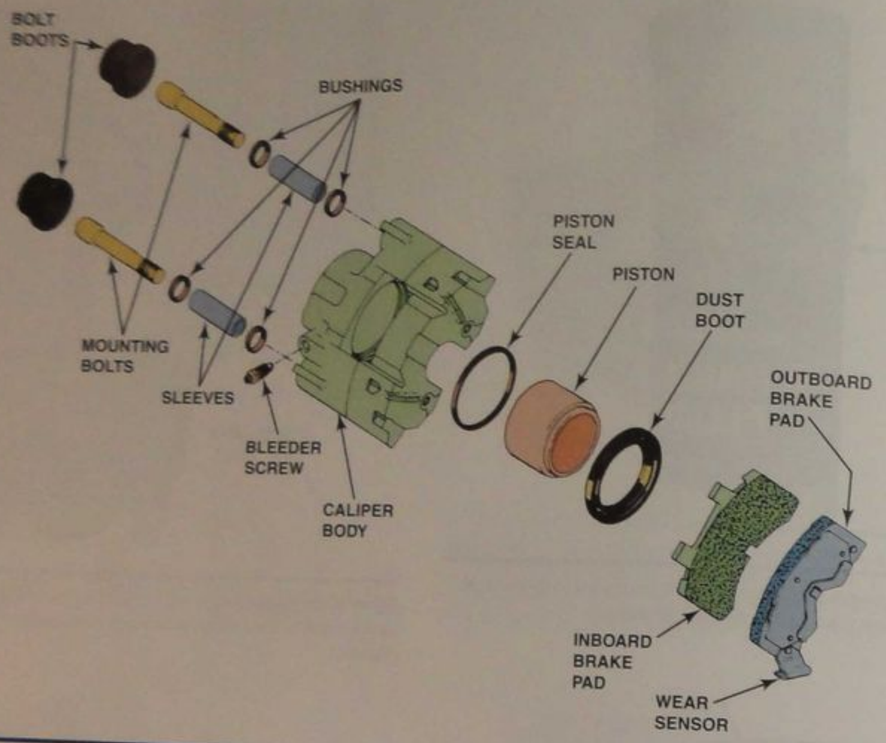


Figure 77–23 All rubber bushings should be lubricated with silicone brake grease for proper operation.

between the caliper and the mounting. When this occurs, the caliper often rotates against the abutment when the brakes are first applied, making a loud "knocking" noise. If this occurs, the service technician can repair this type of wear two ways:

Method 1 Replace the entire steering knuckle or caliper mount. This is the recommended method and also the most expensive. Replacement caliper mounts or knuckles may also be difficult to locate.

Method 2 Some aftermarket brake supply companies offer "abutment repair kits" that include oversize slides.

ROTATING PISTONS BACK INTO THE CALIPER

Many disc brake calipers used on the rear wheels require that the piston be rotated to reseat the pistons. When the parking brake is applied, the actuating screw moves the piston outward, forcing the pads against the disc brake rotor. The piston is kept from rotating because of an anti-rotation device or notches on the inboard pad and piston.

When the disc brake pads are being replaced, use a special tool to rotate the piston back into the brake calipers. Insert the tip of the tool in the holes or slots in the piston. Exert inward pressure while turning the piston. Make sure that the piston is retracting into the caliper and continue to turn the piston until it bottoms out.

NOTE: Some pistons are activated with left-handed threads.

After replacing the pads back into the caliper, check that the clearance does not exceed 1/16 in. (1.5 mm) from the rotor. Clearance greater than 1/16 in. may allow the adjuster to be pulled out of the piston when the service brake is applied. If the clearance is greater than 1/16 in., readjust by rotating the piston outward to reduce the clearance. See Figure 77–29.

Test-Drive after Brake Replacement After installing replacement disc brake pads or any other brake work, depress the brake pedal several times before driving the vehicle. This is a very important step! New brake pads are installed with the caliper piston pushed all the way into the caliper. The first few brake pedal applications usually result in the brake pedal going all the way to the floor. The brake pedal must be depressed ("pumped") several times before enough brake fluid can be moved from the master cylinder into the calipers to move the piston tight against the pads and the pads against the rotors.

SAFETY TIP **Always Double-Check Your Work**

Whenever reassembling brakes, it is easy to twist the flexible brake hose as shown in Figure 77–30.

To prevent possible brake hose failure and possibly an accident, always double-check that the ribs on the brake hose are straight. The ribs allow the service technician to easily spot if the hose has been twisted.

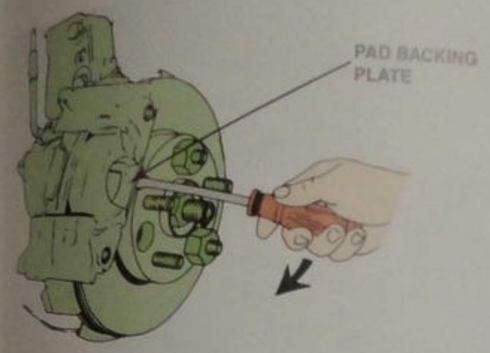


Figure 77–24 (a) Using a screwdriver to force the outboard pad into proper position before bending the retaining tabs. (b) Use two hammers to bend the tab where it extends through the hole in the caliper body.

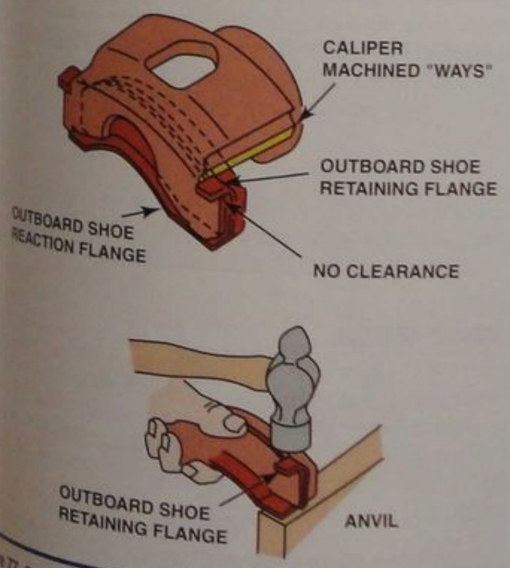


Figure 77–25 Often, a hammer is necessary to bend the retainer flange to make certain that the pads fit tightly to the caliper. If the pads are loose, a "click" may be heard every time the brakes are depressed. This click occurs when the pad(s) move and then hit the caliper or caliper mount. If the pads are loose, a clicking noise may be heard while driving over rough road surfaces.

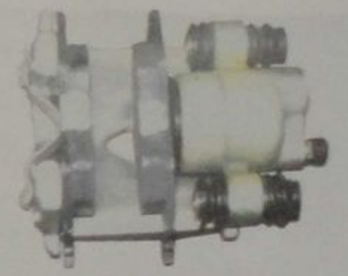


Figure 77–26 A loaded caliper includes all hardware and shims with the correct pads all in one convenient package, ready to install on the vehicle.

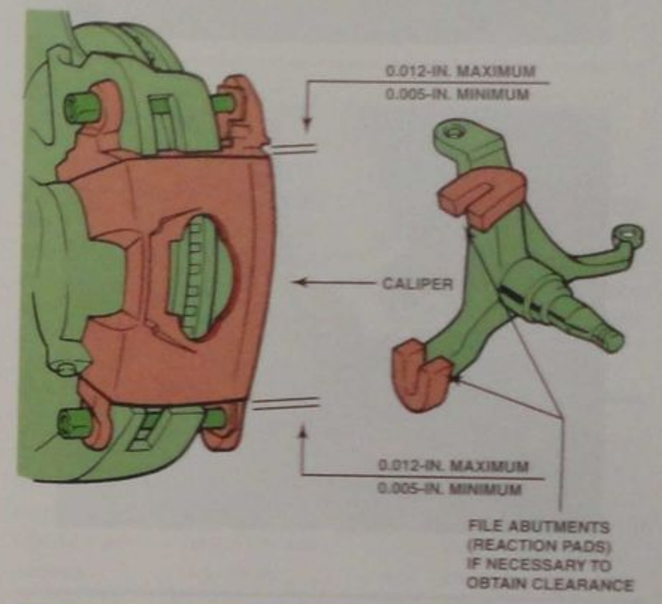


Figure 77–27 Floating calipers must be able to slide during normal operation. Therefore, there must be clearance between the caliper and the caliper mounting pads (abutments). Too little clearance will prevent the caliper from sliding and too much clearance will cause the caliper to make a clunking noise when the brakes are applied.

CAUTION: Never allow a customer to be the first to test-drive the vehicle after brake work has been performed.

Bedding-In Replacement Brake Pads Some manufacturers recommend that their replacement brake pads be **bedded-in** or **burnished** before returning the vehicle to the owner. This break-in process varies with the manufacturer, but usually involves stopping the vehicle from 30 mph (48 km/h) up to 30 times, allowing the brakes to cool 2 to 3 minutes between stops. This break-in procedure helps the replacement pads to conform to the rotor and helps cure the resins used in the manufacture of the pads. Failure to properly break in new pads according to the manufacturer's recommended procedure could result in a hard brake pedal complaint from the driver and/or reduced braking effectiveness.

Even if the brake pad manufacturer does not recommend a break-in procedure, high-speed stops and overheating of the brakes



(a)



(b)

Figure 77–28 (a) Using an air-powered sanding disc to clean the caliper mount pads. (b) Applying silicone brake grease to the slides assures proper caliper operation.

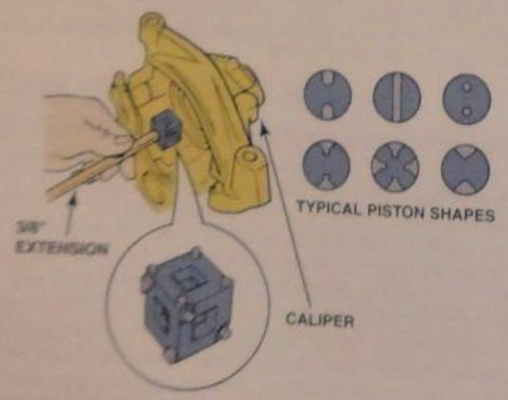


Figure 77–29 Determine which face of the special tool best fits the holes or slots in the piston. Sometimes needle-nose pliers can be used to rotate the piston back into the caliper bore.



Figure 77–30 Note the twisted flexible brake line. This can cause brake hose failure if not corrected.

should be avoided as much as possible during the first 50 to 100 stops.

TECH TIP ✓ **Foot Power Is Stronger than Air Pressure**

Many times, a caliper piston becomes so stuck that normal shop air pressure is not powerful enough to pop the piston out of a caliper. Hydraulic pressure using the service brake pedal is often able to easily remove even the most corroded caliper piston.

If compressed air has been tried with the caliper off the vehicle, reattach the caliper to the brake line. Bleed the brakes by opening the bleeder valve as normal to rid the caliper of any trapped air. Use a wood board or shop rag in front of the caliper piston and apply the brake. Pump the brake pedal as necessary to force the piston out.

CAUTION: Pump the brake pedal *slowly*. The piston normally will be gently pushed from the caliper. If the pedal is pushed hard, the caliper piston could be forced out of the caliper bore with tremendous force. Position the caliper so that no damage will be done when the piston does pop free.

Some technicians will not try to overhaul a caliper, but simply replace it, if compressed air pressure will not remove the piston.

DISC BRAKE SQUEAL

Causes Disc brakes tend to create brake noise (squeal). The cause and correction of brake noise is a major concern for both the vehicle manufacturers and the service technicians. The greatest customer complaint about brake work involves brake noise. Noise is caused by moving air, which is moved by movement of the brake components.

Correcting Disc Brake Squeal Brake squeal can best be *prevented* by careful attention to details whenever servicing any disc brake. Some of these precautions include the following.

Keeping the Disc Brake Pads Clean Grease on brake lining material causes the friction surface to be uneven. When the brakes are applied, this uneven brake surface causes the brake components to move.

TECH TIP ✓ **Increasing Pad Life**

Some vehicles seem to wear out front disc brakes more often than normal. Stop-and-go city-type driving is often the cause. Driving style, such as rapid acceleration, also causes a lot of wear to occur.

The service technician can take some actions to increase brake pad life. These steps are easier than having to cure the driver's habits. These steps include the following:

1. Make sure the rear brakes are properly adjusted and working correctly. If the rear brakes are not functioning, all of the braking is accomplished by the front brakes alone.

NOTE: Remind the driver to apply the parking brake regularly to help maintain proper rear brake clearance on the rear brakes.

2. Use factory brake pads or premium brake pads from a known manufacturer. Tests performed by vehicle manufacturers show that many aftermarket replacement brake pads fail to deliver original equipment brake pad life.

Factory-Type Clips and Antisqueal Shims The vehicle manufacturer has designed the braking system to be as quiet as possible. To assure that the brakes are restored to like-new performance, all of the original hardware should be used. Many original equipment brake pads use **constrained layer shims (CLS)** on the back of the brake pads. These shims are constructed with dampening material between two layers of steel. See Figure 77–31.

NOTE: Many aftermarket disc brake pads do *not* include replacement hardware that usually includes noise-reducing shims and clips. One of the advantages of purchasing original equipment (OE) disc brake pads is that they usually come equipped with all necessary shims and often with special grease that is recommended to be used on metal shims.



Figure 77–31 For best braking performance, purchase replacement disc brake pads that include all clips and shims specified by the vehicle manufacturer. Some pads even come with a package of the specified grease to use on the shims to reduce the possibility of brake noise.

Lubricate All Caliper Slide Points as per Manufacturer's Recommendation Lubrication of moving or sliding components prevents noise from being generated as the parts move over each other. Many vehicle manufacturers recommend one or more of the following greases:

1. **Lithium-based brake grease**
2. **Silicone grease**
3. **Molybdenum disulfide (MOS_2) grease** ("Molykote") often referred to as "moly" grease
4. **Synthetic grease** (usually **polyalphaolefin [PAO]**) sometimes mixed with graphite, Teflon, and/or MOS_2
5. **Antiseize compound**

The grease should be applied on both sides of shims used between the pad and the caliper piston.

CAUTION: Grease should only be applied to the nonfriction (steel) side of the disc brake pads.

Machine the Brake Rotor as Little as Possible and with the Correct Surface Finish Machining the brake rotor reduces its thickness. A thinner rotor will vibrate at a different frequency than a thicker rotor. See Chapter 79 for details on rotor machining and surface finish. Factors that can help or hurt brake squeal are referenced in the following chart.

Factor	Increase Noise	Reduce Noise
brake pad thickness	thinner (worn) pads	thicker (new) pads
rotor (disc) thickness	thinner (worn) rotor	thicker (new) rotor
brake pad material	harder	softer
lubrication of parts	dry—not lubricated	properly lubricated
dampening	no dampening	dampening material behind the pads
pad mounting	pad tabs not bent over	pad tabs securely crimped
antirattle clips	worn, defective, or not lubricated	new and properly lubricated

Vehicle manufacturers also change brake pad (lining) composition and the shape of the pads to help eliminate brake noise. The change of shape changes the frequency of the sound. Noise is vibration, but much of the vibration generated is not heard because the noise is beyond the normal frequency to be heard. Most people can hear from 20 to 20,000 cycles per second (called hertz). To stop brake noise, the manufacturer can change the frequency of the vibration to above or below the hertz range that can be heard. See Figure 77–32.

NOTE: All metal-to-metal contacts *must* be lubricated to help prevent brake noise.

DISC BRAKE SYMPTOM GUIDE

Pulls to One Side during Braking Possible causes of this include the following:

1. Incorrect or unequal tire pressures
2. Front end out of alignment
3. Unmatched tires on the same axle
4. Restricted brake lines or hoses
5. Stuck or seized caliper or caliper piston

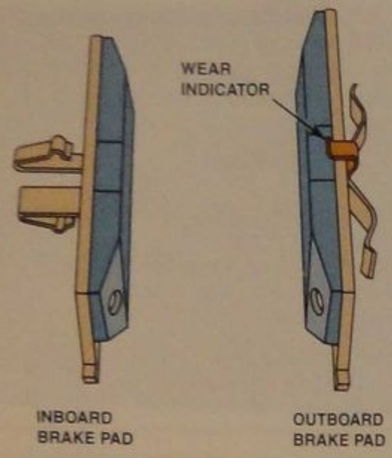


Figure 77–32 Notice the beveled pads. The shape of the pad helps determine the frequency of any vibration in the brakes.

6. Defective or damaged shoe and lining (grease or brake fluid on the lining, or a bent shoe)
7. Malfunctioning rear brakes
8. Loose suspension parts
9. Loose calipers

TECH TIP ✔ **The Screwdriver Trick**

A low brake pedal on GM vehicles equipped with rear disc brakes is a common customer complaint. Often the reason is a lack of self-adjustment that *should* occur whenever the brake pedal (or parking brake) is released. During brake release, the pressure is removed from the caliper piston and the spring inside the caliper piston is free to adjust. Often this self-adjustment does not occur and a low brake pedal results.

A common trick that is used on the vehicle assembly line is to use a screwdriver to hold the piston against the rotor while an assistant releases the brake pedal. See Figure 77–33.

As the brake pedal is released, the adjusting screw inside the caliper piston is free to move. Sometimes, it may be necessary to tap on the caliper itself with a dead-blow hammer to free the adjusting screw. Repeat the process as necessary until the proper brake pedal height returns. If this method does not work, replace the caliper assembly.

In summary, recall these steps.

Step #1 Have an assistant depress the brake pedal.

Step #2 Using a screwdriver through the hole in the top of the caliper, hold the piston against the rotor.

NOTE: Be careful not to damage the dust boot.

Step #3 While still holding the piston against the rotor, have the assistant release the brake pedal. The adjusting screw adjusts when the brake pedal is released and a slight vibration or sound will be noticed as the brake is released. This vibration or sound is created by the self-adjusting mechanism inside the caliper piston taking up the excess clearance.

Step #4 Repeat as necessary until normal brake pedal height is achieved.

Brake Roughness or Chatter (Pedal Pulsates) Possible causes of this include the following:

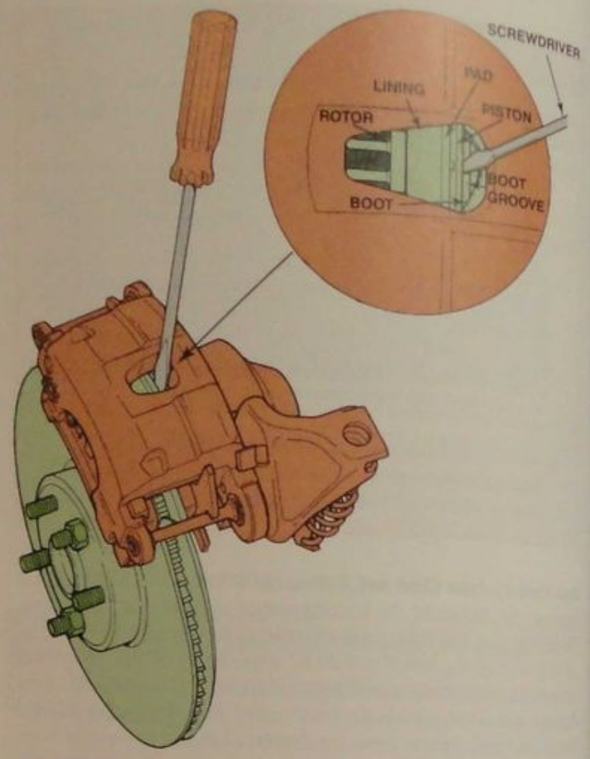


Figure 77–33 The screwdriver blade is used to keep the piston applied to allow self-adjustment to occur when the brake pedal is released.

1. Excessive lateral runout of rotor
2. Parallelism of the rotor not within specifications
3. Wheel bearings not adjusted correctly
4. Rear drums out-of-round
5. Brake pads worn to metal backing plate

Excessive Pedal Effort Possible causes of this include the following:

1. Binding or seized caliper suspension
2. Binding brake pedal mechanism
3. Improper rotor surface finish
4. Malfunctioning power brake
5. Partial system failure
6. Excessively worn shoe and lining
7. Piston in the caliper stuck or sluggish
8. Fading brakes due to incorrect lining

Excessive Pedal Travel Possible causes of this include the following:

1. Partial brake system failure
2. Insufficient fluid in the master cylinder
3. Air trapped in the system
4. Bent shoe and lining
5. Excessive pedal effort
6. Excessive parking brake travel (four-wheel disc brakes, except Corvette)

Dragging Brakes Possible causes of this include the following:

1. Pressure trapped in the brake lines (to diagnose, momentarily open the caliper bleeder valve to relieve the pressure)

2. Restricted brake tubes or hoses
3. Improperly lubricated caliper suspension system
4. Improper clearance between the caliper and torque abutment surfaces
5. Check valve installed in the outlet of the master cylinder to the disc brakes

Front Disc Brakes Very Sensitive to Light Brake Applications Possible causes of this include the following:

1. Metering valve not holding off the front brake application
2. Incorrect lining material
3. Improper rotor surface finish
4. Check other causes listed under "PULLS"

Rear Drum Brakes Skidding under Hard Brake Applications Possible causes of this include the following:

1. Proportioning valve
2. Contaminated rear brake lining
3. Caliper or caliper piston stuck or corroded

TECH TIP ✔ **Pressure Testing Can Help Find Problems**

A stick caliper or caliper slide is often difficult to see or diagnose as a problem because the movement of the broken pads is so little. Using a pressure gauge between the caliper piston and the rotor (inboard) or between the rotor and the caliper (outboard) can tell the service technician if there is a difference between the left and the right side brakes. See Figure 77–34.



(a)

(b)

Figure 77–34 (a) A brake pressure tester. (b) The small "pads" can be placed between the caliper piston and the rotor to check for applied pressure and inserted between the caliper and the rotor on the outside of the rotor to test the pressure—the pressure should be the same if the caliper is able to slide on its pins or slides.

PHOTO SEQUENCE Disc Brake Service Step-by-Step



P77–1 After properly setting the hoist pads under the vehicle, raise the vehicle to chest level and remove the lug nuts.



P77–2 Remove the wheel/tire assembly and place it where it will not get in the way or be damaged.



P77–3 It is recommended that the entire brake assembly be washed using a commercially available cleaner to avoid the possibility of allowing brake dust from becoming airborne.



P77–4 If a commercial brake cleaning unit is not available, use brake cleaner from an aerosol or pressurized container.



P77–5 To service the front disc brake pads on this vehicle, loosen the upper caliper retainer bolt and remove the lower bolt.



P77–6 After the lower caliper bolt has been removed, the caliper assembly can be lifted upward by pivoting on the upper retaining bolt.

(continued)

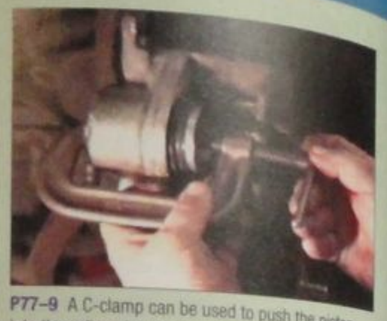
PHOTO SEQUENCE Disc Brake Service Step-by-Step—continued



P77–7 Use mechanic's wire to hold the caliper in the raised position to allow access to the disc brake pads.



P77–8 Notice that both the inboard and outboard pad remain attached to the steering knuckle. The pads and shims can be lifted off.



P77–9 A C-clamp can be used to push the piston into the caliper, but be sure to open the bleeder valve first.



P77–10 The bleeder valve should be opened to allow the old brake fluid to flow out of the caliper and not be forced up into the ABS hydraulic unit or master cylinder.



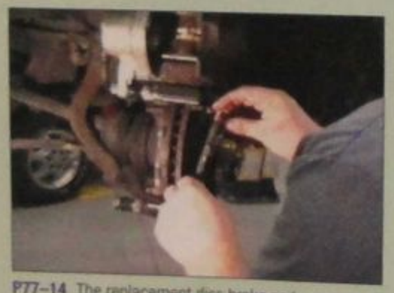
P77–11 Often factory replacement disc brake pads include noise-dampening shims, antirattle clips, and special "moly" disc brake grease that is to be used on the shims.



P77–12 All hardware, including this anchor shim, should be replaced.



P77–13 Install new shims after thoroughly cleaning the steering knuckle area of any rust using a wire brush or other suitable tool.



P77–14 The replacement disc brake pads are installed next to the rotor and held in place by the tension of the anchor shims.



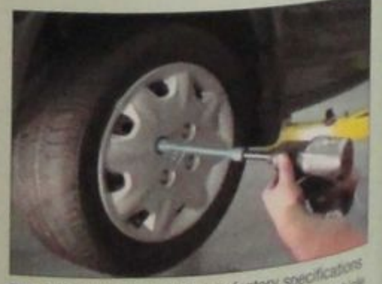
P77–15 After double-checking that all shims, clips, and spacers are correctly installed, lower the calipers and install this lower attaching bolt.



P77–16 Torque the retaining bolts to factory specifications. Repeat the process on the other side and bleed the hydraulic system.



P77–17 Reinstall the wheel/tire assembly.



P77–18 Torque the lug nuts to factory specifications or use a torque-limiting adapter. Test drive the vehicle before returning it to the customer.

SUMMARY

1. Caliper pistons are either chrome-plated steel or plastic (phenolic). Any damaged piston must be replaced. Both the square-cut O-ring and the dust boot must be replaced when the caliper is disassembled.
2. All metal-to-metal contact points of the disc brake assembly should be coated with an approved brake lubricant such as synthetic grease, "moly" (molybdenum disulfide) grease, or antiseize compound.
3. After a brake overhaul, the brake pedal should be depressed several times until a normal brake pedal is achieved before performing a thorough test-drive.
4. Many rear disc brake systems use an integral parking brake. Regular use of the parking brake helps maintain proper rear brake clearance.

REVIEW QUESTIONS

1. List what parts are included in a typical overhaul kit for a single-piston floating caliper.
2. Describe how to remove caliper pistons and perform a caliper overhaul.
3. Explain what causes disc brake squeal and list what a technician can do to reduce or eliminate the noise.

CHAPTER QUIZ

1. Uneven disc brake pad wear is being discussed. Technician A says the caliper piston may be stuck. Technician B says the caliper may be stuck on the slides and unable to "float." Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. A "chirping" noise is heard while the vehicle is moving forward, but stops when the brakes are applied. Technician A says that the noise is likely caused by the disc brake pad wear sensors. Technician B says the noise is likely a wheel bearing because the noise stops when the brakes are applied. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that disc brake pads should be replaced when worn to the thickness of the steel backing. Technician B says the pads should be removed and inspected whenever there is a brake performance complaint. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. A typical disc brake caliper overhaul (OH) kit usually includes what parts?
   a. Square-cut O-ring seal and dust boot
   b. Replacement caliper piston and dust boot
   c. Dust boot, return spring, and caliper seal
   d. Disc brake pad clips, dust boot, and caliper piston assembly
5. Technician A says that a lack of lubrication on the back of the disc brake pads can cause brake noise. Technician B says that pads that are not correctly crimped to the caliper housing can cause brake noise. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Two technicians are discussing ways of removing a caliper piston. Technician A says to use compressed air. Technician B says to use large pliers. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Which is *not* a recommended type of grease to use on brake parts?
   a. Silicone grease
   b. Wheel bearing (chassis) grease
   c. Synthetic grease
   d. Antiseize compound
8. Technician A says that many rear disc brake caliper pistons must be turned to retract before installing replacement pads. Technician B says that some vehicles equipped with rear disc brakes use a small drum brake as the parking brake. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A vehicle is hoisted during routine service and the service technician discovers that the left front wheel does not turn when force is applied. Technician A says that the hoist (lift) pads could be against the left front tire. Technician B says that the disc brake caliper piston stuck in the bore is the most likely cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Technician A says that a steel piston should be cleaned with sandpaper to remove rust. Technician B says that the brake assembly fluid or clean brake fluid should be used to lubricate the caliper pistons before installing in the caliper. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 78

Parking Brake Operation, Diagnosis, and Service

OBJECTIVES: After studying Chapter 78, the reader will be able to: Prepare for ASE Brakes (A5) certification test content area "E" (Miscellaneous Systems Diagnosis and Repair). • Describe what is required of a parking brake. • Describe the parts and operation of the parking brake as used on a rear drum brake system. • Describe how a parking brake functions when the vehicle is equipped with rear disc brakes. • Explain how to adjust a parking brake properly.

KEY TERMS: application cables • control cables • electric parking brake (EPB) • equalizer • intermediate lever • red brake warning lamp • vacuum servo

PARKING BRAKE

Before 1967, most vehicles had only a single master cylinder operating all four brakes. If the fluid leaked at just one wheel, the operation of all brakes was lost. This required the use of a separate method to stop the vehicle in case of an emergency. This alternative method required that a separate mechanical method be used to stop the vehicle using two of the four wheel brakes. After 1967, federal regulations required the use of dual or tandem master cylinders where half of the braking system has its own separate hydraulic system. In case one-half of the system fails, a dash brake warning lamp lets the driver know that a failure has occurred. The term *parking brake* has replaced the term *emergency brake* since the change to dual master cylinder design.

According to Federal Motor Vehicle Safety Standard (FMVSS) 135, the parking brake must hold a fully loaded (laden) vehicle stationary on a slope of 20% up or down grade. The hand force required cannot exceed 80 lb. (18 N) or a foot force greater than 100 lb. (22 N). See Figure 78–1 for a typical parking brake system.

PEDALS, LEVERS, AND HANDLES

Parking brakes are applied by a pedal, a lever, or a handle from inside the vehicle. Foot pedals and floor-mounted levers are the most common means of applying parking brakes. See Figures 78–2 and 78–3.

All parking brake controls incorporate a *ratchet* mechanism to lock the brake in the applied position. See Figure 78–4.

When service brake friction assemblies are used as the parking brakes, the service brake pedal should be depressed while the parking brake control is set. Applying the service brake increases parking brake holding power because the brake hydraulic system provides the actual application force, which is far greater than the force that can be developed mechanically. The parking brake mechanism simply locks the brakes in position. If the parking brake is operated only by the pedal, lever, or handle, holding power will be reduced, and the cables in the linkage will tend to stretch.

All parking brakes are applied manually and the release procedure varies with the design of the parking brake control.

Parking Brake Pedals A parking brake pedal is applied by depressing it with a foot. The ratchet engages automatically and the pedal remains in the depressed position. The pedal is released by a pull or a small T-handle or lever under the dash. This disengages the ratchet mechanism, and allows a return spring to move the pedal to the unapplied position. On some vehicles, the release lever is integrated into the underside of the dash and connects to the release mechanism through a rod or cable. See Figure 78–5.

Some vehicles were equipped with a special pedal design that enabled them to meet federal regulations on parking brake holding power while keeping maximum pedal application force within legal limits. This type of pedal had a high leverage ratio and a special ratchet mechanism that locked the brake pedal in the applied position, but allowed the pedal to return after it had been depressed. Two full pedal strokes, or several partial strokes, were required to fully apply the parking brake. The brake was released by a single pull on a T-handle or release lever.

Some vehicles were equipped with a system that required the driver to depress the parking brake pedal to release the parking brake once it was set. The rubber pad on the parking brake pedal usually states "push to release."

Automatic Parking Brake Release Some vehicles with pedal-operated parking brakes have an automatic release mechanism that disengages the parking brake using a **vacuum servo** controlled by an electrical solenoid. See Figure 78–6.

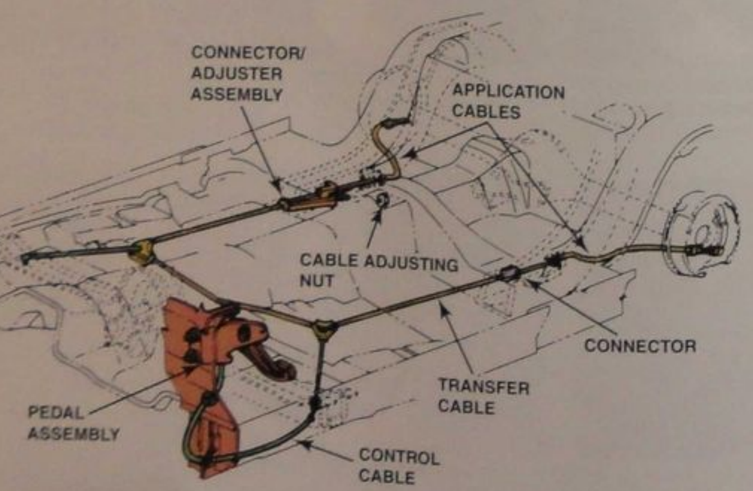


Figure 78–1 Typical parking brake cable system showing the foot-operated parking brake lever and cable routing.

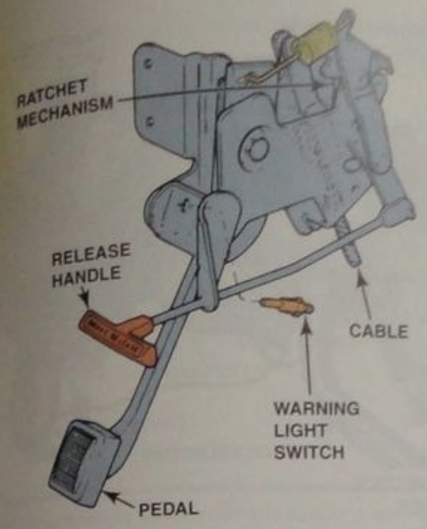


Figure 78–2 A typical parking brake pedal assembly.

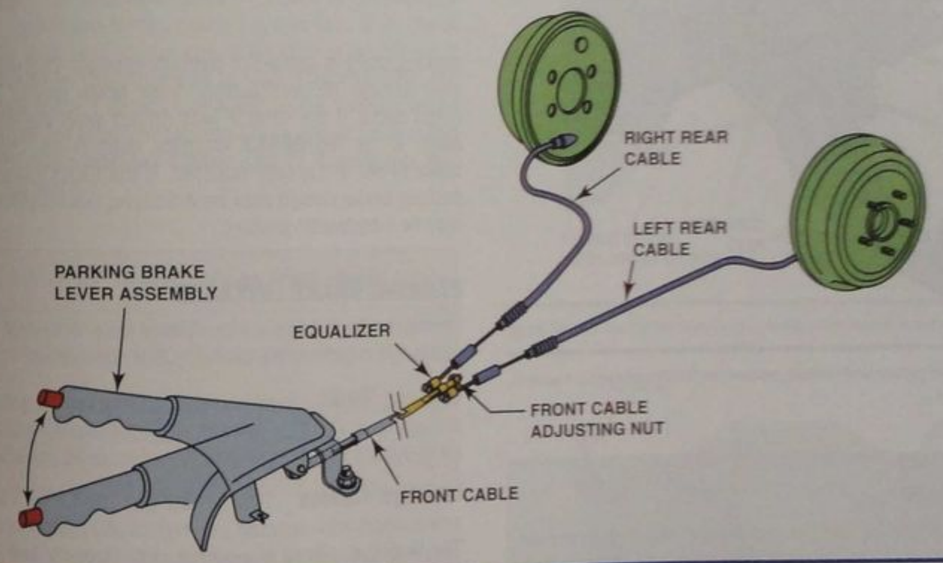


Figure 78–3 Typical hand-operated parking brake. Note that the adjustment for the cable is underneath the vehicle at the equalizer.

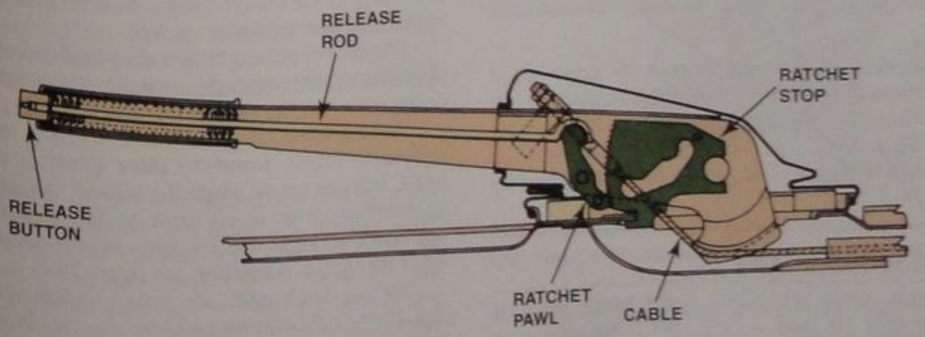


Figure 78–4 A ratchet mechanism is used to lock parking brakes in the applied position.

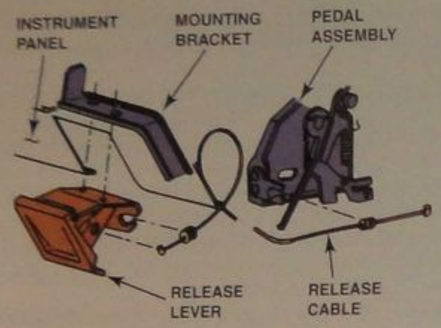


Figure 78–5 A remote-mounted parking brake release lever.

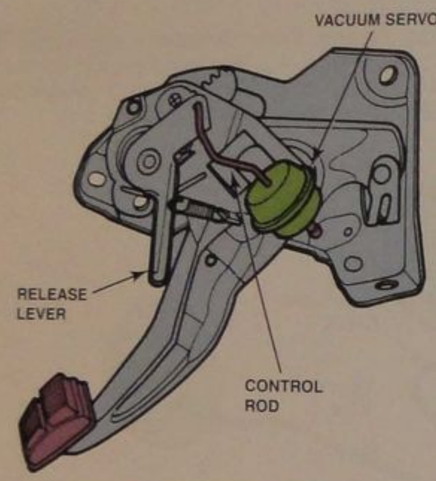


Figure 78–6 Automatic parking brake release mechanisms usually use a vacuum servo to operate the release lever.

REAL WORLD FIX **Pump to Release?**

A customer called and asked a dealer for help because the parking brake could not be released. The service technician discovered that the customer was attempting to release the parking brake by depressing the parking brake pedal, as was done on the customer's previous vehicle. The service technician simply pulled on the release lever and the parking brake was released.

A metal rod connects the vacuum servo to the upper end of the parking brake release lever. When the engine is running (to provide vacuum) and the shifter is placed in gear, an electrical contact closes to energize the solenoid and route vacuum to the servo. The servo diaphragm then retracts the rod, which releases the parking brake. See Figure 78–7.

PARKING BRAKE WARNING LAMP

Whenever the parking brake is engaged, a **red brake warning lamp** lights on the dash. On most vehicles, this is the same lamp that lights when there is a hydraulic or brake fluid level problem. The warning lamp for the parking brake warns the driver that the parking brake is applied or partially applied. This warning helps prevent damage or overheating to the brake drums and linings that could occur if the vehicle was driven with the parking brake applied. If the red BRAKE warning lamp is on, check the parking brake to see if it is fully released. If the BRAKE lamp is still on, the parking brake switch may be defective, out of adjustment, or there may be a hydraulic problem.

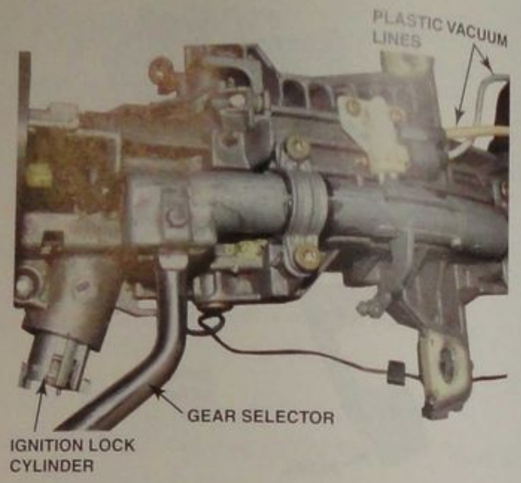


Figure 78–7 The two plastic vacuum tubes on the steering column are used to release the parking brake when the gear selector is moved from park into a drive gear.

PARKING BRAKE LINKAGES

Parking brake linkages transmit force from the pedal, lever, or handle inside the vehicle to the brake friction assemblies.

Linkage Rods Parking brake linkage rods made from solid steel are commonly used with floor-mounted actuating levers to span the short distance to an intermediate lever or an equalizer.

Linkage Cables The typical parking brake cable is made of woven-steel wire encased in a reinforced rubber or plastic housing. The housing is fixed in position at both ends, and is routed under the vehicle through mounting brackets that hold the cable in position, yet allow a small amount of movement. The cable slides back and forth inside the housing to transmit application force, and depending on the linkage design, the outer housing may play a part in parking brake application as well.

The ends of parking brake cables are fitted with a wide variety of connectors that attach to actuating devices, other linkage parts, or the wheel friction assemblies.

Parking brake linkages use control cables, transfer cables, and application cables. **Control cables** attach to the parking brake pedal, lever, or handle inside the vehicle, and transmit force to an intermediate lever or equalizer to the application cables. The **application cables** use the force passed through the linkage to apply the friction assemblies. See Figure 78–8.

Parking brake cables are subject to damage from water, dirt, and other debris thrown up under the vehicle by the tires. Most parking brake cables do not require lubrication because they are lined with nylon or Teflon, and any cable housing ends located under the vehicle are protected by rubber or nylon seals.

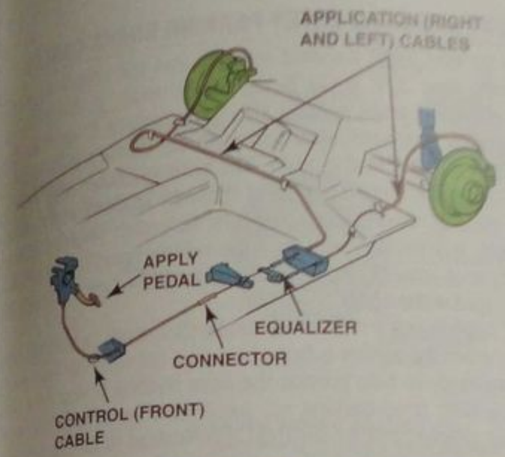


Figure 78–8 The cable from the activating lever to the equalizer is commonly called the control cable. From the equalizer, the individual brake cables are often called application cables. These individual cables can usually be purchased separately.

Linkage Levers The rods and cables described in the previous section transmit application force in direct proportion. If 50 lbs of application force is delivered to one end of a rod or cable, 50 lbs of force will be available at the other end as well. Unfortunately, the amount of physical force a driver can apply to the parking brake pedal is insufficient for effective parking brake operation. For this reason, all parking brake linkages contain one or more levers that increase application force.

TECH TIP **Look for Swollen Parking Brake Cables**

Always inspect parking brake cables for proper operation. A cable that is larger in diameter in one section indicates that it is rusting inside and has swollen. See Figure 78–9.

A rusting parking brake cable can keep the rear brake applied even though the parking brake lever has been released. This can cause dragging brakes, reduced fuel economy, and possible vehicle damage due to overheated brakes.

The parking brake pedals, floor-mounted levers, and pivoting under-dash handles described earlier are all types of levers used to increase parking brake application force. Straight-pull parking brake handles are not levers themselves, although they are commonly connected to other levers in the linkage.

A lever in the parking brake linkage under the vehicle is called an **intermediate lever.** See Figure 78–10.

To further increase parking brake application force, intermediate levers provide leverage in addition to that supplied by the parking brake control.

Linkage Equalizers In some parking brake linkages, the rods or cables to the two friction assemblies are adjusted separately. If the adjustments are unequal, one brake will apply before the other, preventing full lining-to-drum contact at the opposite wheel and greatly reducing the holding power of the parking brake. To prevent unequal application, most parking brake systems use an **equalizer** to balance the force from the parking brake control, and transmit an equal amount to each friction assembly.



Figure 78–9 Notice how rust inside the covering of this parking brake cable has caused the cable to swell.

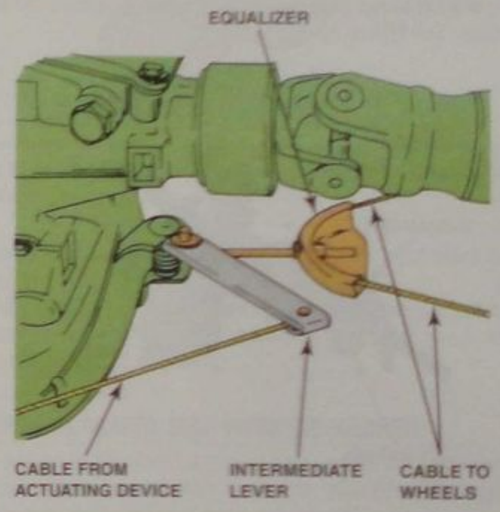


Figure 78–10 Intermediate levers in the parking brake linkage increase the application force.

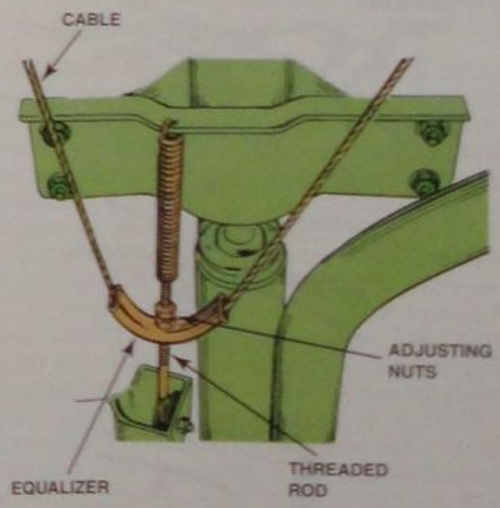


Figure 78–11 A cable guide is a common type of parking brake linkage equalizer.

Equalizers come in many shapes and sizes, but the simplest is the cable guide attached to a threaded rod. See Figure 78–11. This type of equalizer pivots or allows the inner cable to slide back and forth to even out application force.

Another type of equalizer installs in a long application cable that runs from the linkage at the front of the vehicle to one rear brake. See Figure 78–12.

A short application cable is routed from the equalizer to the other rear brake. When the parking brake is applied, the long cable actuates its brake directly. Once the shoes make contact with the drum, however, the inner cable cannot move any farther so the entire cable assembly, along with the equalizer, is pulled toward the front of the vehicle. Movement of the equalizer then applies the other rear brake through the short cable.

Linkage Design The number of different parking brake linkage designs is almost as great as the number of vehicle models on the road. Most linkages combine intermediate levers and equalizers in various ways and use from one to four cables to actuate the friction assemblies. See Figure 78–13.

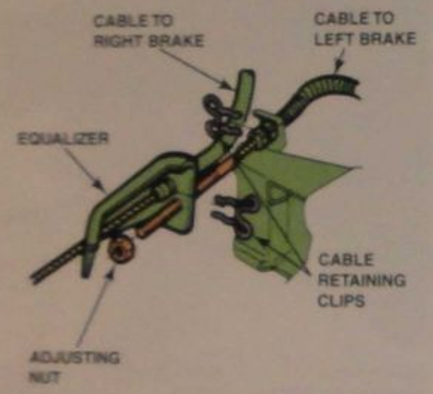


Figure 78–12 Some parking brake equalizers are installed in the brake cable.

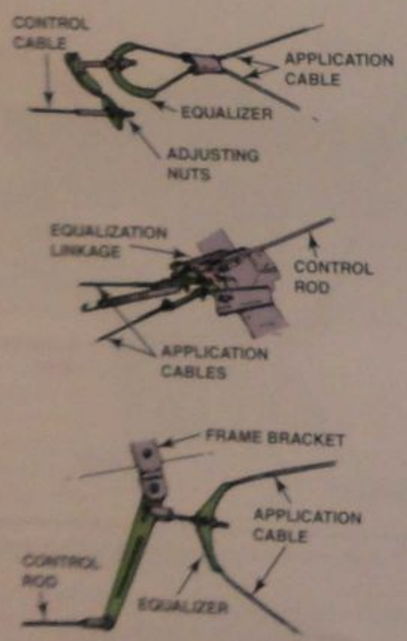


Figure 78–13 Many parking brake linkages use both an intermediate lever and an equalizer.

FRONT AND REAR ENTRY PARKING BRAKE CABLES

The parking brake standard requires that the vehicle be held stationary on a 20% grade facing either uphill or downhill. Many drum parking brake systems attach the parking brake lever on the secondary (rearward) shoe and push the primary (forward facing) brake shoe against the drum. The parking brake cable enters the backing plate from the front of the vehicle (front entry). Because the primary shoe is attached to the secondary shoe on dual-servo brakes, any forward motion of the vehicle tends to wedge the primary shoe into the brake drum *and* force the rear secondary lining also against the drum.

Applying only the forward brake shoe tends to hold the vehicle best when the vehicle is being held on a hill with the front pointing downward. To help provide the same holding power for a vehicle being held from backing up, some vehicles reverse the parking brake arrangement for the right side. Instead of having the parking brake cable enter the backing plate from the front, this style has the cable entering from the rear (rear entry). In this case the right rear brake has the parking brake lever installed on the *primary* shoe.

NOTE: An easy way to remember how to reassemble a drum brake is to realize that the parking brake lever is usually attached to the secondary (rearward) brake shoe. The parking brake strut attaches between the shoes with the spring toward the front of the vehicle (remember, "spring forward").

DRUM PARKING BRAKES

Drum parking brakes are the most common types on vehicles and light trucks. Drum brakes make excellent parking brakes because they have a high static coefficient of friction combined with self-energizing action and, in the case of dual-servo brakes, servo action that increases their application force.

Integral Drum Parking Brakes Integral drum parking brakes mechanically apply the rear drum service brakes to serve as the parking brakes. See Figure 78–14.

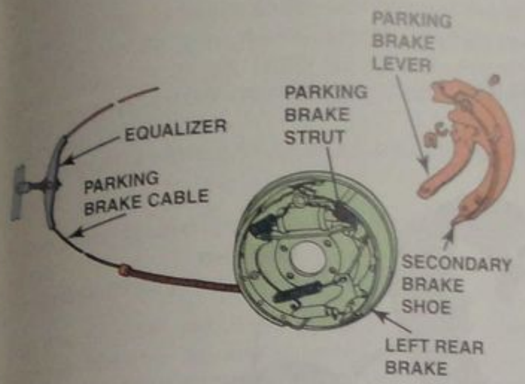
Integral drum parking brakes are the most common type not only because of their natural superiority in this application, but because it is simple and inexpensive to design a parking brake linkage into a drum brake.

The typical integral drum parking brake has a pivoting lever mounted on one brake shoe, and a strut placed between the lever and the other shoe. The strut may be fitted with a spring that takes up slack to prevent noise when the parking brake is not applied. The end of the lever opposite the pivot is moved by the parking brake cable, which enters through an opening in the backing plate. All integral drum parking brakes operate in essentially the same manner. See Figure 78–15.

When the parking brake control is operated, the cable pulls the end of the lever away from the shoe it is attached to. The lever pivots at the attaching point and moves the strut to apply the forward shoe. Once the forward brake shoe lining contacts the drum, the strut can travel no farther. The lever then pivots on the strut and forces the lining of the reverse shoe against the drum.

Rear Disc Auxiliary Drum Parking Brakes Rear disc service brakes with fixed calipers commonly have a parking brake drum formed into the hub of the brake rotor. See Figure 78–16.

Inside the drum is a small dual-servo drum brake friction assembly that serves as the parking brake. The rotor splash shield, or a special mounting bracket, provides the backing plate for the



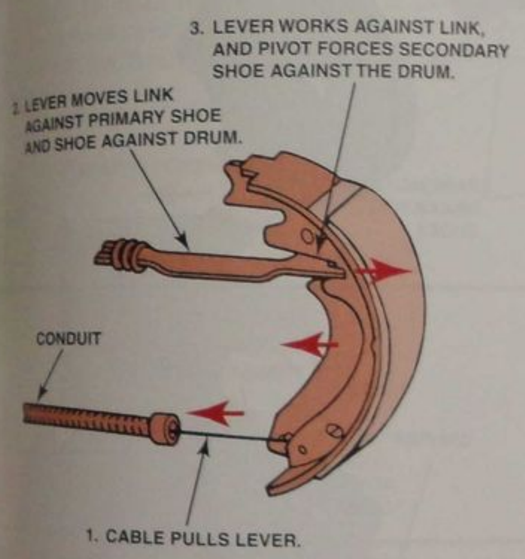


Figure 78–14 Notice the spring at the end of the parking brake strut. This antirattle spring puts tension on the strut. The parking brake lever is usually attached with a pin and spring washer and retained by a horseshoe clip.

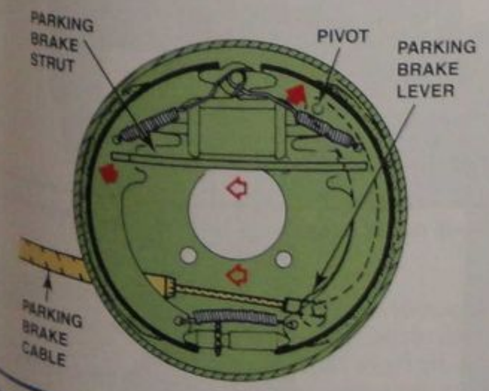


Figure 78–15 The parking brake cable pulls on the parking brake lever, which in turn forces the brake shoe against the drum.

assembly. Rear disc auxiliary drum parking brakes use the dual-servo friction assembly design because it provides the most stopping power, and does so equally in both forward and reverse directions. Dual-servo parking brake friction assemblies operate in essentially the same manner as service brakes except that the wheel

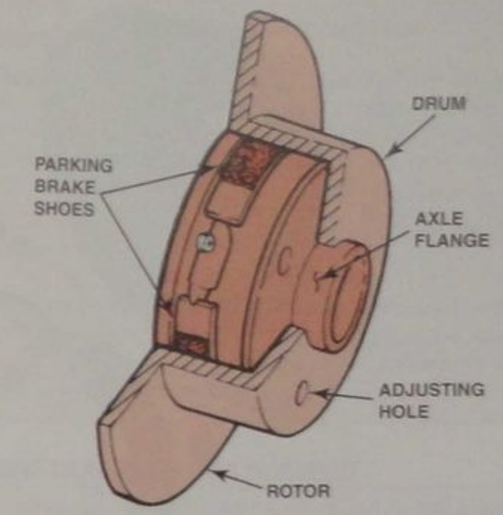


Figure 78–16 The inside "hat" of the disc brake rotor is the friction surface for the parking brake shoes.

cylinder is eliminated and the friction assembly is actuated mechanically. See Figure 78–17.

All rear disc auxiliary drum parking brakes are adjusted manually using a starwheel adjuster, which is reached through an opening in the outside of the drum.

CALIPER-ACTUATED DISC PARKING BRAKES

Caliper-actuated disc parking brakes are used on vehicles whose rear disc brakes are equipped with floating or sliding brake calipers. The single-piston construction of these calipers makes them easier to mechanically actuate than multiple-piston fixed calipers. In this design, a special mechanism in the caliper applies the caliper piston mechanically. The mechanism is operated by a parking brake cable attached to a lever that protrudes from the inboard side of the caliper.

Ball and Ramp Actuation The ball and ramp actuating system found in Ford rear brake calipers has three steel balls located in ramp-shaped detents between two plates. See Figure 78–18.

One plate has a thrust screw attached that is threaded into an adjuster mechanism in the caliper piston. The other plate is part of the operating shaft that extends out of the caliper. The actuating lever is mounted to the end of this shaft.

As the parking brake cable moves the lever and rotates the operating shaft, the balls ride up the ramps and force the two plates apart. The operating shaft plate cannot move because it butts against the caliper body. The thrust screw plate, which is pinned to the caliper body to prevent it from rotating, is driven away from the operating shaft and toward the rotor where the thrust screw moves the caliper piston to apply the brake. See Figure 78–19.

Adjustment of the ball and ramp linkage within the caliper is automatic, and takes place during service brake application. When the caliper piston moves away from the thrust screw, an adjuster nut inside the piston rotates on the thrust screw to take up any slack created by wear. See Figure 78–20.

A drive ring on the nut prevents it from rotating in the opposite direction when the parking brake is applied.

Screw, Nut, and Cone Actuation General Motors' rear disc parking brake uses a screw, nut, and cone mechanism to apply the caliper piston. See Figure 78–21.

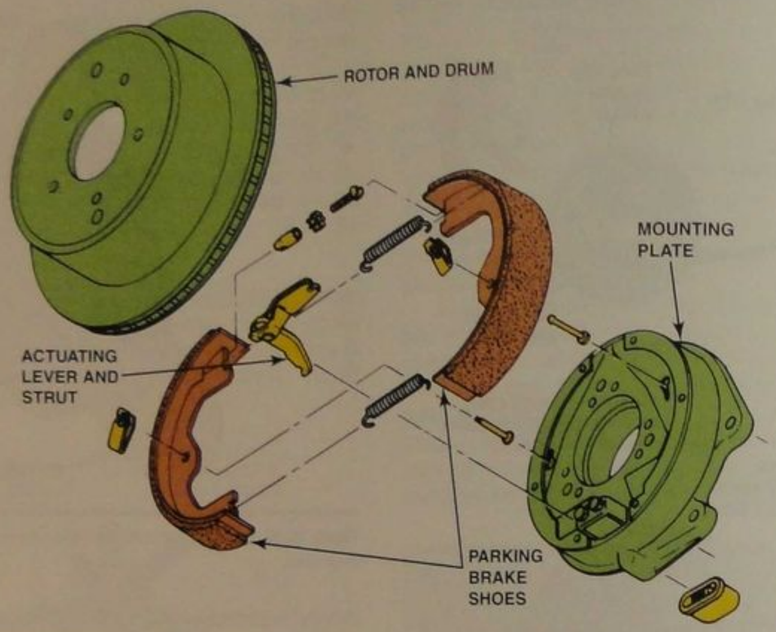


Figure 78–17 A typical rear disc brake auxiliary drum brake friction assembly.

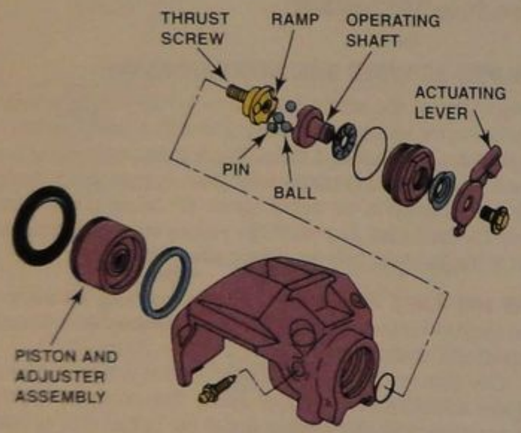


Figure 78–18 A Ford rear brake caliper ball and ramp-type apply mechanism.

In this design, the actuator screw with the parking brake lever attached extends through the caliper body. The caliper piston contains a specially shaped nut that threads onto the actuator screw when the piston is installed in the bore. The nut butts against the backside of the cone, and is splined to the cone so that it cannot rotate unless the cone does so as well. The cone is a slip fit in the piston, and is free to rotate unless it is held tightly against a clutch surface located near the outer end of the piston bore.

When the parking brake is applied, the cable moves the lever and rotates the actuator screw. See Figure 78–22.

The nut then unthreads along the screw, and jams the cone against the clutch surface of the caliper piston. This prevents the cone from rotating because the caliper piston is keyed to the brake pad, which is fixed in the caliper. Because the cone cannot rotate, movement of the nut along the actuator thread forces the cone and piston outward against the inboard pad to apply the brake.

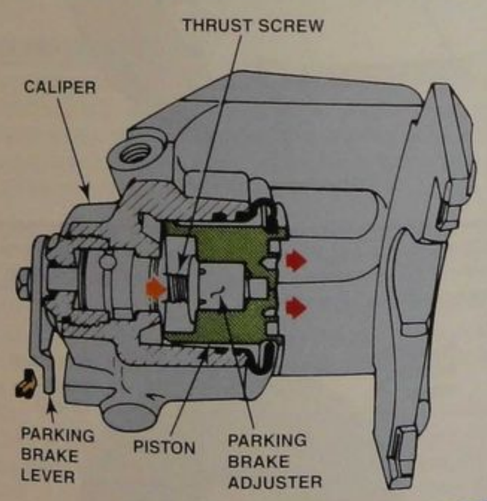


Figure 78–19 Operation of a ball and ramp-type rear disc brake caliper parking brake.

Adjustment of the screw, nut, and cone mechanism occurs automatically during normal operation as the service brakes are released. See Figure 78–23.

When the service brakes are applied, the cone and piston move outward in the bore under hydraulic pressure. The nut, however, remains fixed because the actuator screw does not rotate. As long as there is brake application pressure, the cone is held tightly against the clutch surface of the piston, which prevents the cone, and the nut splined to it, from rotating.

The result of the above actions is that a gap develops between the outer end of the nut and the backside of the cone when the brakes are applied. If sufficient brake lining wear has occurred, a gap remains after seal deflection retracts the piston and cone when the brakes are released. Once the brakes are released, the cone is

no longer held against the clutch surface, and becomes free to rotate on the piston. At this point, the adjuster spring, which exerts enough axial pressure on the nut, causes the nut and cone to unthread along the actuator screw and take up any clearance between the cone and piston.

The balance spring between the piston and the caliper bore has two purposes.

1. It prevents excessive piston retraction when the brakes are released.
2. It counterbalances the pressure of the adjuster spring.

Note that the outer end of the nut is in constant contact with the cone whenever the service brakes are not applied. If the automatic adjusting system fails, the tension of the adjustor spring against the thrust bearing at the back of the piston will retract the cone and piston from the rotor until the cone does contact the nut, resulting in a low brake pedal. See Figures 78–24 through 78–31.

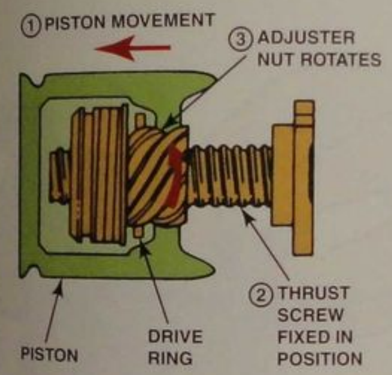


Figure 78–20 Automatic adjustment of a ball and ramp-type rear disc brake parking brake occurs when the service brakes are applied.

TECH TIP ✓ **The Parking Brake "Click" Test**

When diagnosing any brake problem, apply the parking brake and count the "clicks." This method works for both hand- and foot-operated parking brakes. Most vehicle manufacturers specify a maximum of 10 clicks. If the parking brake travel exceeds this amount, the rear brakes may be worn or out of adjustment.

CAUTION: Do not adjust the parking brake cable until the rear brakes have been thoroughly inspected and adjusted.

If the rear brake lining is usable, check for the proper operation of the self-adjustment mechanism. If the rear brakes are out of adjustment, the service brake pedal will also be low. This 10-click test is a fast and easy way to determine if the problem is due to rear brakes.

PARKING BRAKE CABLE ADJUSTMENT

Most manufacturers specify a minimum of 3 or 4, and a maximum of 8 to 10, clicks when applying the parking brake. Consult the service manual for the vehicle being serviced on the exact specification and adjustment procedures. Most vehicle manufacturers specify that the rear brakes be inspected and adjusted correctly before attempting to adjust the parking brake cable. Always follow the manufacturer's recommended procedure exactly.

Below is a general procedure for parking brake adjustment.

1. Make certain that the rear service brakes are adjusted correctly and the lining is serviceable.
2. With the drums installed, apply the parking brake 3 or 4 clicks. There should be a slight drag on both rear wheels.
3. Adjust the cable at the equalizer (equalizes one cable's force to both rear brakes) if necessary until there is a slight drag on both rear brakes. See Figures 78–32 and 78–33.
4. Release the parking brake. Both rear brakes should be free and not dragging. Repair or replace rusted cables or readjust as necessary to ensure that the brakes are not dragging.

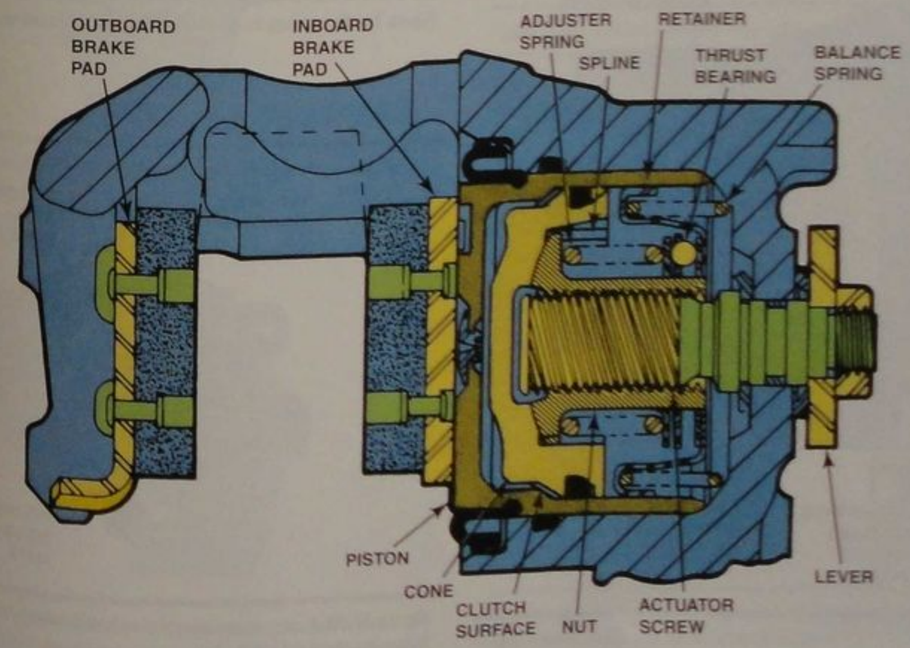


Figure 78–21 A typical General Motors rear disc brake with an integral parking brake. This type uses a screw, nut, and cone mechanism to apply the caliper piston.

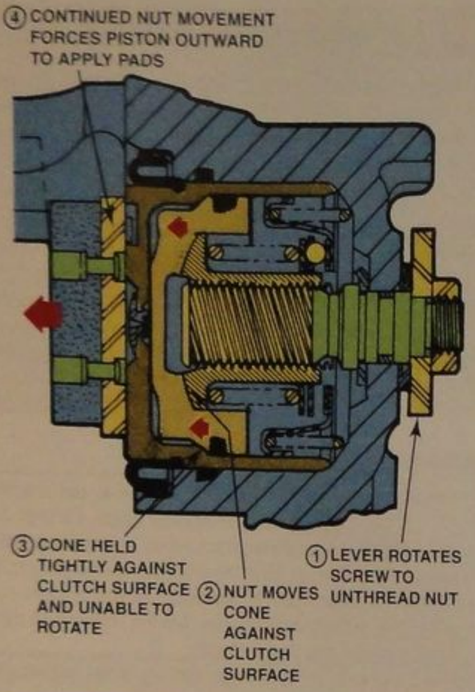


Figure 78–22 Parking brake application of a General Motors rear drive brake caliper.

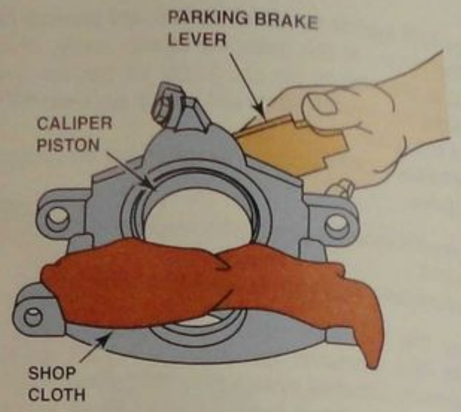


Figure 78–24 Removing the piston from a typical General Motors rear disc brake caliper.

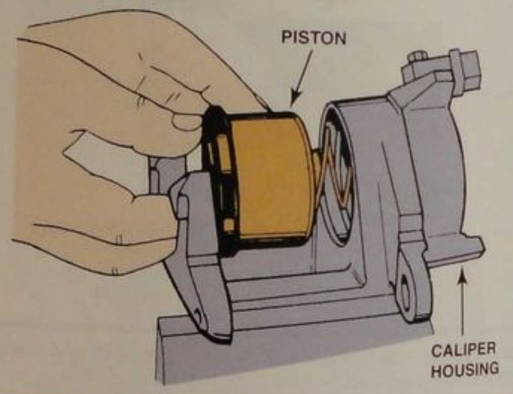


Figure 78–25 Installing the piston into a General Motors rear disc brake caliper.

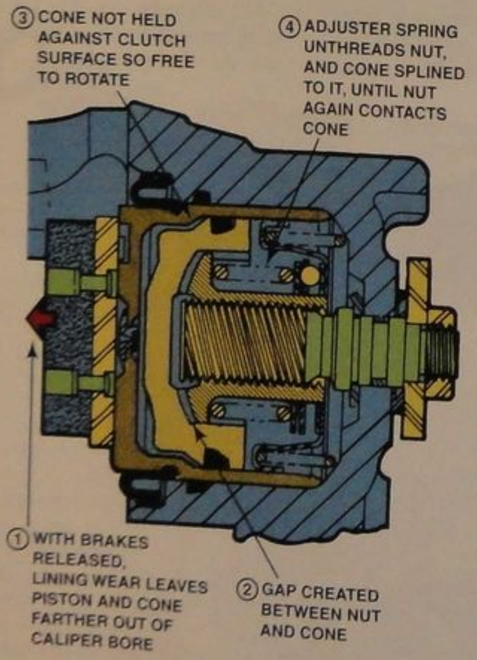


Figure 78–23 Automatic adjustment of a General Motors rear disc brake caliper.

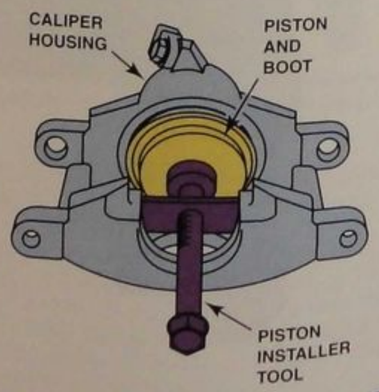


Figure 78–26 A piston installation tool is required to fully install the piston into a General Motors rear disc brake caliper.

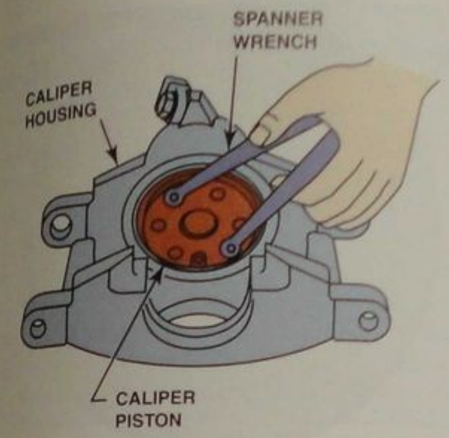


Figure 78–27 A spanner wrench (or needle-nose pliers) can be used to rotate the caliper piston prior to installing the disc brake pads. A notch on the piston must line up with a tab on the back of the brake pad to keep the piston from rotating when the parking brake is applied.

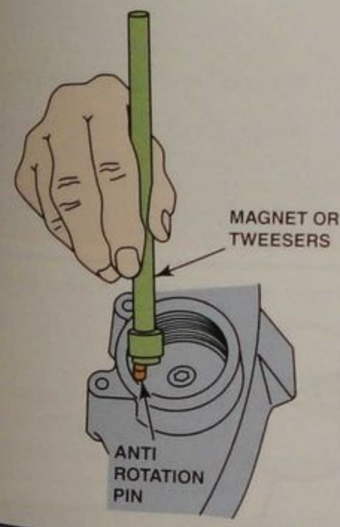


Figure 78–28 After removing the parking brake lever and thrust bearing, remove the anti-rotation pin.



Figure 78–29 Unscrew the thrust screw from the piston with an Allen (hex) wrench. After removing the thrust screw, push the piston out of the caliper bore.



Figure 78–30 To test the piston adjuster, thread the thrust screw into the piston. Hold the piston and pull the thrust screw outward 1/4 in. (6 mm). The adjuster nut should not turn when the thrust screw retracts. Replace the piston assembly if not functioning correctly.

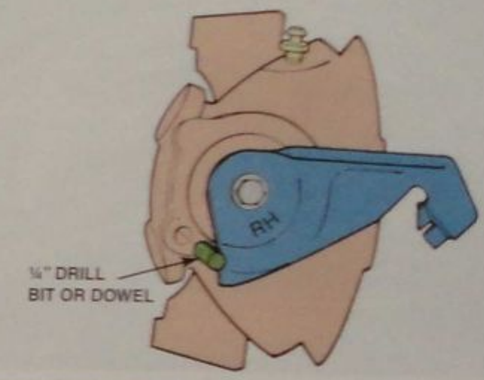


Figure 78–31 To adjust the parking brake cable on a Ford vehicle equipped with rear disc brakes, start by loosening the cable adjustment until the cables to the calipers are slack. Tighten until the caliper lever moves. Position a 1/4-in. drill bit or dowel into the caliper alignment hole. Adjustment is correct if the parking brake lever does not hit the 1/4-in. dowel.

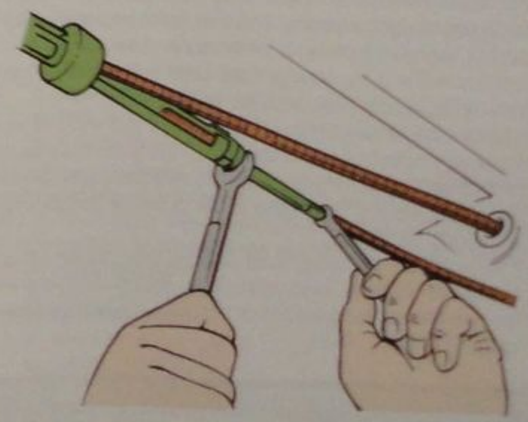


Figure 78–32 After checking that the rear brakes are okay and properly adjusted, the parking brake cable can be adjusted. Always follow the manufacturer's recommended procedure.

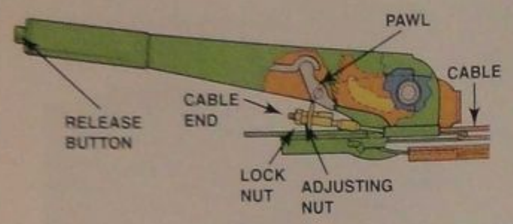


Figure 78–33 Many hand-operated parking brakes are adjusted inside the vehicle.

NOTE: The rear parking brake adjustment should always be checked whenever replacing the rear brake linings. It may be necessary to loosen the parking brake cable adjustment to allow clearance to get the drum over the new linings. This could happen because someone may have adjusted the parking brake cable during the life of the rear linings. See Figure 78–34.

With new thicker linings, the parking brake adjustment can keep the brake shoes pushed outward toward the drum.

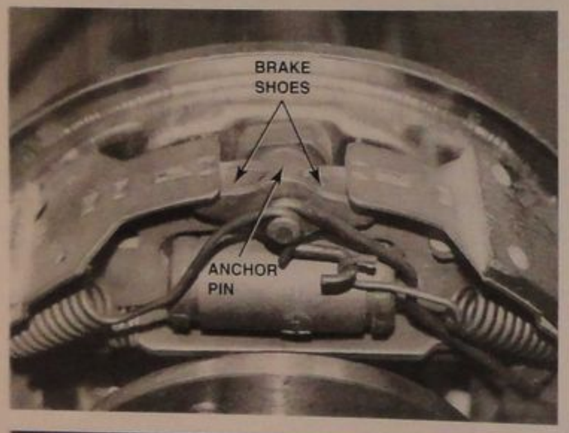


Figure 78–34 Always check that the brake shoes contact the anchor pin.

To prevent possible parking brake cable adjustment problems when installing new rear brakes, always observe the following:

1. Both brake shoes should make contact with the anchor pin at the top. If not, check the parking brake cable for improper adjustment or improper installation of the brake shoes.
2. Feel the tension of the parking brake cable underneath the vehicle. It should be slightly loose (with the parking brake "off").
3. Lubricate the parking brake cable to ensure that water or ice will not cause rust or freezing of the cable. This is necessary because even though the parking brake lever is released inside the vehicle, a stuck parking brake cable could cause the linings to remain out against the drums.
4. If the parking brake needs to be adjusted (will not hold on a hill or requires excessive lever movement), always check and adjust the rear brake adjustment before adjusting the parking brake cable. See Figure 78–35.

NOTE: Some vehicles are equipped with an automatic adjusting parking brake lever/cable. Simply cycling the parking brake on/off/on three times is often all that is required to adjust the parking brake cable.

5. Replace any stuck, corroded, or broken parking brake cable.

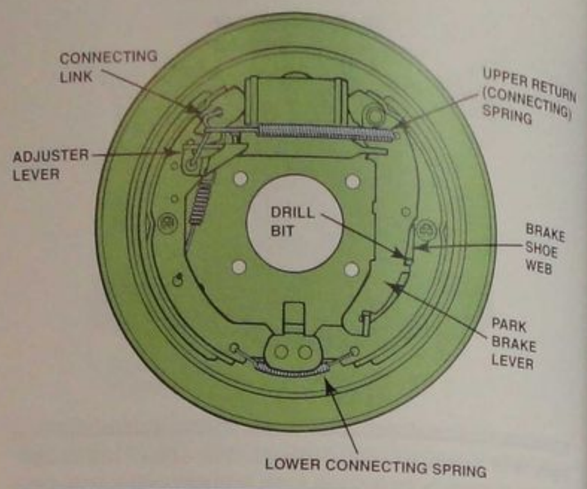


Figure 78–35 A 1/8-in. (3-mm) drill bit is placed through an access hole in the backing plate to adjust this General Motors leading-trailing rear parking brake. Adjust the parking brake cable until the drill can just fit between the shoe web and the parking brake lever.

TECH TIP ✔ **The Hose Clamp or Wrench Trick**

It is often difficult to remove a parking brake cable from the backing plate due to the design of the retainer. The many fingers used to hold the cable to the backing plate can be squeezed all at once if a hose clamp is used to compress the fingers. A wrench as shown in Figure 78–36 can also be used.

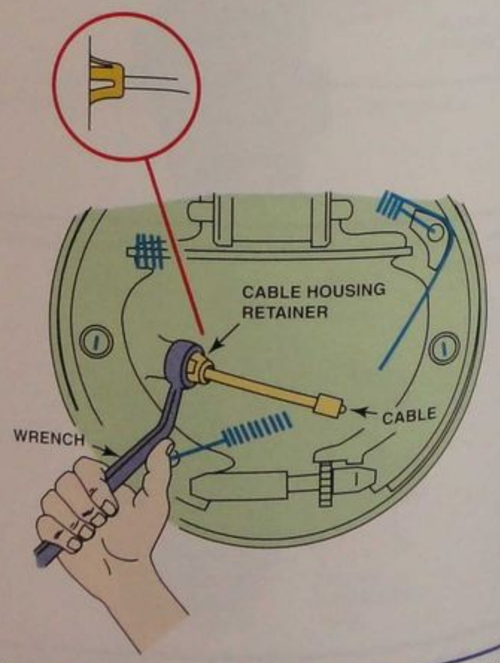


Figure 78–36 Many parking brake cables can be removed easily from the backing plate using a 1/2-in. (13-mm) box-end wrench. The wrench fits over the retainer finger on the end of the parking brake cable.

FREQUENTLY ASKED QUESTION ???

How Does an Electric Parking Brake Work?

Electric **parking brake (EPB)** systems are available using two different designs including:

1. A cable-pulling type that uses an electric motor to pull the parking brake cable rather than a mechanical handle or foot pedal.
2. A more advanced unit uses a computer-controlled motor attached to the brake caliper to activate it.

Some vehicle already use an **electric parking brake (EPB)** that can be activated when the vehicle stops and then goes off as soon as the gas pedal is pressed, preventing the car from moving while stopped. See Figure 78–37.



Figure 78–37 An electric parking brake button on the center console of a Jaguar.

SUMMARY

1. Government regulation requires that the parking brake be able to hold a fully loaded vehicle on a 20% grade.
2. The typical parking brake uses either a hand-operated lever or a foot-operated pedal to activate the parking brake.
3. On a typical drum brake system, the parking brake cable moves a parking brake lever attached to the secondary brake shoe. The primary shoe is applied through force being transferred through the strut.
4. All parking brake cables should move freely. The rear brakes should be adjusted properly before the parking brake is adjusted.

REVIEW QUESTIONS

1. Describe how a typical parking brake functions on a vehicle equipped with rear drum brakes.
2. Describe how a typical parking brake functions on a vehicle equipped with an integral rear disc brake system.
3. Explain how to adjust a parking brake properly.

CHAPTER QUIZ

1. Technician A says that the parking brake cable should be adjusted at each wheel. Technician B says that the parking brake cable adjustment is usually done after adjusting the rear brakes. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that the parking brake hand lever can turn on the red brake warning lamp. Technician B says that a foot-operated parking brake can turn on the red brake warning lamp. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that if the parking brake cable is adjusted too tight, the rear brakes may drag and overheat. Technician B says that the parking brake is adjusted properly if the cable is tight when in the released position. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. On most drum brake systems, the parking brake lever and strut transfer the pulling force of the parking brake cable against the _____.
   a. Primary shoe
   b. Secondary shoe
5. On most vehicles, the antirattle spring (strut spring) should be installed on the parking brake strut toward the _____ of the vehicle.
   a. Front
   b. Rear
6. In a typical integral rear disc brake caliper, the parking brake cable moves the _____.
   a. Caliper
   b. Actuator screw
   c. Auxiliary piston
   d. Rotor
7. The rear brakes should be inspected, and adjusted if necessary, if the parking brake requires more than _____.
   a. 5 clicks
   b. 10 clicks
   c. 15 clicks
   d. 20 clicks
8. A rear drum brake is being inspected. The primary shoe is not contacting the anchor pin at the top. Technician A says that this is normal. Technician B says that the parking brake cable may be adjusted too tight or is stuck. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Technician A says that a hose clamp can be used to compress the retainer fingers of a parking brake cable in order to remove it from the backing plate. Technician B says a box-end wrench can be used instead of a hose clamp. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. The wrong replacement rear disc brake pads were installed on a vehicle that used an integral parking brake. The inboard pad did not have a pin that fit into a notch on the caliper piston. Technician A says that the brakes will likely overadjust. Technician B says that the parking brake will not work. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 79

Machining Brake Drums and Rotors

OBJECTIVES: **After studying Chapter 79, the reader will be able to:** Prepare for ASE Brakes (A5) certification test content area "E" (Miscellaneous Systems Diagnosis and Repair). • Discuss the construction of brake drums and rotors. • Explain the formation of hard spots in drums and rotors. • Describe how to measure and inspect drums and rotors before machining. • Discuss how surface finish is measured and its importance to satisfactory brake service. • Demonstrate how to machine a brake drum and rotor correctly.

KEY TERMS: bellmouth • chill spots • composite rotors • convection • discs (disks) • eccentric distortion • elastic limit • hard spots • heat checking • lateral runout (LRO) • microinches (μin.) • out-of-round • parallelism • ra • root mean square (RMS) • scoring • scratch out • self-aligning spacer (SAS) • thickness variation (TV)

BRAKE DRUMS

Brake drums are constructed of cast iron where the lining contacts the drum with mild steel centers. The drum is drilled for the lug studs. Cast iron contains approximately 3% carbon, which makes the drum hard, yet brittle. For this reason it is recommended that any grinding needed to remove drums be done on the center mild steel portion, which due to its material characteristics can take this force without damage. This 3% carbon content of the cast iron also acts as a lubricant, which prevents noise during braking. Also, the rubbing surface can be machined without the need of a coolant (as would be required if constructed of mild steel). Because of these properties, cast iron is used on the friction surface of all drums. See Figure 79–1.

Even aluminum brake drums use cast iron for the friction surface area. Besides saving weight, aluminum brake drums transfer heat to the surrounding air faster than cast iron or steel. Brake drums and rotors are the major energy-absorbing parts of the braking system. Friction between the friction material and the drum or rotor creates heat. This heat is absorbed by the drum or rotor and travels from the friction surface to the remainder of the drum or rotor by heat **convection.** As energy continues to be absorbed, the drum or rotor increases in temperature. Airflow across the drum or rotor helps to dissipate the heat and keep the temperature rise under control. See Figures 79–2 through 79–4 for examples of how drums and rotors are cooled.

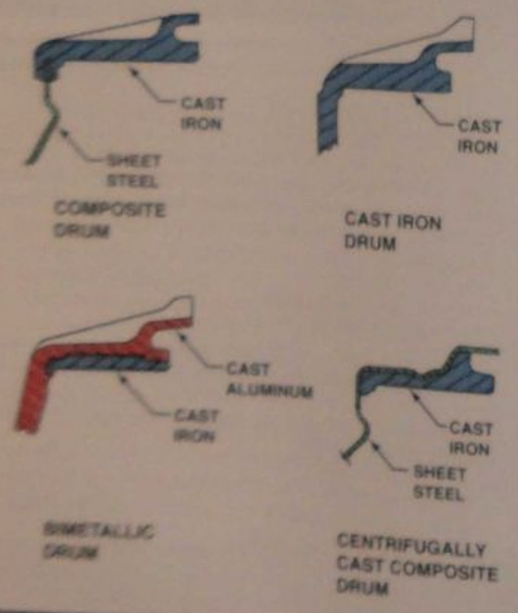


Figure 79–1 Types of brake drums. Regardless of the design, all types use cast iron as a friction surface.

BRAKE DRUM AND ROTOR DAMAGE

Besides wear, drums and rotors often experience damage to their friction surfaces. Because drum and rotor damage is caused by extremes of operation, it is most commonly found on front brakes, which experience more severe use than rear brakes.

Scoring **Scoring** is an extreme form of drum and rotor wear consisting of scratches, deep grooves, and a generally rough finish on the friction surface. See Figure 79–5.

There are a number of causes for scoring, but the most common is brake linings that have worn to the point where a rivet, lining table, or pad backing plate contacts the drum or rotor. Certain friction materials are more likely to score drums and rotors than others, and glazed linings that have hardened from exposure to extreme heat can also cause scoring.

Drum brakes are more likely to become scored than disc brakes because their closed construction holds dirt, sand, and abrasive dust inside the friction assembly. This allows the contaminants to be scrubbed repeatedly between the linings and drum. Severe drum scoring often results when metal parts of the friction assembly fatigue, break loose, and are trapped between the linings and drum.

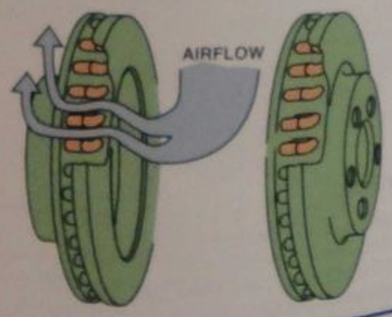


Figure 79–2 The airflow through cooling vents helps brakes from overheating.



Figure 79–3 This air scoop is part of the water/dirt shield attached next to the rotor.

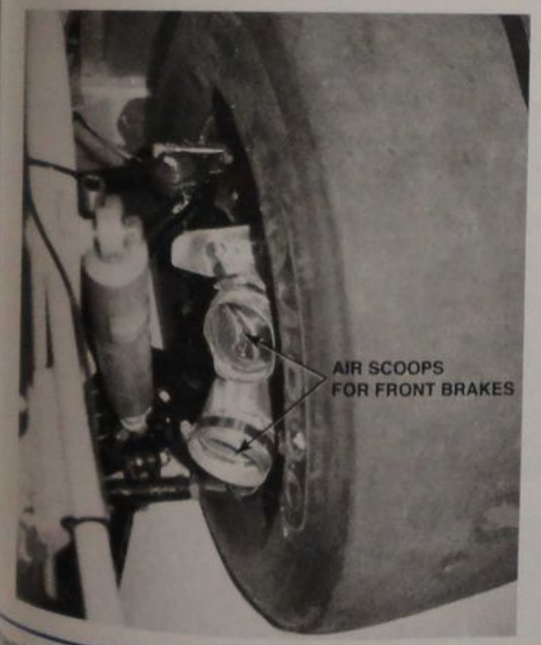


Figure 79–4 Most race cars are equipped with scoops to direct air past the brakes to remove the heat quickly. The cooler the air, the more efficient and effective the brakes.

A scored drum or rotor will cause very rapid lining wear, often accompanied by a growling or grinding noise, particularly if there is metal-to-metal contact between the shoe and drum or pad and rotor. Scoring can be machined out of a drum or rotor so long as the amount of metal removed is within the allowable limits.

Cracking Cracks in a brake drum or rotor are caused by the stress of severe braking or an impact during an accident. See Figure 79–6.

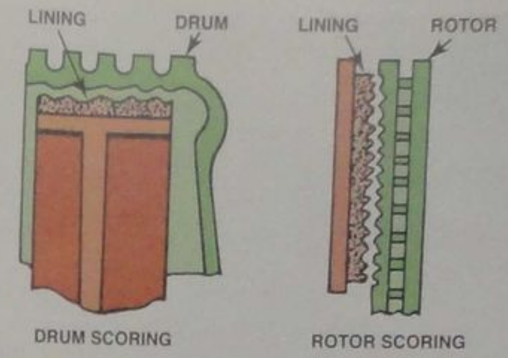


Figure 79–5 Scored drums and rotors often result in metal-to-metal contact.

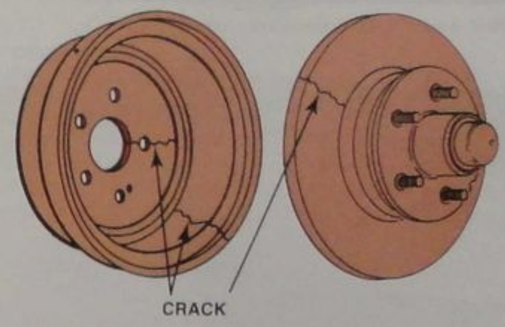


Figure 79–6 Cracked drums or rotors must be replaced.

Generally, drums and rotors that have been previously machined are more susceptible to cracking than new parts. Cracks can appear anywhere on a drum or rotor, although on drums they are most often found near the bolt circle on the web, or at the open edge of the friction surface. Rotors generally crack first at the edge of their friction surfaces.

TECH TIP ✓ **The Tap Test**

Using a steel hammer, lightly tap a brake drum or rotor. It should ring if it is not cracked. If a dull thud is heard, the drum or rotor is likely cracked and should be replaced.

Heat Checking A lesser form of drum and rotor cracking is called **heat checking,** which consists of many small, interlaced cracks on the friction surface. See Figure 79–7.

These cracks typically penetrate only a few thousandths of an inch into the metal and seldom pass through the structure of the drum or rotor. Heat checking is usually caused by a driver who leaves one foot on the brake pedal while applying the accelerator with the other. Heat checking can also be caused by repeated heavy braking or numerous panic stops made in rapid succession.

Light heat checking can often be machined away. In more severe cases the drum or rotor must be replaced.

Hard or Chill Spots Earlier, it was stated that cast-iron drums and rotors are durable because the friction, heat, and pressure of braking cause a tough "skin" to form on their friction surfaces. However, if brake temperatures become too great, localized impurities in



Figure 79–7 A heat-checked surface of a disc brake rotor.



Figure 79–8 These dark hard spots are created by heat that actually changes the metallurgy of the cast-iron drum. Most experts recommend replacement of any brake drum that has these hard spots.

the metal can be burned away, altering the structure of the metal and causing **hard spots,** also called **chill spots,** to appear. Hard spots are roughly circular, bluish/gold glassy appearing areas on the friction surface. See Figure 79–8.

Hard spots create a number of problems including the following:

- They are harder than surrounding areas of the friction surface, and do not wear at the same rate. Once the spots begin to stand out from the rest of the friction surface, they cause rapid brake lining wear.
- The friction coefficient of hard spots is less than that of surrounding areas so braking power is reduced or becomes uneven. This can cause the brakes to chatter, or result in a hard or pulsating brake pedal.
- A drum or rotor is more likely to crack in the area of hard spots than elsewhere.

Most vehicle manufacturers recommend that the drum or rotor should be replaced if hard spots are found.

BRAKE DRUM DISTORTION

To ensure smooth brake application without pedal pulsation or other problems, brake drum friction surfaces must remain in a fixed position in relation to the shoes. In some cases, a position variation of less than a thousandth of an inch will create braking problems. Distortion puts the drum friction surfaces out of proper alignment with the shoes.

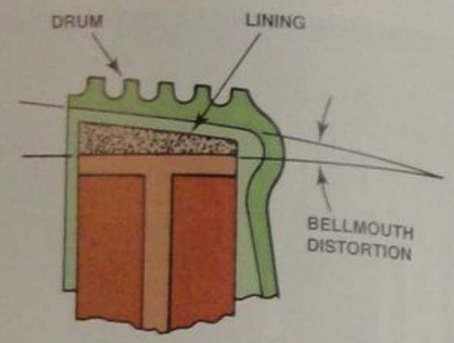


Figure 79–9 Bellmouth brake drum distortion.

TECH TIP ✓ **Storing Drums and Rotors**

A common cause of distortion in new brake drums and rotors is improper storage. Drums and rotors should always be stored lying flat; they should never be stood on edge. Distortion of new drums and rotors is common, so they should be routinely checked before installation.

Drum Distortion The friction surface of a brake drum in perfect condition is parallel to the axis of the axle, and rotates in a precise circle centered on the axle or hub. All brake drums suffer from distortion during brake operation, but they usually return to their original shape once the brakes are released. When the friction surface does not return to its proper shape, is no longer parallel to the axle, or does not rotate in a precise circle around the axle, the drum is distorted.

Bellmouth Drums When an open edge of a brake drum friction surface has a larger diameter than the closed edge, the drum is suffering from **bellmouth** distortion. See Figure 79–9. Bellmouth distortion is caused by poor drum rigidity combined with high heat and brake application force.

Bellmouth distortion occurs when a drum suffers mechanical fade and its open edge, unsupported by the drum web, expands more than its closed edge. When the brakes are applied harder to compensate for the fade, the shoes distort the open edge of the drum so far outward that the **elastic limit** of its metal is exceeded. Once this happens, the drum will not return to its original shape after it cools. Repeated occurrences of this process eventually cause the drum to take on a bellmouth shape.

Bellmouth distortion is especially common on wide drums and commonly occurs when a drum has had too much metal machined from it. If new shoes are installed in a bellmouthed drum, brake fade and unusual lining wear will result.

Out-of-Round Drums Uneven heat distribution can sometimes cause **out-of-round** distortion in which the drum radius varies when measured at different points around its circumference. See Figure 79–10.

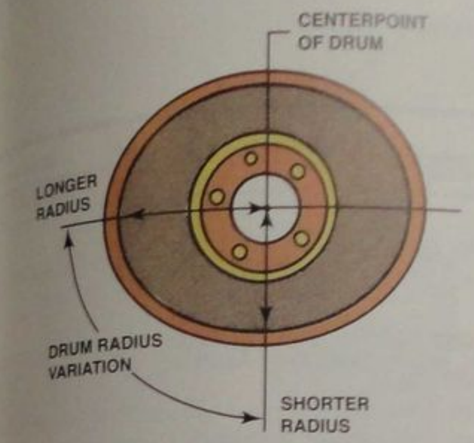


Figure 79–10 Out-of-round brake drum distortion.

Out-of-round distortion can take place when a vehicle drives through a puddle after a series of hard stops and cold water splashed on the brakes causes rapid and uneven cooling of the drums. It can also result if the parking brake is firmly applied after a series of hard stops before the drums have had a chance to cool. In this case, the shoes extend out against the heat-expanded drum and prevent it from contracting to its original circular shape as it cools. Instead, the extended shoes force the drum into an out-of-round shape.

The most common symptom of an out-of-round drum is a pulsating brake pedal when the brakes are applied at all speeds. Out-of-round drums can also cause a vibration or brake chatter at speeds above approximately 40 mph (60 km/h). In more extreme cases, an out-of-round drum can result in erratic braking action, and possibly cause the brakes to grab with every revolution of the wheel.

TECH TIP ✓ **The Parking Brake Trick**

Whenever attempting to diagnose a brake pedal pulsation, drive to a deserted road or parking lot and try stopping the vehicle using the parking brake. If a vibration occurs, the problem is due to a fault with the rear brakes. If a vibration does not occur except when using the service brakes, the problem is most likely due to a fault with the front brakes.

Eccentric Drums **Eccentric distortion** exists when the geometric center of the circle described by the brake drum friction surface is other than the center of the axle or the bolt circle of the drum hub. See Figure 79–11. This type of distortion causes the drum to wobble with a cam-like motion. An eccentric drum will result in a pulsating brake pedal similar to that caused by an out-of-round drum.

Eccentric distortion is often caused by overtightened or unevenly tightened lug nuts or bolts. Not only will this cause an immediate problem, but it can lead to additional problems later. If a vehicle is driven for an extended time with an eccentric drum, the linings may slowly wear the friction surface "round" again. However, as soon as tension on the lug nuts or bolts is released, the drum will relax back to its original shape creating an out-of-round condition that was not apparent before the wheel was removed.

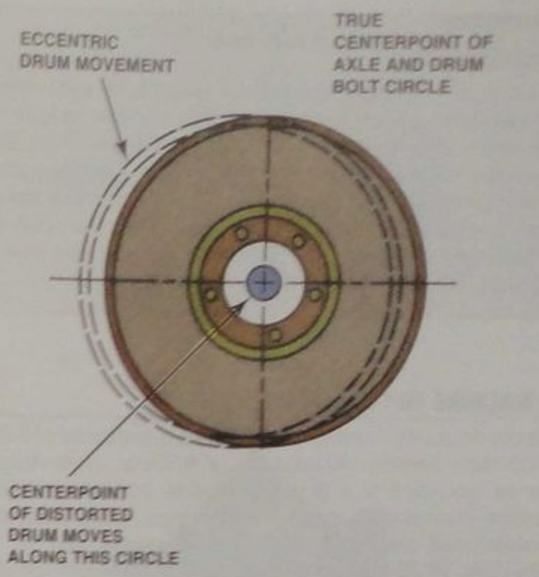


Figure 79–11 Eccentric brake drum distortion. This can occur in new drums that were not drilled correctly causing a hard-to-find vibration problem.

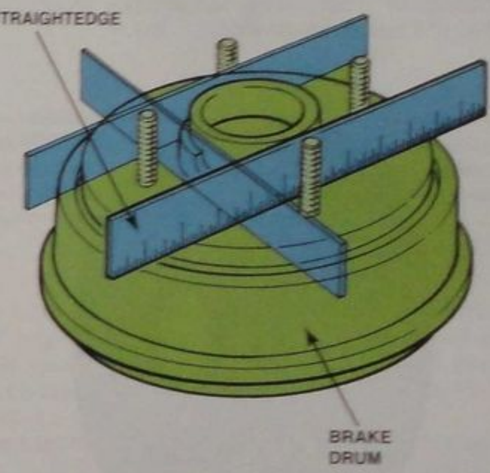


Figure 79–12 A straightedge can be used to check for brake drum warpage.

REMOVING DRUMS

Metal clips called tinnerman nuts are installed at the factory to keep the brake drums from falling off during vehicle assembly. These clips can be removed and do not need to be reinstalled since the wheel lug nuts hold onto the brake drum.

The first inspection step after removing a brake drum is to check it for warpage using a straightedge, as shown in Figure 79–12.

A warped drum is often a source of vibration. A brake drum that is out-of-round can cause a brake pedal pulsation during braking.

NOTE: To help diagnose if the front brakes or rear brakes are the cause of the vibration, try slowing the vehicle using the parking brake. If vibration occurs, the problem is due to the rear brakes.

TECH TIP ✔ **Mark It to Be Sure**

Most experts recommend that brake rotors, as well as drums and wheels, be marked before removing them for service. Many disc brake rotors are directional and will function correctly only if replaced in the original location. A quick-and-easy method is to use correction fluid. This alcohol-based liquid comes in small bottles with a small brush inside, making it easy to mark rotors with an "L" for left and an "R" for right. Correction fluid (also called "white-out" or "liquid paper") can also be used to make marks on wheel studs, wheels, and brake drums to help ensure reinstallation in the same location.

"MACHINE TO" VERSUS "DISCARD"

Brake drums can usually be machined a maximum of 0.060 in. (1.5 mm) oversize (for example, a 9.500-in. drum could wear or be machined to a maximum inside diameter of 9.560 in.) unless otherwise stamped on the drum. Most brake experts recommend that both drums on the same axle be within 0.010 in. (0.25 mm) of each other. *The maximum specified inside diameter (ID) means the maximum wear inside diameter.* See Figure 79–13.

Always leave at least 0.015 in. (0.4 mm) after machining (resurfacing) for wear. Many manufacturers recommend that 0.030 in. (0.8 mm) be left for wear.

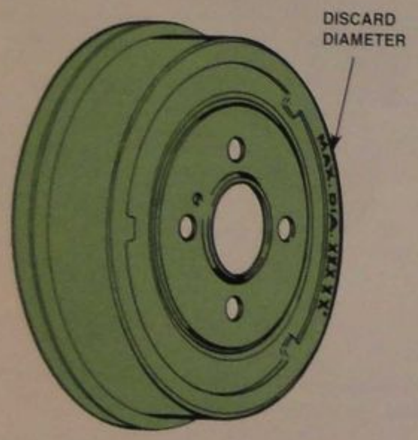


Figure 79–13 Discard diameter and maximum diameter are brake drum machining and wear limits.

REASONS FOR EQUAL DRUM INSIDE DIAMETER

There are several reasons why the service technician should check and make sure that both brake drums on the same axle are close to the same inside diameter (ID).

- **Reason 1.** Since heat is generated by braking, if there is less material (larger ID), the drum will tend to expand more rapidly than a drum with more material (smaller ID).
- **Reason 2.** If one drum expands more than the drum on the other side of the vehicle, unequal braking forces result.
- **Reason 3.** The drum that is larger in ID will expand away from the brake linings more than the other side.

For example:

Left Drum	Right Drum
9.500 in.	9.560 in.

In this example, when the drums get hot (heavy braking), the vehicle will tend to pull to the left.

TECH TIP ✔ **Brake Drum Chamfer**

Look at the chamfer on the outer edge of most brake drums. When the chamfer is no longer visible, the brake drum is usually at or past its maximum ID. See Figure 79–14. Although this chamfer is not an accurate gauge of the ID of the brake drum, it still is a helpful indicator to the technician.



Figure 79–14 Most brake drums have a chamfer around the edge. If the chamfer is no longer visible, the drum is usually worn (or machined) to its maximum allowable ID.

MEASURING AND MACHINING BRAKE DRUMS

Before measuring a brake drum, be sure it is not cracked by tapping it with a steel hammer. The brake drum should ring like a bell. If the brake drum makes a dull thud sound, discard the drum. Brake drums are usually measured using a micrometer especially designed for brake drums. See Figure 79–15. Compare the micrometer reading to the discard diameter. Both drums should be measured whenever they are removed for any brake service or inspection.

Always start any machining operation by making certain that the brake drum is clean and that excess grease is removed from the hub. If the drum has a hub with bearings, check the outer bearing races (cups) for wear and replace as necessary before placing the drum on the brake lathe. Also, carefully inspect and clean the lathe spindle shaft and cones before use. Use a **self-aligning spacer (SAS)** to be assured of even force being applied to the drum by the spindle nut. Always follow the instructions for the lathe you are using.

Hubless drums use a hole in the center of the brake drum for centering. Always check that the center hole is clean and free of burrs or nicks. Typical drum brake machining steps include the following:

Step #1 Mount the drum on the lathe and install the silencer band as shown in Figures 79–16 and 79–17.

Step #2 Turn the drum by hand before turning on the lathe to be sure everything is clean. Advance the tool bit manually until it just contacts the drum. This is called a **scratch cut.** See Figure 79–18.



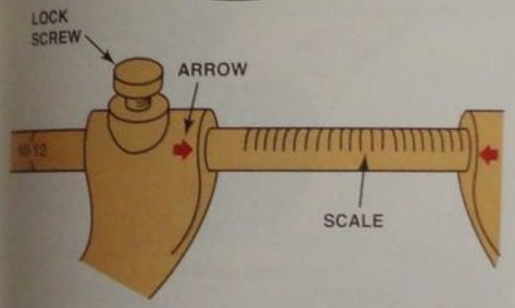


Figure 79–15 Typical needle-dial brake drum micrometer. The left movable arm is set to the approximate drum diameter and the right arm to the more exact drum diameter. The dial indicator (gauge) reads in thousandths of an inch.

Step #3 Stop the lathe and back off the tool bit. Loosen the arbor nut, rotate the drum one-half turn (180°) on the arbor, and retighten the arbor nut. See Figure 79–19. Turn the lathe on and make a second scratch cut.

a. If the scratch cuts are side-by-side, the lathe is okay and machining can begin.
b. If the scratch cuts are opposite, remove the drum and check for nicks, burrs, or chips on the mounting surfaces.

Step #4 Start the lathe and set the depth of the cut. See Figures 79–20 and 79–21.

The maximum rough cut depends on the lathe type. The minimum cut is usually specified as no less than 0.002 in. (0.05 mm). A shallower cut usually causes the tool bit to slide over the surface of the metal rather than cut into the metal.

See Figure 79–22 for an example of a drum machined without properly positioning the antichatter (vibration) strap.

DISC BRAKE ROTORS

Disc brake rotors use cast gray iron at the area that contacts the friction pad. Rotors, also called **discs** or **disks,** have mass (weight) and absorb heat. The heavier the rotor, the more heat can be absorbed. Vehicle downsizing has resulted in the use of thinner and lighter-weight rotors. As the weight of the rotor decreases, so does the heat the rotor can "store" or absorb, resulting in the rotor getting hotter. As the rotor gets hotter, the rotor expands and "grows" larger where it is the hottest. If the rotor is allowed to cool gradually, the rotor simply returns to its original shape. If, however, the rotor is exposed to water, it may cool rapidly, causing the rotor to distort.

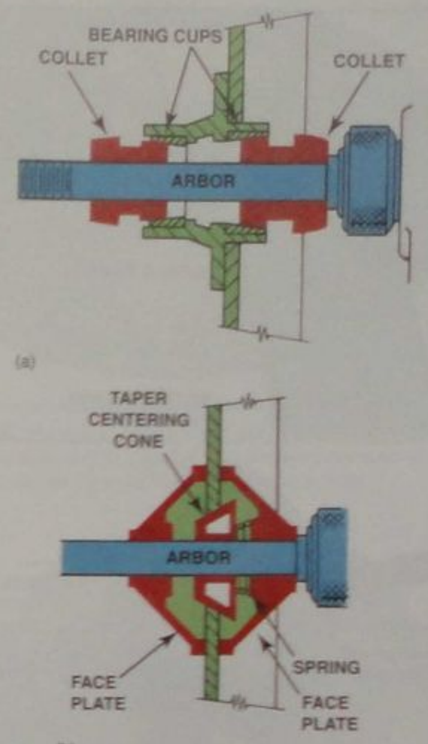


Figure 79–16 (a) A rotor or brake drum with a bearing hub should be installed on a brake lathe using the appropriate size collet that fits the bearing cups (races). (b) A hubless rotor or brake drum requires a spring and a tapered centering cone. A faceplate should be used on both sides of the rotor or drum to provide support.

Rotors are made in several styles, including the following:

1. **Solid.** These are used on the rear of many vehicles equipped with rear disc brakes and on the front of some small and midsize vehicles. Solid rotors are usually used on the rear where only 20% to 40% of the braking occurs. Solid rotors are much thinner than vented rotors. See Figure 79–23 for an example of an excessively worn solid rotor.
2. **Vented.** These are used on the front of most vehicles. The internal vanes allow air to circulate between the two friction surfaces of the rotor. Rotors can either be straight vane design, as shown in Figure 79–24, or directional vane design, as shown in Figure 79–25.

Composite rotors use a steel center section with a cast iron wear surface. These composite rotors are lighter in weight than conventional cast iron rotors. See Figure 79–26.

The light weight of composite rotors makes them popular with vehicle manufacturers. However, technicians should be aware that full-contact adapters that simulate the actual wheel being bolted to the rotor must be used when machining composite rotors. If composite rotors are machined incorrectly, they must usually be replaced.

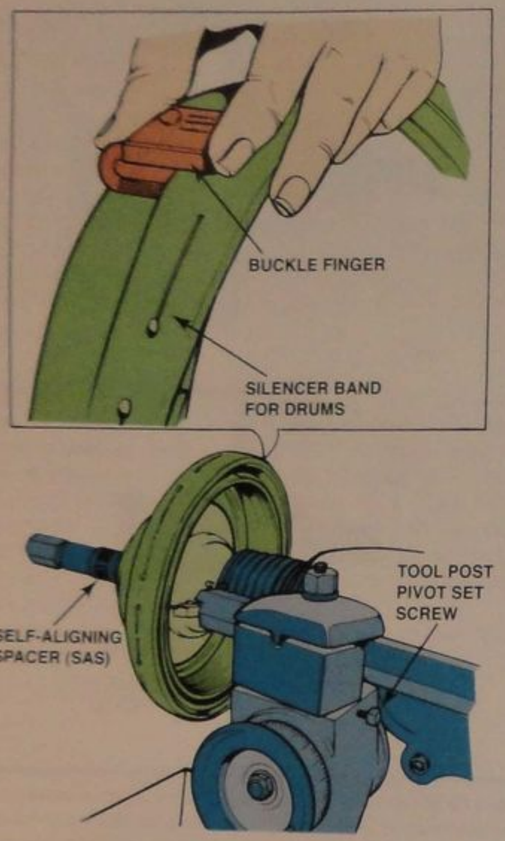


Figure 79–17 A self-aligning spacer (SAS) should always be used between the drum or rotor and the spindle retaining nut to help ensure an even clamping force and to prevent the adapters and cone from getting into a bind. A silencer band should always be installed to prevent turning-tool chatter and to ensure a smooth surface finish. *(Courtesy of Ammco Tools, Inc.)*



Figure 79–18 After installing a brake drum on the lathe, turn the cutting tool outward until the tool just touches the drum. This is called a scratch cut. *(Courtesy of Ammco Tools, Inc.)*

ALUMINUM METAL MATRIX COMPOSITE ROTORS

Some disc brake rotors are manufactured from an aluminum metal matrix composite alloy reinforced with 20% silicon carbide particulate. Aluminum composites combine the light weight and thermal conductivity of aluminum with the stiffness and wear resistance of a ceramic to create a disc brake rotor with excellent heat dissipation and service life.

These rotors can be distinguished from conventional cast iron rotors in several ways. At first glance the rotors are silver gray with a dark gray or black transfer layer (from the brake pad) on the rubbing surface. Unlike cast iron, these rotors will show no signs of rust and are nonmagnetic. When removed from the vehicle, the aluminum composite rotors can be further distinguished by their light weight, usually under 6 lb. (2.7 kg) versus over 12 lb. (5.4 kg) for cast-iron rotors on the typical passenger vehicle. See Figure 79–27 on page 958.

Servicing these rotors is slightly different from cast-iron rotors. The dark transfer layer on the rubbing surface does not harm rotor performance and should not be removed unless the rotor needs to be machined due to being warped. *Aluminum composite disc brake rotors cannot be machined with steel cutting tools!* Carbide tools can be used to machine a single set of aluminum composite rotors. If a shop receives these rotors on a regular basis, a polycrystalline diamond (PCD)-tipped tool is a good investment. Although more expensive initially, the PCD tool can last 100 times longer than a carbide tool.

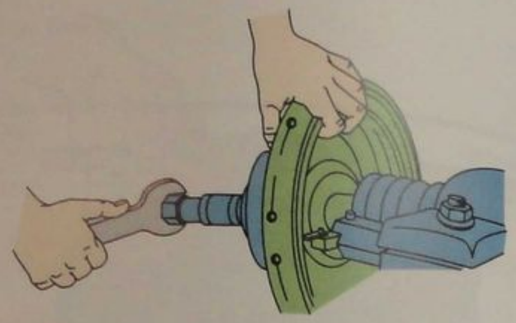


Figure 79–19 After making a scratch cut, loosen the retaining nut, rotate the drum on the lathe, and make another scratch cut. If both cuts are in the same location, the drum is installed correctly on the lathe and drum machining can begin.



Figure 79–20 Set the depth of the cut indicator to zero just as the turning tool touches the drum. *(Courtesy of Ammco Tools, Inc.)*

Disc Brake Rotor Distortion The friction surfaces of a rotor in perfect condition are perpendicular to the axle centerline, and

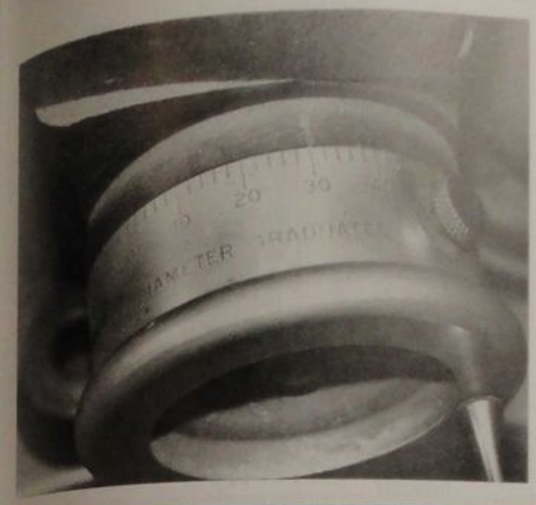


Figure 79–21 This lathe has a dial that is "diameter graduated." This means that a reading of 0.030 in. indicates a 0.015 in. cut that increases the inside diameter of the brake drum by 0.030 in.



Figure 79–22 Notice the chatter marks at the edge of the friction-area surface of the brake drum. These marks were caused by vibration of the drum because the technician failed to wrap the dampening strap (silencer band) over the friction-surface portion of the brake drum.



Figure 79–23 This excessively worn (thin) rotor was removed from the vehicle in this condition. It is amazing that the vehicle was able to stop with such a thin rotor.



Figure 79–24 Severely worn vented disc brake rotor. The braking surface has been entirely worn away exposing the cooling fins. The owner brought the vehicle to a repair shop because of a "little noise in the front." Notice the straight vane design.

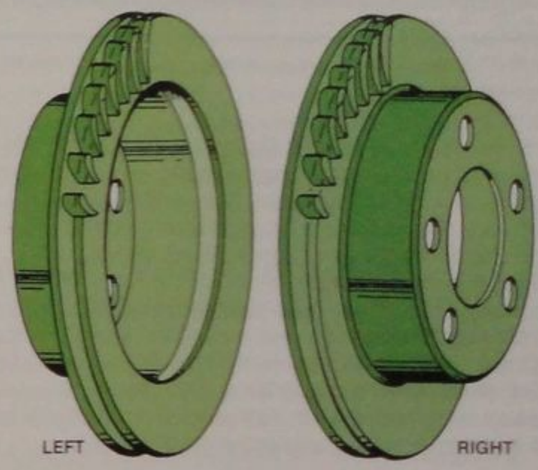


Figure 79–25 Directional vane vented disc brake rotors. Note that the fins angle toward the rear of the vehicle. It is important that this type of rotor be reinstalled on the correct side of the vehicle. *(Courtesy of Allied Signal Automotive Aftermarket)*

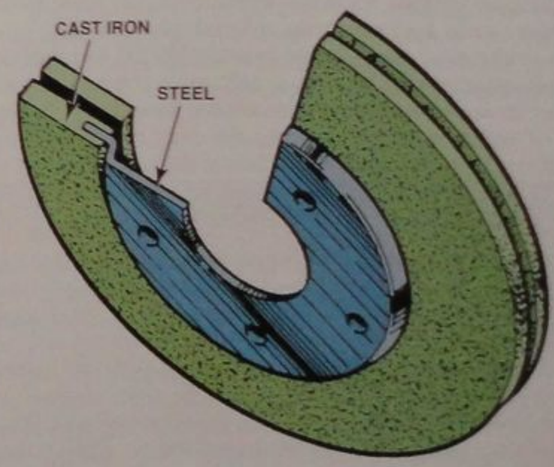


Figure 79–26 Typical composite rotor that uses cast iron friction surfaces and a steel center section.



Figure 79–27 An aluminum metal matrix composite rear rotor for a Chrysler Plymouth Prowler. (Courtesy of Duralcan, USA)

have no side-to-side movement. Unlike brake drums, rotors do not suffer distortion as a routine part of brake operation. However, distortion can occur during braking if there is a problem with the friction assembly, such as a frozen caliper piston that creates unequal application force on the two sides of the rotor.

Friction surface distortion is much more significant in a disc brake rotor than in a brake drum because the design of the friction assembly magnifies the effect of any wear. The hydraulic principles dictate that small movements of the large pistons in the brake calipers are converted into large movements of the small pistons in the master cylinder. Even very small amounts of distortion in a disc brake rotor can cause large amounts of pedal pulsation.

Rotor Lateral Runout **Lateral runout,** often abbreviated **LRO,** is side-to-side wobble of the rotor as it rotates on the spindle. See Figure 79–28. A small amount of runout provides caliper piston knockback that reduces drag when the brakes are not applied. However, if the amount of runout is too great, excessive brake pedal travel and front-end vibration, felt in the steering wheel, will result. In cases of severe runout, a pulsating brake pedal may also be present.

Lateral runout can be caused by several factors. Overtightened or unevenly tightened lug nuts or bolts are a common source of runout on newer vehicles with downsized brake rotors. Extreme heat or rapid temperature variations also cause runout. Inaccurate machining at the factory or in the field is also a common cause of this distortion. Most maximum values range between .002 and .008 in. (0.05 and 0.20 mm). See Figures 79–29 and 79–30.

Rotor Lack of Parallelism Lack of **parallelism,** also called **thickness variation (TV),** is a variation in the thickness of the rotor when it is measured at several places around its circumference. See Figure 79–31.

A rotor with friction surfaces that are not parallel is the most common disc brake cause of a pulsating brake pedal. A lack of rotor parallelism will cause a pedal pulsation when the brakes are applied at all speeds, and can also cause front-end vibration during braking. See Figure 79–32.

Lack of parallelism can be caused by a soft spot in the rotor casting that wears more rapidly than surrounding areas, but the most common cause is rust buildup on the rotor when the vehicle

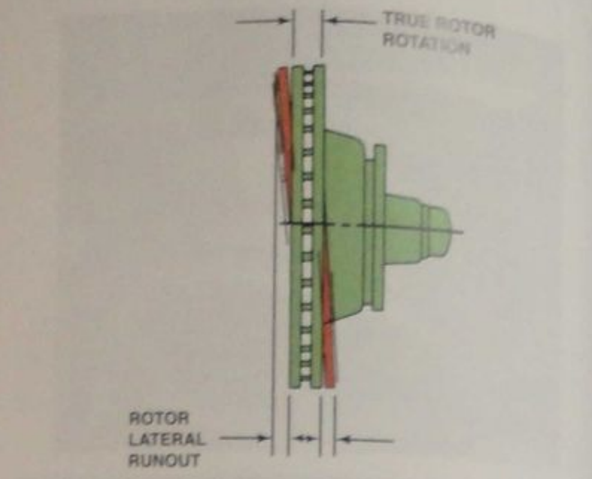


Figure 79–28 Brake rotor lateral-runout distortion.

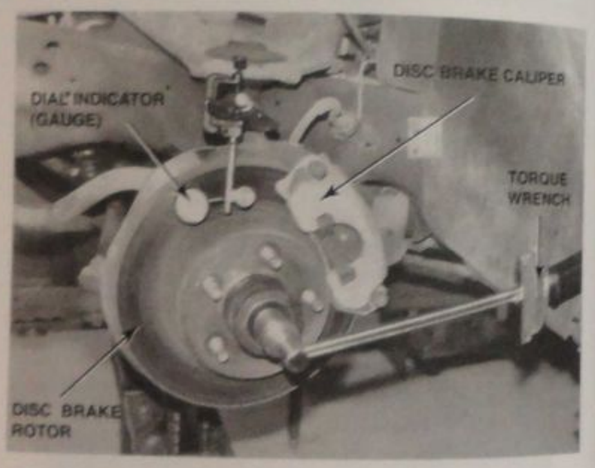


Figure 79–29 Before measuring lateral runout with a dial indicator (gauge), remove any wheel bearing end play by torquing the spindle nut to 10 to 20 ft-lb with a torque wrench. This step helps prevent an inaccurate reading. If the vehicle is to be returned to service, be sure to loosen the spindle nut and retighten to specifications (usually, finger tight) to restore proper bearing clearance.

is not driven for an extended period. The part of the friction surface protected by the brake pads does not rust as much as the rest of the rotor, and because the rusted areas wear faster, this results in a thickness variation when the vehicle is driven again.

TECH TIP ✔ **Braking Vibration Could Be Due to the Tires**

A vibrating condition (roughness) during braking is usually caused by disc brake rotor thickness variation or an out-of-round brake drum. Both conditions should be investigated. However, the tires and/or road conditions can also cause the same vibrations.

Tests performed by vehicle and tire-manufacturing engineers have shown that tires, and tires alone, could be the cause. If no other problem can be isolated, install a different brand of tire on the vehicle and retest. The cause of the tire vibration seems to be due to distortion or movement of the tire tread. A different brand of tires would have a different tread rubber compound, carcass body ply angles, or other factor that can contribute to a vibration during braking.

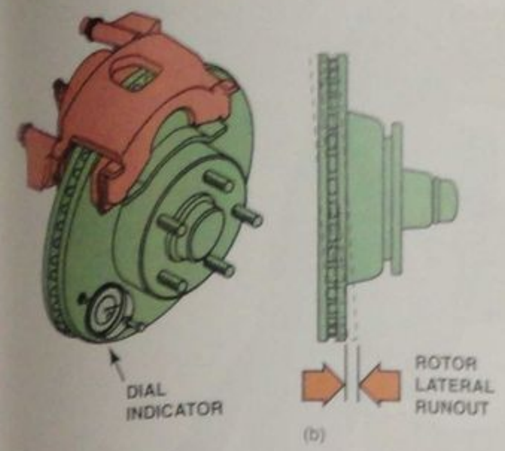


Figure 79–30 (a) Rotate the disc brake rotor one complete revolution while observing the dial indicator (gauge). (b) Most vehicle manufacturers specify a maximum runout of about .003 in. (0.08 mm).

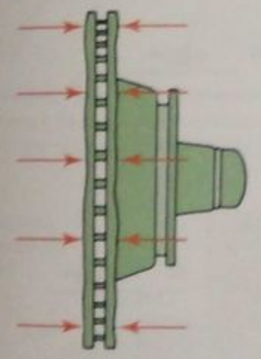


Figure 79–31 Brake rotor lack-of-parallelism distortion.

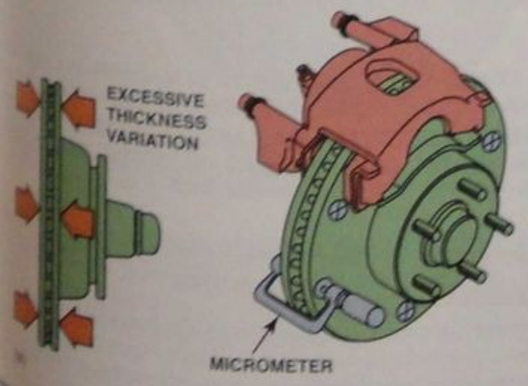


Figure 79–32 (a) Disc brake rotor thickness variation (parallelism). (b) The rotor should be measured with a micrometer at four or more equally spaced locations around the rotor.

Because parallelism variation is much more likely to cause a problem than lateral runout, the maximum amount allowed is much smaller than for runout. Most manufacturers specify that the two friction surfaces of a rotor must be parallel within half a thousandth of an inch, .0005 in. (0.013 mm), or less.

TECH TIP ✔ **Think of A Human Hair**

Measurements and specifications do not seem to mean much unless you can visualize the size compared to something with which you are familiar. The diameter of a human hair is from 0.002 to 0.004 in. (2 to 4 thousandths of an inch).

The maximum lateral runout of a rotor is usually within this same dimension. The reason a dial indicator has to be used to measure runout, and a micrometer to measure parallelism, is that the dimensions involved are less than the diameter of a human hair. See Figure 79–33.

MINIMUM THICKNESS

Most rotors have a minimum thickness cast or stamped into the rotor. This thickness is minimum wear thickness. At least 0.015 in. (0.4 mm) must remain after machining to allow for wear. (Some vehicle manufacturers, such as General Motors, specify that 0.030 in. [0.8 mm] be left for wear.) See Figure 79–34.

Whenever machining (resurfacing) a rotor, an equal amount of material must be removed from each side.

WHEN THE ROTORS SHOULD BE MACHINED

According to brake design engineers, a worn rotor has a very smooth friction surface that is ideal for replacement (new) disc brake pads. Often when the rotors are machined, the surface finish is not as smooth as specified. Therefore, a rotor should be machined only if one of the following conditions exists:

1. Deep grooves deeper than 0.060 in. (1.5 mm). This is the approximate thickness of a nickel! See Figure 79–35.
2. Thickness variation exceeding specifications and a brake pedal pulsation complaint.
3. Heavy rust that has corroded the friction surface of the rotor, as shown in Figures 79–36 and 79–37.

Therefore, if there is no complaint of a pulsating brake pedal during braking and the rotor is not deeply grooved or rusted, it should not be machined. New disc brake pads perform best against a smooth surface, and a used disc brake rotor is often smoother than a new rotor.

TECH TIP ✔ **Brown = Semimetallic**

Brake rotors that have used semimetallic brake pads during operation are brown on the friction surface. The reason for the brown color is the rust from the steel used in the manufacture of the pads.

If the friction surface of the disc brake rotor is shiny, then organic (asbestos), nonasbestos organic (NAO), or nonasbestos synthetic (NAS) pads have been used on the rotor.

This information is helpful to know, especially if the vehicle being serviced is to be equipped with semimetallic pads as specified by the manufacturer and the rotors are shiny. In this case the incorrect lining may have been installed during a previous service. Friction surface color is a quick-and-easy way to determine whether or not semimetallic pads have been used.

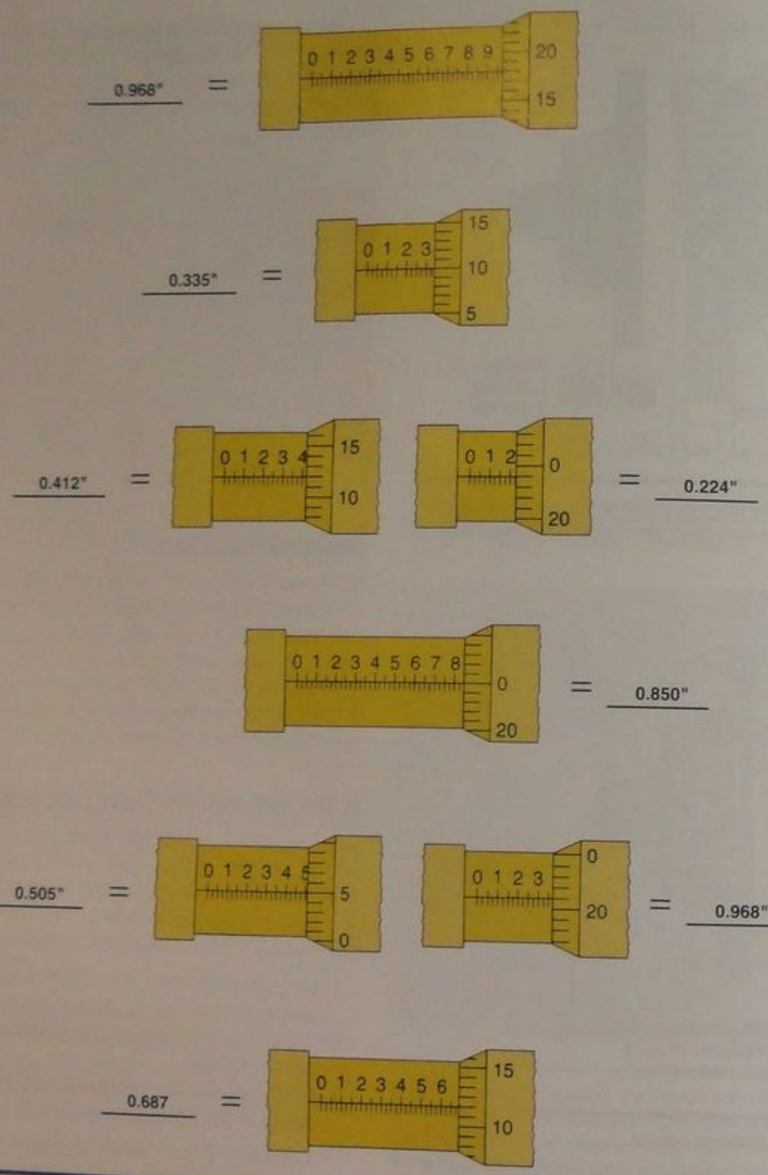


Figure 79–33 Sample micrometer readings. Each larger line on the barrel between the numbers represents 0.025". The number on the thimble is then added to the number showing and the number of lines times 0.025".

ROTOR FINISH

The smoothness of the rotor is called rotor finish or surface finish. Surface finish is measured in units called **microinches,** abbreviated **μin.,** where the symbol in front of "in." is the Greek lowercase letter μ (mu). One microinch equals 0.000001 in. (0.025 micrometer [mm]). The finish classification of microinch means the distance between the highest peaks and the deepest valley. The usual method of expressing surface finish is the arithmetic average roughness height, abbreviated **Ra,** which is the average of all peaks and valleys from the mean (average) line. This surface finish is measured using a machine with a diamond stylus, as shown in Figure 79–38.

Another classification of surface finish that is becoming obsolete is the **root mean square (RMS).** The RMS method gives a slightly higher number and can be obtained by multiplying Ra × 1.11 = RMS.

Often, a machined rotor will not be as smooth as a new rotor, resulting in a hard stopping complaint after new brakes have been installed. A rough rotor has less surface area touching the new brake pads, resulting in a hard brake pedal and reduced braking effectiveness. Most new rotors have a surface finish of 45 to 60 μin. Ra.

TECH TIP ✔ **The Ballpoint Pen Test**

A smooth friction surface on a drum or rotor is necessary for proper brake operation. To quickly determine if the friction surface of a brake drum or rotor is not smooth enough, draw a ballpoint pen across the surface. If the surface is smooth enough, a solid ink line will be observed. If the line drawn by the pen is not solid, then the surface is not smooth enough.

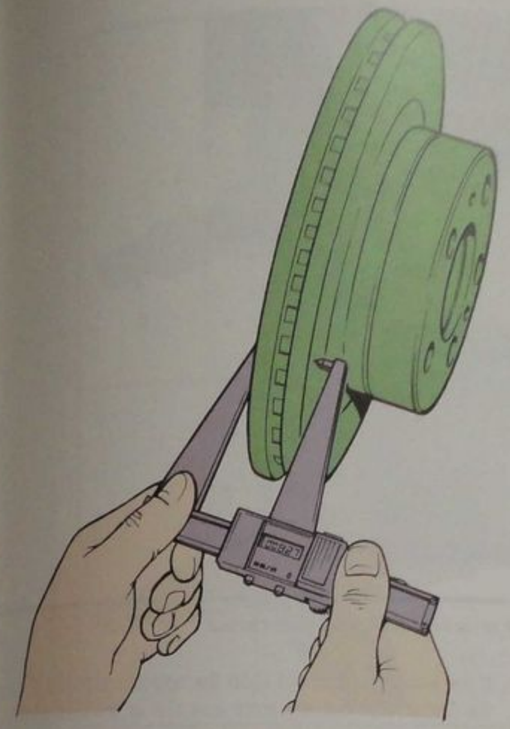


Figure 79–34 A digital readout rotor micrometer is an accurate tool to use when measuring a rotor. Both fractional inches and metric millimeters are generally available.

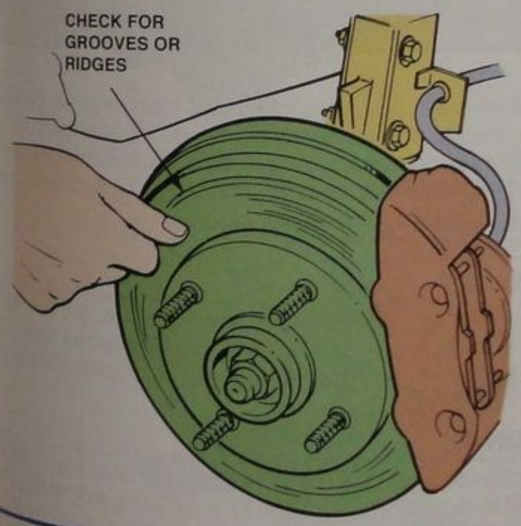


Figure 79–35 If a fingernail catches on a groove in the rotor, the rotor should be machined.

POSITIVE RAKE VERSUS NEGATIVE RAKE BRAKE LATHES

Many lathes are capable of removing a large amount of material in one pass, thereby reducing the time necessary to refinish a drum or rotor. These lathes usually use a positive rake tool bit angle. See Figure 79–39.

Other lathes that use six-sided reversible tool bits usually use a negative rake tool bit angle. Ammco is an example of a negative rake lathe, whereas Perfect-Hofmann and Accu-turn are examples of positive rake lathes.



Figure 79–36 This rusted rotor should be machined.



Figure 79–37 Rotors that have deep rust pockets usually cannot be machined.

MACHINING A DISC BRAKE ROTOR

Before machining a rotor, be sure that it can be machined by comparing the minimum thickness specification and the measured thickness of the rotor.

CAUTION: Some original equipment and replacement disc brake rotors are close to the minimum allowable thickness when new. Often, these rotors cannot be safely machined at all!

Following is an example of the steps necessary to machine a disc brake rotor. Always follow the instructions for the equipment you are using.

Step #1 Mount the disc brake rotor to the spindle of the lathe using the cones and adapters recommended. See Figures 79–40 and 79–41.

Step #2 Install a rotor damper and position the cutting tools close to the rotor surface as shown in Figure 79–42.

NOTE: Failure to install the damper causes vibrations to occur during machining that create a rough surface finish.

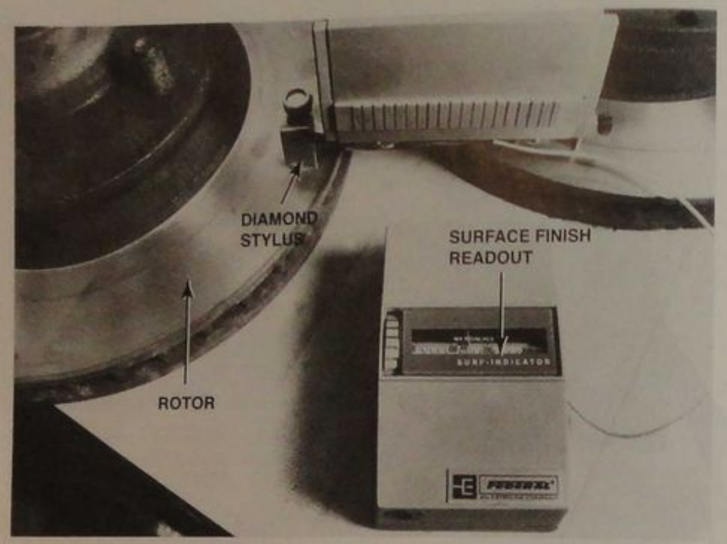


Figure 79–38 Electronic surface finish machine. The reading shows about 140 µin. This is much too rough for use but is typical for a rough cut surface.

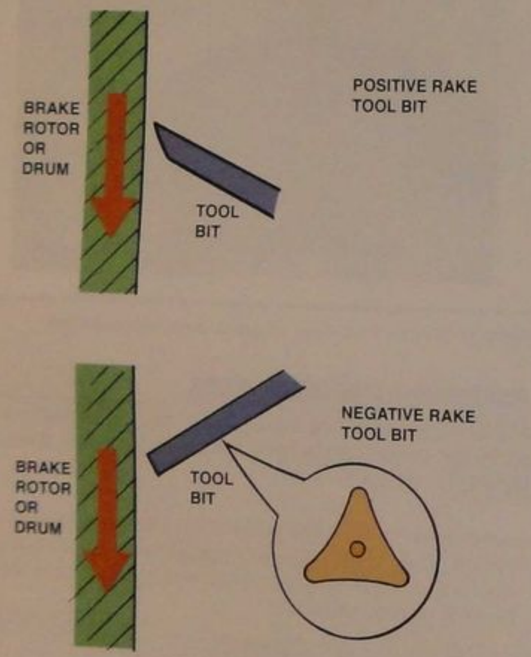


Figure 79–39 Most positive rake brake lathes can cut any depth in one pass, thereby saving time. A typical negative rake lathe uses a three-sided turning tool that can be flipped over, thereby giving six cutting edges.

Step #3 Make a scratch cut on the rotor face, as shown in Figure 79–43.

Step #4 To check that the rotor is mounted correctly, loosen the retaining nut, turn the rotor one-half turn (180°), and retighten the nut. Make another scratch cut.

a. The second scratch cut should be side-by-side with the first scratch cut if the rotor is properly installed, as shown in Figure 79–44.

b. If the second scratch cut is on the opposite side (180°) from the first scratch cut, the rotor may not be installed on the lathe correctly.

> **NOTE:** The runout as measured with a dial indicator on the brake lathe should be the same as the runout measured on the vehicle. If the runout is not the same, the rotor is not installed on the brake lathe correctly.

After proper installation of the disc brake rotor on the brake lathe, proceed with machining the rotors. For best results do not machine any more material from the rotor than is absolutely necessary. Always follow the recommendations and guidelines as specified by the vehicle manufacturer.

ROUGH CUT

A rough cut on a lathe involves cutting 0.005 in. per side with a feed of 0.008 in. per revolution and 150 RPM spindle speed. This usually results in a very coarse surface finish of about 150 µin. Ra.

FINISH CUT

A finish cut means removing 0.002 in. per side with a feed of 0.002 in. per revolution and 150 RPM spindle speed. Although this cut usually looks smooth, the surface finish is about 90 to 100 µin. Ra. Even a typical finish cut is still not nearly as smooth as a new rotor.

> **NOTE:** Measure the thickness of the rotor after the finish cut and compare with manufacturers' specifications. Be sure to allow for wear. See the chart in Figure 79–45 for a metric/fractional measurement chart.

Nondirectional Finish Most vehicle and brake component manufacturers recommend a nondirectional finish to help prevent the grooves machined into the rotor from acting like record grooves that can force the pads to move outward while the rotor rotates.

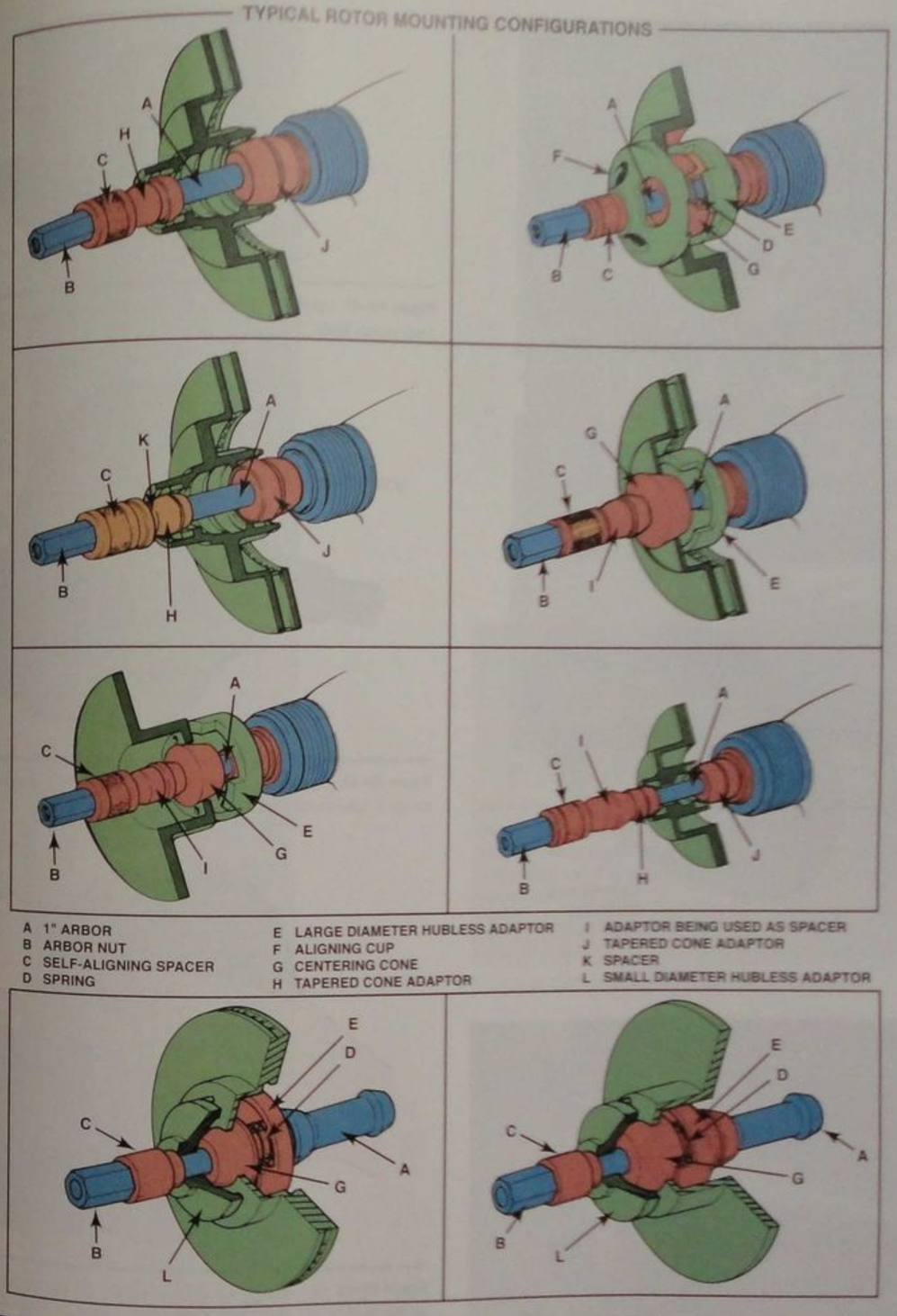


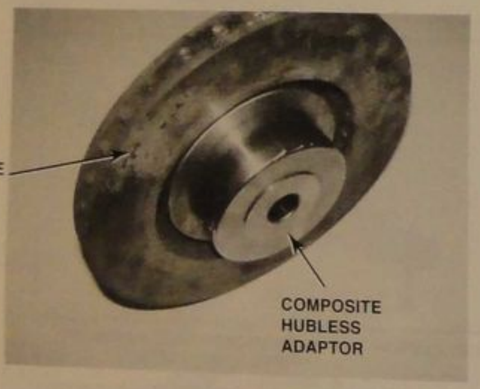
Figure 79–40 Recommended adapters and location for machining hubbed and hubless rotors. *(Courtesy of Hennessey Industries)*

> **CAUTION:** Some nondirectional finish tools such as those that use Scotch Brite (a registered trademark) plastic pads often do not make the rotor as smooth as new, even though the finish has been swirled.

Surface Finishing the Rotor The goal of any brake repair or service should be to restore the braking effectiveness to match new vehicle brakes. This means that the rotor finish should be as smooth or smoother than a new rotor for maximum brake pad contact. Research conducted at Delphi has shown that like-new rotor



(a)



(b)



(c)

Figure 79–41 (a) Typical hubless adapters necessary to properly mount a composite rotor to a brake lathe. (b) Composite adapter fitted to a rotor. (c) Composite rotor properly mounted on a lathe.

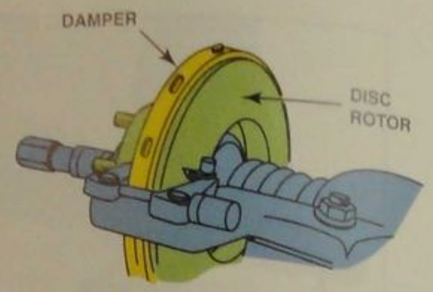


Figure 79–42 A damper is necessary to reduce cutting-tool vibrations that can cause a rough surface finish.

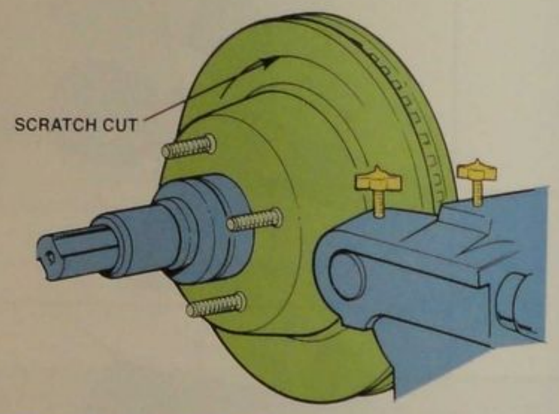


Figure 79–43 After installing the rotor on the brake lathe, turn the cutting tool in just enough to make a scratch cut.

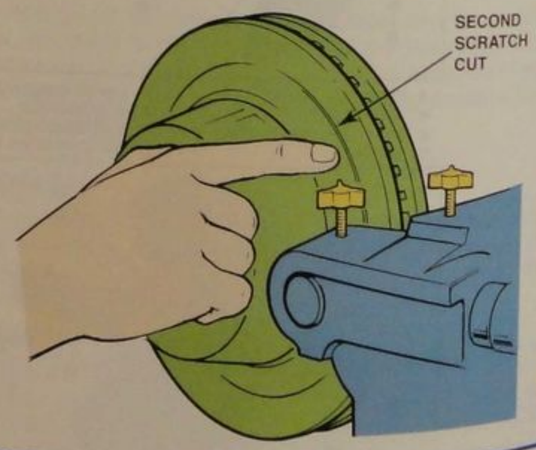


Figure 79–44 After making a scratch cut, loosen the retaining nut and rotate the rotor on the spindle of the lathe one-half turn. Tighten the nut and make a second scratch cut. The second scratch cut should be side-by-side with the first scratch if the rotor is installed correctly on the brake lathe.

finish can easily be accomplished by using a block and sandpaper. After completing the finish cut, place 150-grit aluminum-oxide sandpaper on a block and apply steady pressure against the rotor surface for 60 seconds on each side of the rotor. See Figure 79–46.

The aluminum oxide is hard enough to remove the highest ridges left by the lathe cutting tool. This results in a surface finish

Inch	Decimal Inch	Millimeter
1/64	0.015625	0.396875
1/32	0.03125	0.79375
3/64	0.046875	1.190625
1/16	0.0625	1.5875
5/64	0.078125	1.984375
3/32	0.09375	2.38125
7/64	0.109375	2.778125
1/8	0.125	3.175
9/64	0.140625	3.571875
5/32	0.15625	3.96875
11/64	0.171875	4.365625
3/16	0.1875	4.7625
13/64	0.203125	5.159375
7/32	0.21875	5.55625
15/64	0.234375	5.953125
1/4	0.25	6.35001
17/64	0.265625	6.746875
9/32	0.28125	7.14375
19/64	0.296875	7.540625
5/16	0.3125	7.9375
21/64	0.328125	8.334375
11/32	0.34375	8.73125
23/64	0.359375	9.128125
3/8	0.375	9.525
25/64	0.390625	9.921875
13/32	0.40625	10.31875
27/64	0.421875	10.715625
7/16	0.4375	11.1125
29/64	0.453125	11.509375
15/32	0.46875	11.90625
31/64	0.484375	12.303125
1/2	0.50	12.7
33/64	0.515625	13.096875
17/32	0.53125	13.49375
35/64	0.546875	13.890625
9/16	0.5625	14.2875
37/64	0.578125	14.684375
19/32	0.59375	15.08125
39/64	0.609375	15.478125
5/8	0.625	15.875
41/64	0.640625	16.271875
21/32	0.65625	16.66875
43/64	0.671875	17.065625
11/16	0.6875	17.4625
45/64	0.703125	17.859375
23/32	0.71875	18.25625
47/64	0.734375	18.653125
3/4	0.75	19.05
49/64	0.765625	19.446875
25/32	0.78125	19.84375
51/64	0.796875	20.240625
13/16	0.8125	20.6375
53/64	0.828125	21.034375
27/32	0.84375	21.43125
55/64	0.859375	21.828125
7/8	0.875	22.225
57/64	0.890625	22.621875
29/32	0.90625	23.01875
59/64	0.921875	23.415625
15/16	0.9375	23.8125
61/64	0.953125	24.209375
31/32	0.96875	24.60625
63/64	0.984375	25.003125
1	1.00000	25.4

Figure 79–45 Metric/fractional chart.



(a)



(b)

Figure 79–46 (a) This technician uses two sanding blocks each equipped with 150-grit aluminum-oxide sandpaper. (b) With the lathe turned on, the technician presses the two sanding blocks against the surface of the rotor after the rotor has been machined, to achieve a smooth microinch surface finish.

ranging from 20 to 80 µin. and usually less than 40 µin., which is smoother than a new rotor. See Figure 79–47.

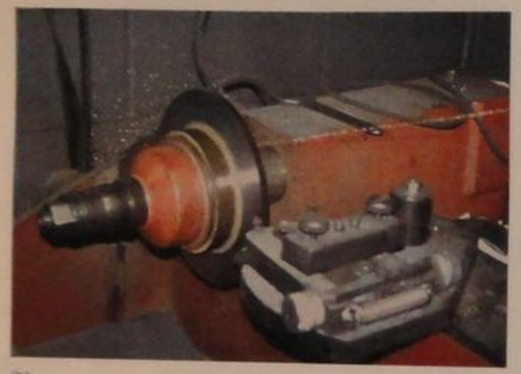
NOTE: Many commercial rotor-finish products may also give as smooth a surface finish. See Figures 79–48 and 79–49 on page 966. Always compare rotor finish to the rotor finish of a new rotor. Microinch finish is often hard to distinguish unless you have a new rotor with which to compare.

TECH TIP ✓ **Turn or Machine?**

When asked about what was done to their vehicle, a common response of customers is "They rotated my rotors." Many customers do not understand the terms that are commonly used in the vehicle service industry. Try to use terms that are technically correct and avoid slang when talking to customers. For example, the expression *machined the rotors* indicates an operation, whereas the expression *turned the rotors* may be misinterpreted by some customers as simply meaning using your hand and moving (rotating) the rotor. *Resurfacing, refinishing,* and *reconditioning* are other terms that could be used to describe a drum or rotor machining operation.



(a)



(b)

Figure 79–47 (a) After machining and sanding the rotor, it should be cleaned. In this case brake cleaner from an air pressurized spray can is used. (b) With the lathe turning, the technician stands back away from the rotor and sprays both sides of the rotor to clean it of any remaining grit from the sanding process. This last step ensures a clean, smooth surface for the disc brake pads and a quality brake repair. Sanding each side of the rotor surface for one minute using a sanding block and 150-grit aluminum-oxide sandpaper after a finish cut gives the rotor the proper smoothness and finish.

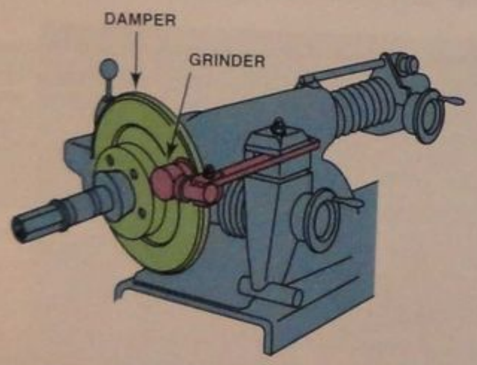


Figure 79–48 A grinder with sandpaper can be used to give a smooth nondirectional surface finish to the disc brake rotor.

ON-THE-VEHICLE ROTOR MACHINING

Many vehicle manufacturers recommend on-the-vehicle machining for rotors if the disc brake rotor must be machined due to deep scoring or pulsating brake pedal complaint. This is especially true of composite rotors or for vehicles such as many Honda vehicles that require major disassembly to remove the rotors.

Caliper mount, on-the-vehicle lathes require that the disc brake caliper be removed. The cutter attaches to the steering knuckle or caliper support in the same location as the caliper.

Hub mount, on-the-vehicle lathes attach to the hub using the lug nuts of the vehicle. To achieve a proper cut, the hub mount must be calibrated for any runout caused by the hub bearings and the outside surface face of the rotor. See Figures 79–50 and 79–51.

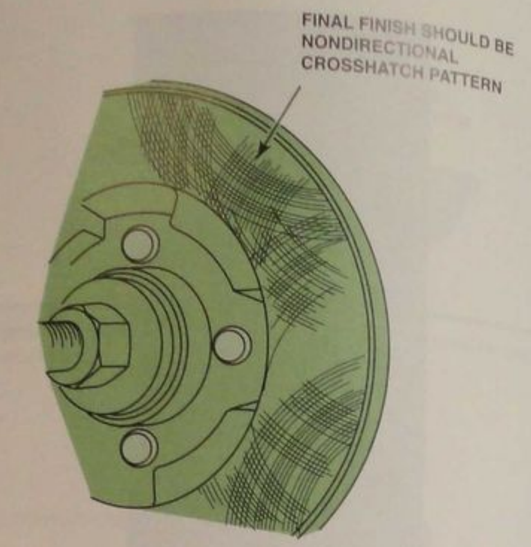


Figure 79–49 The correct final surface finish should be smooth and nondirectional.



Figure 79–50 Rust should always be cleaned from both the rotor and the hub whenever the rotors are machined or replaced. An air-powered die grinder with a sanding disc makes quick work of cleaning this hub.

NOTE: All on-the-vehicle lathes require that the wheel be removed. For best results always use a torque wrench when tightening lug nuts or lathe adapters. Unequal torque on the bolts causes stress and distortion that can cause warped rotors and a pulsating brake pedal.



Figure 79–51 A typical hub-mount on-the-vechicle lathe. This particular lathe oscillates while machining the rotor, thereby providing a smooth and nondirectional finish at the same time.



Figure 79–52 A Corvette equipped with high-performance brakes including cross-drilled brake rotors.

FREQUENTLY ASKED QUESTION ???

What Does "Cross-Drilled" and "Slotted" Mean?

The expression "cross-drilled" and "slotted" refers to two separate processes. The first procedure involves drilling rows of holes through the friction surfaces of the rotor. The second procedure refers to milling a series of specially machined grooves from the center of the disc toward the edge. When the friction surfaces of a rotor are smooth and flat, there is no means of escape for the gases and dust, which build up between pad and rotor. This is not a huge problem in normal driving, but is an important consideration in street performance applications.

The drill holes (which are sometimes called "gas relief openings") provide an exit route for the dust and gas. The holes are also commonly labeled "cooling holes" because of the improvements they make in this area. Better cooling means less fade during repeated heavy brake application. They also help dissipate water when driving in poor weather. See Figure 79–52.

Slotting increases the bite of the pads and is even more effective than cross-drilling in combating the problem known as "out-gassing." This is when, at very high braking temperatures, the bonding agents used in some brake pads produce a gas. Under extreme conditions, this gas can create a gas cushion between pad and rotor, giving a driver a normal pedal feel but reducing the amount of friction being generated. The slots pump away gas and restore full contact. The "microshaving" effect of the slots also serves to deglaze the pads and this is why the edges of the slots are not chamfered or "radiused." It also tends to even out the wear across the brake pad faces, increasing the effective contact area.

TECH TIP ✓ Always Check the Wheel Studs

Before installing the wheel after brake service, check the condition of the wheel studs and lug nuts. Check for stripped threads, rust, or cracks. If necessary, replace the stud. Most studs are replaced by driving them out using a large hammer and then using washers and a lug nut to draw the serrated shoulder of the lug stud into the rotor stud hole. See Figure 79–53. Always use a torque wrench when installing lug nuts to ensure proper and even torque on all lug nuts. This helps to prevent rotor distortion, which can lead to vibration in the steering and/or pedal pulsation during braking.



Figure 79–53 A wheel stud was replaced on the rotor hub assembly when it was discovered to be stripped.

SUMMARY

1. Brake drums and rotors must absorb the heat generated by the friction of slowing and stopping a vehicle.
2. All rotors should be marked before removing them from the vehicle to assure that they will be reinstalled in the same position and on the same side of the vehicle.
3. All brake drums should be machined only enough to restore proper braking action. Brake drums should be the same size on the same axle to help prevent unequal braking.
4. Disc brake rotors should be machined and allow up to 0.030 in. (0.8 mm) for wear.
5. To assure proper braking, all rotors should be machined to a very smooth surface of less than 60 µin. finish.

REVIEW QUESTIONS

1. Explain the difference between "machine to" specifications and "discard."
2. List the steps for machining a brake drum.
3. Describe how to measure a disc brake rotor for lateral runout and thickness variation.
4. List the steps for machining a disc brake rotor.
5. Describe what is necessary to achieve "like-new" disc brake rotor finish.



P79–1 Before starting to machine a brake drum, check the drum for any obvious damage such as heat cracks or hard spots.



P79–2 Lightly tap the drum. It should ring like a bell. If a dull thud is heard, the drum may be cracked and should be discarded.



P79–3 Use a drum micrometer to measure the inside diameter of the drum and compare this measurement to specifications to be sure that the drum can be safely machined.



P79–4 Most brake drums have the maximum inside diameter cast into the drum as shown.



P79–5 Thoroughly clean the outside and inside of the drum.



P79–6 Be sure the center hole in the drum is clean and free from any burrs that could prevent the drum from being properly centered on the shaft of the brake lathe.



P79–7 A typical brake lathe used to machine drums.



P79–8 Locate a tapered, centering cone that best fits inside the hole of the brake drum.



P79–9 Slide the large face plate over the shaft of the brake lathe.



P79–10 Slide the tapered centering cone onto the shaft with the spring between the face plate and the centering cone.



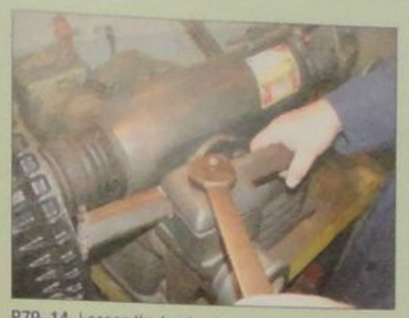
P79–11 Slide the other face plate onto the shaft.



P79–12 Install the self-aligning spacer (SAS) and left-hand-thread spindle nut.



P79–13 Tighten the spindle nut.



P79–14 Loosen the turning bar retainer.



P79–15 Carefully check the cutting bits and either rotate the bit to a new cutting point or replace it with a new part as necessary.



P79–16 Turn the spindle control knob until the spindle is as short as possible (i.e., the drum as close to the machine as possible) to help reduce vibration as much as possible.



P79–17 Position the cutting bar so that the cutting bit is located at the back surface of the drum.



P79–18 Install the silencer band (vibration dampener strap).



P79–19 Be sure the tool bit and clothing are away from the drum and turn the brake lathe on.



P79–20 Center the bit in the center of the brake surface of the drum and rotate the control knob that moves the bit into contact with the drum friction surface. This should produce a light scratch cut.



P79–21 Turn the lathe off.



P79–22 Observe the scratch cut.



P79–23 Loosen the spindle nut.



P79–24 Rotate the drum 180° (one-half turn) on the spindle.

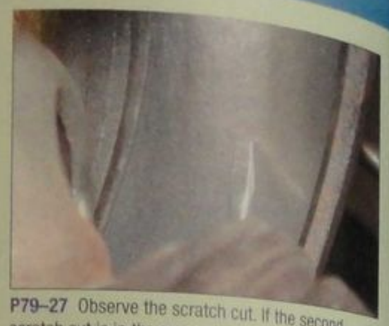
(continued)



P79–25 Tighten the spindle nut.



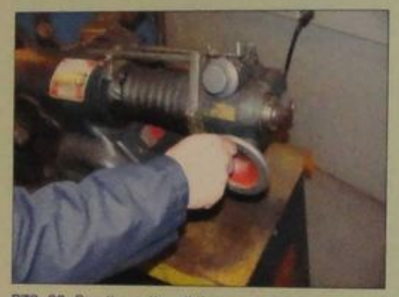
P79–26 Turn the lathe on, rotate the control knob, and run the cutter into the drum for another scratch cut.



P79–27 Observe the scratch cut. If the second scratch cut is in the same place as the first scratch cut or extends all the way around the drum, the drum is correctly mounted on the lathe.



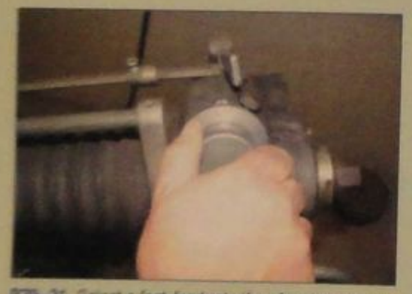
P79–28 Adjust the depth gauge to zero when the cutter just touches the drum.



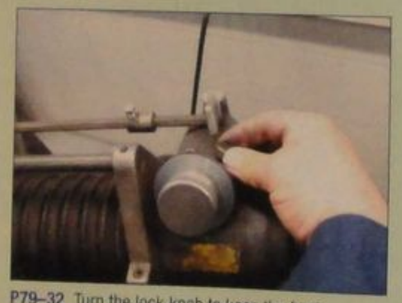
P79–29 Run the cutter all the way to the back surface of the drum.



P79–30 Adjust the depth of the cut and lock it in position by turning the lock knob. Most vehicle manufacturers recommend a rough cut depth should be 0.005–0.010 in. and a finish cut of 0.002 in.



P79–31 Select a fast-feed rate if performing a rough cut (0.006–0.016 in. per revolution) or 0.002 in. per revolution for a finish cut.



P79–32 Turn the lock knob to keep the feed adjustment from changing.



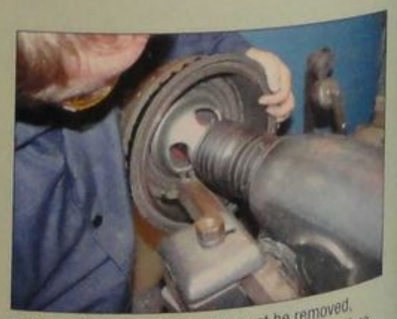
P79–33 Engage the automatic feed.



P79–34 The drum will automatically move as the tool remains stationary to make the cut.



P79–35 Turn the lathe off.



P79–36 If additional material must be removed, proceed with the finish cut. Clean thoroughly before installing on a vehicle.



P79–1 Before machining any rotor, use a micrometer to measure the thickness of the rotor.

Nominal Thickness	1.03 in
Minimum Refinish Thickness	0.972 in
Thickness Variation (Parallelism)	0.0005 in
Lateral Run-out (T.I.R.)	0.003 in
Finish	10–80 micro-in

P79–2 Check the specifications for the minimum allowable thickness.



P79–3 Visually check the rotor for evidence of heat cracks or hard spots that would require replacement (rather than machining) of the rotor.



P79–4 After removing the grease seal and bearings, remove the grease from the bearing races.



P79–5 Clean and inspect the brake lathe spindle for damage or burrs that could affect its accuracy.



P79–6 Select a tapered cone adapter that fits the inner bearing race.



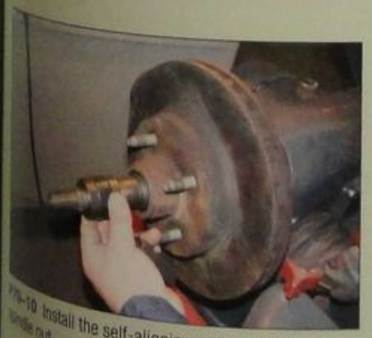
P79–7 Slide the cone adapter onto the brake lathe spindle.



P79–8 Select the proper size tapered cone adapter for the smaller outer wheel bearing race.



P79–9 Place the rotor onto the large cone adapter and then slide the small cone adapter into the outer wheel bearing race.



P79–10 Install the self-aligning spacer (SAS) and spindle nut.



P79–11 Tighten the spindle nut (usually left-hand threads).



P79–12 If a hubless rotor is being machined, be sure to thoroughly clean the inside surface.

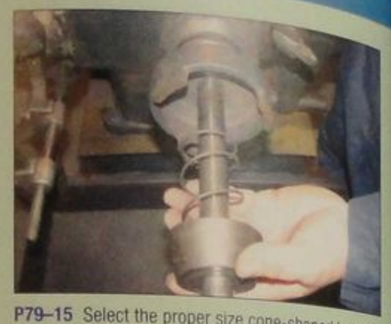
(continued)



P79–13 Also remove all rust from the other side of the hubless rotor.



P79–14 Select the proper centering cone for the hole in the center of the hub.



P79–15 Select the proper size cone-shaped hubless adapter and the tapered centering cone with a spring in between.



P79–16 After sliding the rotor over the centering cone, install the matching hubless adapter.



P79–17 Install the self-aligning spacer (SAS) and spindle nut.



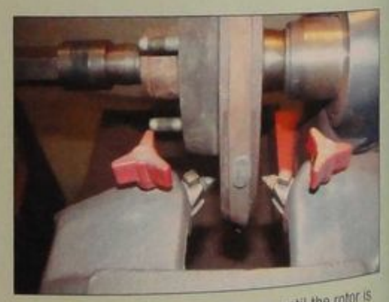
P79–18 After the rotor has been secured to the brake lathe spindle, install the noise silencer band (dampener).



P79–19 Carefully inspect the cutting bits and replace, if necessary.



P79–20 Loosen the tool holder arm.



P79–21 Adjust the twin cutter arm until the rotor is centered between the two cutting bits.



P79–22 Turn the lathe on.



P79–23 Move the cutter arm toward the center of the rotor, placing the cutting bits in about the center of the friction surface.



P79–24 Turn one cutting bit into the surface of the rotor to make a scratch cut. This step checks the lathe setup for accuracy.



P79–25 Turn the lathe off.



P79–26 Observe the first scratch cut.



P79–27 Loosen the spindle retaining nut.



P79–28 Rotate the rotor 180° (one-half turn) on the spindle of the brake lathe.



P79–29 Tighten the spindle nut.



P79–30 Turn the lathe back on and turn the cutting bit slightly into the rotor until a second scratch cut is made.



P79–31 If the second scratch cut is in the same position as the first scratch cut or extends all around the surface of the rotor, then the rotor is properly installed on the lathe.



P79–32 Start the machining process by moving the twin cutters to about the center of the rotor friction surface.



P79–33 Turn the cutting bits inward until they touch the rotor and zero the depth adjustment.



P79–34 Adjust the twin cutters, then dial in the amount of depth (0.005–0.010 in. per side for a rough cut or 0.002 in. for a finish cut) and lock the adjustment so that vibration will not change the setting.



P79–35 Turn the feed control knob until the desired feed rate is achieved for the first or rough cut (0.006–0.010 in. per revolution) or finish cut (0.002 in. per revolution).



P79–36 Engage the automatic feed.

(continued)



P79–37 Observe the machining operation.



P79–38 After the cutting bits have cleared the edge of the rotor, turn the lathe off and measure the thickness of the rotor.



P79–39 Readjust the feed control to a slow rate (0.002 in. per revolution or less) for the finish cut.



P79–40 Reposition the cutting bits for the finish cut.



P79–41 Loosen the adjustment locks.



P79–42 Turn the depth of the cut for the finish cut (0.002 in. maximum).



P79–43 Lock the adjustment.



P79–44 Engage the automatic feed.



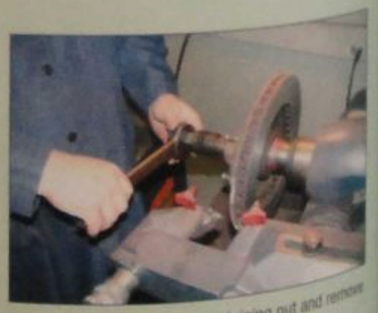
P79–45 Use 150-grit aluminium-oxide sandpaper on a block of wood for 60 seconds per side or a grinder to give a nondirectional and smooth surface to both sides of the rotor.



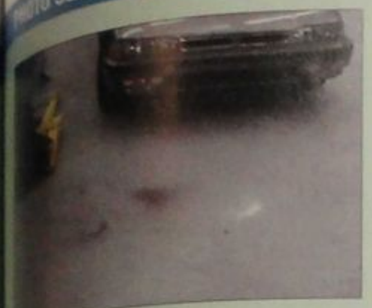
P79–46 After the sanding or grinding operation, thoroughly clean the machined surface of the rotor to remove any and all particles of grit that could affect the operation and life of the disc brake pads.



P79–47 Remove the silencer band.



P79–48 Loosen the spindle retaining nut and remove the rotor.



P79–1 Prepare to machine a disc brake rotor using an on-the-vehicle lathe by properly positioning the vehicle in the stall and hoisting the vehicle to a good working height.



P79–2 Remove the wheels and place them out of the way.



P79–3 Remove the disc brake caliper and use a wire to support the caliper out of the way of the rotor.



P79–4 Measure the rotor thickness and compare it with factory specifications before machining. If a wear thickness is specified, be sure to allow an additional 0.015 in. for wear.



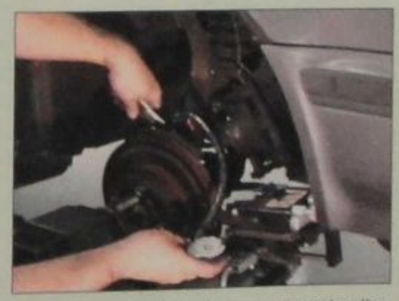
P79–5 Install the hub adapter onto the hub and secure it using the wheel lug nuts.



P79–6 Engage the drive unit by aligning the hole in the drive plate with the raised button on the adapter.



P79–7 Use the thumb wheel to tighten the drive unit to the adapter.



P79–8 Attach a dial indicator to a secure part on the vehicle and position the dial indicator on a flat portion of the lathe to measure the lathe runout.



P79–9 Rotate the wheel or turn the lathe motor on and measure the amount of runout.



P79–10 Use a wrench to adjust the runout using the adjusters stamped on the edge of the drive flange or plate.



P79–11 After the hub runout is adjusted to 0.005 in. or less, remove the dial indicator from the vehicle.



P79–12 Using a T-handle Allen wrench, adjust the cutter arms until they are centered on the disc brake rotor.

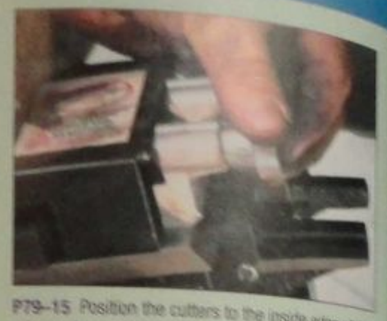
(continued)



P79–13 Move the cutters to the center of the rotor.



P79–14 Adjust the cutter depth until each cutter barely touches the rotor.



P79–15 Position the cutters to the inside edge of the rotor surface and adjust the cutters to the desired depth of cut.



P79–16 Adjust the automatic shut-off so the lathe will turn itself off at the end of the cut.



P79–17 Turn the lathe on by depressing the start button.



P79–18 Monitor the machining operations as the lathe automatically moves the cutters from the center toward the outside edge of the rotor.



P79–19 After the lathe reaches the outside edge of the rotor, the drive motor should stop.



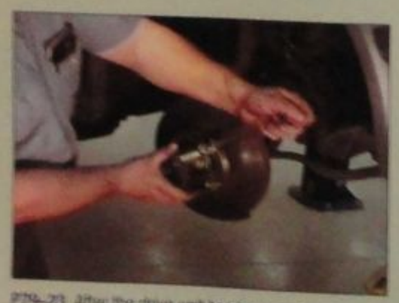
P79–20 Measure the thickness of the rotor after machining to be certain that the rotor thickness is within service limits.



P79–21 The technician is using 150-grit aluminum-oxide sandpaper and a wood block for 60 seconds on each side of the rotor to provide a smooth surface finish.



P79–22 After completing the machining and resurfacing of the rotor, unclamp the drive unit from the hub adapter and clean the rotor.



P79–23 After the drive unit has been removed, remove the lug nuts holding the adapter to the rotor hub.



P79–24 After removing the hub adapter, the caliper can be reinstalled.



P79–25 Be sure to torque the caliper retaining bolts to specifications.



P79–26 Install the wheel and wheel cover. On this vehicle, the wheel cover must be installed before the lug nuts because the lug nuts hold the wheel cover on the wheel.



P79–27 Always use a torque wrench or a torque-limiting adapter with an air impact wrench as shown here when tightening lug nuts.



P79–28 Be sure to clean the wheel covers of any suave fingerprints before returning the vehicle to customer.



P79–29 Pump the brake pedal several times to restore proper brake pedal height. Check and add brake fluid as necessary before moving the vehicle.



P79–30 Carefully back out of the stall and test-drive the vehicle to be assured of proper brake operation before returning the vehicle to the customer.

CHAPTER QUIZ

1. Technician A says that aluminum brake drums use cast-iron friction surfaces. Technician B says that up to 0.030 in. (0.8 mm) should be left after machining a drum to allow for wear. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that hard spots in a brake drum should be removed using a carbide-tip machining tool. Technician B says that the drum should be replaced if hard spots are discovered. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that brake drums on the same axle should be close to the same inside diameter for best brake balance. Technician B says that a brake drum may be cracked if it rings like a bell when tapped with a light steel hammer. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. A rubbing brake drum cannot be machined because it cannot be held in a lathe.
   a. True
   b. False
5. The major reason for brake pedal pulsation during braking is due to excessive rotor thickness variation.
   a. True
   b. False
6. Rotor finish is measured in _____.
   a. Millimeters
   b. Inches
   c. Microinches
   d. Centimeters
7. The lower the Ra of a rotor, the _____ the surface.
   a. Smoother
   b. Rougher
   c. Higher
   d. Lower
8. A disc brake rotor is being installed on a lathe for machining. During the setup a scratch test is performed. The scratch extended all the way around the rotor. Technician A says that the rotor should be loosened, rotated 180°, and retightened. Technician B says that the rotor is not warped. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. Typical maximum rotor runout specifications are _____.
   a. 0.0003 to 0.0005 in. (0.008 to 0.013 mm)
   b. 0.003 to 0.005 in. (0.08 to 0.13 mm)
   c. 0.030 to 0.050 in. (0.8 to 1.3 mm)
   d. 0.300 to 0.500 in. (8.0 to 13 mm)
10. Typical maximum rotor thickness variation (parallelism) specifications are _____.
    a. 0.0003 to 0.0005 in. (0.008 to 0.013 mm)
    b. 0.003 to 0.005 in. (0.08 to 0.13 mm)
    c. 0.030 to 0.050 in. (0.8 to 1.3 mm)
    d. 0.300 to 0.500 in. (8.0 to 13 mm)

CHAPTER

80 Power Brake Unit Operation, Diagnosis, and Service

OBJECTIVES: After studying Chapter 80, the reader will be able to: Prepare for ASE Brakes (A5) certification test content area "D" (Power Assist Units Diagnosis and Repair). • List the parts of a vacuum brake booster. • Describe how a vacuum brake booster operates. • Explain how to test a vacuum brake booster. • Describe how a hydraulic or electrohydraulic brake booster operates.

KEY TERMS: atmospheric pressure • brake assist system (BAS) • dual-diaphragm vacuum booster • inches of mercury (in. Hg) • millimeters of mercury (mm Hg) • power chamber • pressure differential • supplemental brake assist (SBA) • tandem-diaphragm vacuum booster • vacuum

THE NEED FOR POWER BRAKE ASSIST

To double the stopping power of a disc brake, the driver must double the force on the brake pedal. This is the reason that most vehicles equipped with disc brakes are power assisted, even on small, lightweight vehicles. The use of semimetallic brake pads also requires greater force. The most commonly used power-assisted units are vacuum operated.

When a power booster is fitted, the brake pedal ratio is decreased and the master cylinder bore size is increased. The combined effect of these changes is to reduce pedal effort, while greatly increasing pedal reserve. See Figure 80–1.

Power boosters do not alter the hydraulic system and they still allow braking even if the booster fails or its power supply is cut off. All boosters have a power reserve that provides assist for at least one hard stop, and sometimes several light brake applications, even after power is lost. However, because power brake systems are designed with the added force of the booster taken into account, the amount of brake pedal pressure required to slow or stop a vehicle is much higher than in a nonboosted system once the reserve is used up. For this reason, some vehicles with power brakes have a brake pedal that is wide enough to allow two-foot braking should the booster fail. See Figure 80–2.

PRINCIPLES OF VACUUM

Most vacuum-powered brake boosters get their vacuum supply from the engine intake manifold. An engine is essentially a big air pump because the pistons move up and down in the cylinders to pump in air and fuel, and pump out exhaust. They do this by creating differences in air pressure.

As a piston moves downward on an intake stroke with the intake valve open, it creates a larger area inside the cylinder for air to fill. This lowers the air pressure within the cylinder, and the higher-pressure air outside the engine flows in through the intake manifold in an attempt to fill the low-pressure area. Although it may seem as though the low pressure is pulling air into the engine, it is really the higher pressure outside that forces air in. The difference in pressure between two areas is called a **pressure differential.**

Because throttle valves and manifold shape restrict intake airflow, high pressure air from outside the engine is almost never able to move into the cylinders fast enough to fill the space created. As a result, gasoline-powered internal-combustion engines normally operate with a low-pressure area, or partial vacuum, in the intake manifold. The term ***vacuum*** is used to refer to any pressure lower than **atmospheric pressure.** Atmospheric pressure varies with

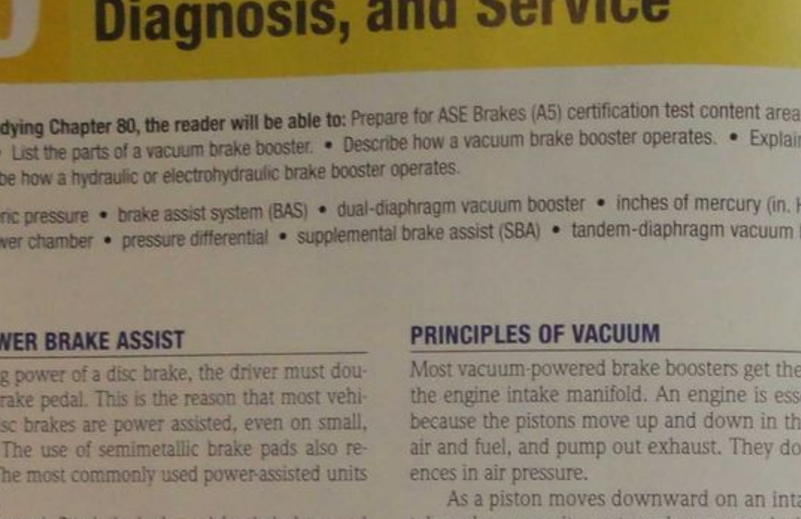


Figure 80–1 Typical vacuum brake booster assembly. The vacuum hose attaches to the intake manifold of the engine. The brake pedal travel sensor is an input sensor for the antilock braking system.



Figure 80–2 A wide brake pedal allows two-foot braking if power assist is lost.

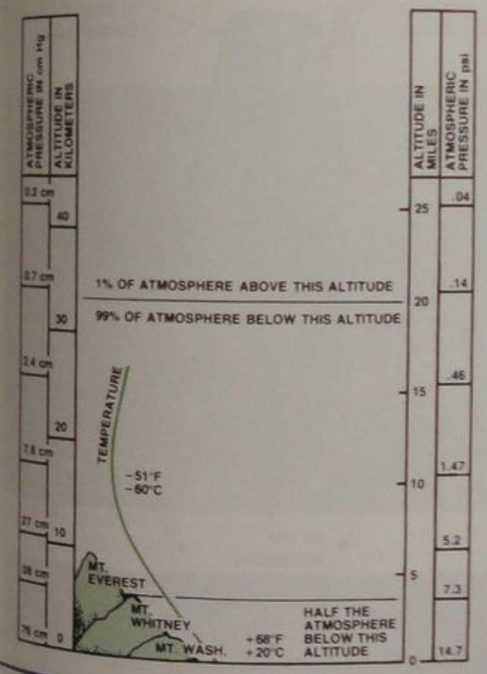


Figure 80–3 Atmospheric pressure varies with altitude.

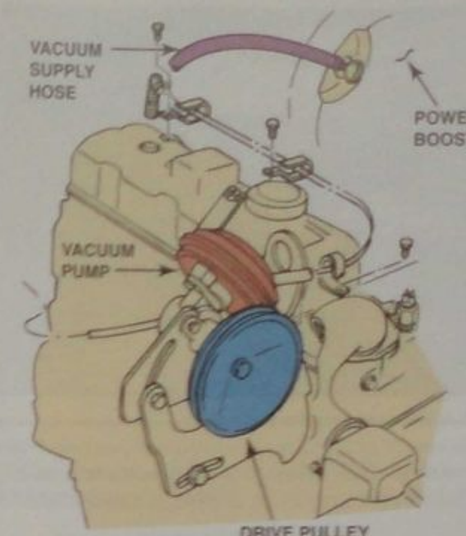


Figure 80–4 A belt-driven auxiliary vacuum pump.

...itude, but is approximately 14.7 pounds per square inch (PSI) at ...a level. See Figure 80–3.

Measuring Vacuum Vacuum is measured in **inches of mercury (in. Hg)** or in **millimeters of mercury (mm Hg),** a figure that indicates how far a column of mercury in a tube will rise when a vacuum is applied at one end, and atmospheric pressure at the other. Vacuum is a measurement of the pressure differential between the lower pressure inside the tube, and the higher pressure outside it.

A perfect vacuum is about 30 in. Hg (762 mm Hg). However, a perfect vacuum occurs only in space, and is never achieved in an engine's intake manifold. Manifold vacuum varies with throttle position. The lowest manifold vacuum (highest pressure) occurs when the throttle is wide open with the engine under load. The highest manifold vacuum (lowest pressure) may be as much as 24 in. Hg (610 mm Hg) when the vehicle is rolling rapidly downhill in gear with the throttle closed. Manifold vacuum at idle typically falls between 15 and 20 in. Hg (381 and 508 mm Hg), and most vacuum brake boosters are designed to operate with vacuum levels in this range.

Booster Vacuum Supply Vacuum boosters get their vacuum supply from the engine intake manifold. Diesel engines, however, run unthrottled (engine speed is controlled strictly by the amount of fuel injected) and have little or no intake manifold vacuum. If a vehicle with a diesel engine is equipped with a vacuum-powered brake booster, it must also be fitted with an auxiliary vacuum pump.

Some small gasoline-powered and diesel engines use a belt-driven add-on pump. See Figure 80–4.

An electrically powered vacuum pump is turned on and off by a pressure switch on the booster. This means they operate only when needed, and thus reduce power drain on the engine. See Figure 80–5.

VACUUM BOOSTER THEORY

Vacuum boosters use the principle of pressure differential to increase brake application force. The typical vacuum booster has a **power chamber** separated into two smaller chambers by a flexible diaphragm. When air pressure is greater on one side of the diaphragm than the other, a pressure differential is created. In an attempt to equalize pressure in the two chambers, the higher pressure exerts a force that moves the diaphragm toward the lower pressure area. Rods attached to the diaphragm transmit this force, plus the force the driver exerts on the brake pedal, to the master cylinder.

The amount of force created in this manner is proportional to the difference in pressure between the two sides. In other words, the greater the pressure differential, the greater the force. To calculate the force, the pressure differential is multiplied by the diaphragm surface area. For example, if a power booster diaphragm has atmospheric pressure (14.7 PSI) on one side, and a typical intake

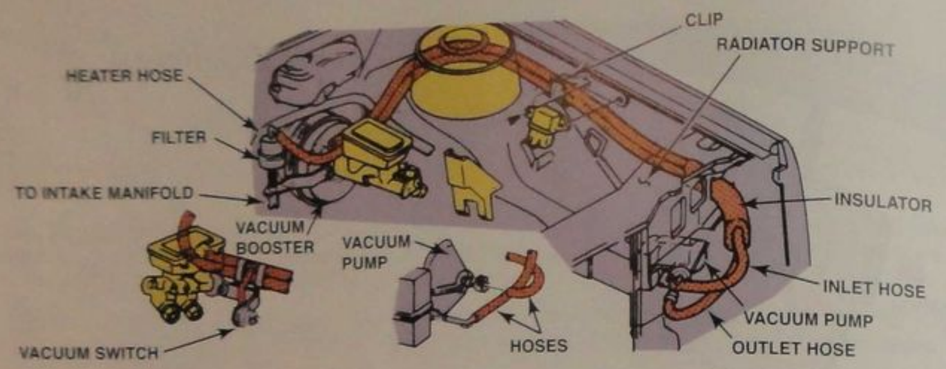


Figure 80–5 An electrically powered vacuum pump.

manifold vacuum of 20 in. Hg (10 PSI of absolute pressure), the pressure differential acting on the diaphragm would be as follows:

14.7 PSI − 10 PSI = 4.7 PSI

If we once again multiply this times the area of the diaphragm, the result is as follows:

4.7 PSI × 50 sq. in. = 235 pounds of force

Vacuum booster diaphragms are sized to fit specific applications and provide the necessary application force. Most vacuum boosters are capable of providing hundreds of pounds of application force. See Figure 80–6.

TECH TIP ✔ **Check the Vacuum, Then the Brakes**

A customer complained of a very rough idle and an occasional pulsating brake pedal. The customer was certain that the engine required serious work since there were over 100,000 miles on the vehicle. During the troubleshooting procedure, a spray cleaner was used to find any vacuum (air) leaks. A large hole was found melted through a large vacuum hose next to the vacuum hose feeding the vacuum-operated power brake booster.

After repairing the vacuum leak, the vehicle was test driven again to help diagnose the cause of the pulsating brake pedal. The engine idled very smoothly after the vacuum leak was repaired and the brake pulsation was also cured. The vacuum leak resulted in lower-than-normal vacuum being applied to the vacuum booster. During braking, when engine vacuum is normally higher (deceleration), the vacuum booster would assist, then not assist when the vacuum was lost. This on-and-off supply of vacuum to the vacuum booster was noticed by the driver as a brake pulsation. Always check the vacuum at the booster whenever diagnosing any brake problems. Most vehicle manufacturers specify a maximum of 15 in. Hg of vacuum at the booster. The booster should be able to provide at least two or three stops even with no vacuum. The booster should also be checked to see if it can hold a vacuum after several hours. A good vacuum booster, for example, should be able to provide a power assist after sitting all night without starting the engine.

CHARCOAL FILTER

The vacuum hose leading from the engine to the power booster should run downward without any low places in the hose. If a dip or sag occurs in the vacuum hose, condensed fuel vapors and/or moisture can accumulate that can block or restrict the vacuum to the booster. Many manufacturers use a small charcoal filter in the vacuum line between the engine and booster, as shown in Figure 80–7.

The charcoal filter attracts and holds gasoline vapors and keeps fumes from entering the vacuum booster. Without this filter, gasoline

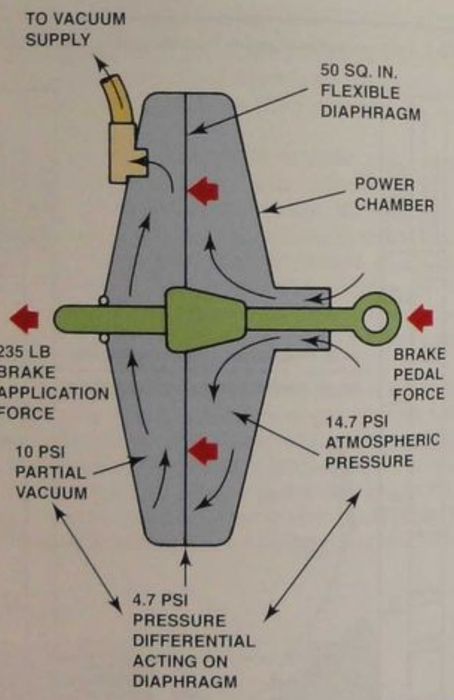


Figure 80–6 Vacuum brake boosters operate on the principle of pressure differential.



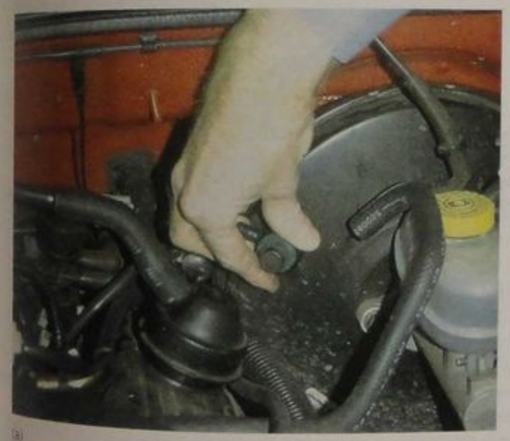
Figure 80–7 The charcoal filter traps gasoline vapors that are present in the intake manifold and prevents them from getting into the vacuum chamber of the booster.

fumes can enter the vacuum booster, where it can deteriorate the rubber diaphragm and other rubber components of the booster.

VACUUM CHECK VALVE

All vacuum boosters use a one-way vacuum check valve. This valve allows air to flow in only one direction—from the booster toward the engine. This valve prevents loss of vacuum when the engine stops. Without this check valve, the vacuum stored in the vacuum booster would simply be lost through the hose and intake manifold of the engine. See Figures 80–8 and 80–9.

CAUTION: Sometimes an engine backfire can destroy or blow the vacuum check valve out of the booster housing. If this occurs, all power assist will be lost and a much greater-than-normal force must be exerted on the brake pedal to stop the vehicle. Be sure to repair the cause of the backfire before replacing the damaged or missing check valve. Normal causes of backfire include an excessively lean air–fuel ratio or incorrect firing order or ignition timing.



(a)



(b)

Figure 80–8 (a) Many vacuum-brake-booster check valves are located where the vacuum hose from the engine (vacuum source) attaches to the vacuum booster. (b) This one-way valve prevents the loss of vacuum when the engine is off. The diaphragm inside allows air to flow in one direction only.

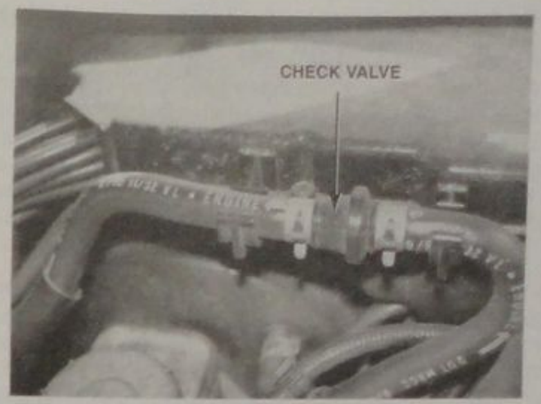


Figure 80–9 Not all check valves are located at the vacuum line to the booster housing connection. This vehicle uses an inline check valve located between the intake manifold of the engine and the vacuum brake booster.

VACUUM BRAKE BOOSTER OPERATION

A vacuum power-brake booster contains a rubber diaphragm(s) connected to the brake pedal at one end and to the master cylinder at the other end. When the brakes are off or released, there is equal vacuum on both sides of the diaphragm.

The vacuum power unit contains the power-piston assembly, which houses the control valve and reaction mechanism, and the power-piston return spring. The control valve is composed of the air valve (valve plunger), the floating control-valve assembly, and the pushrod. The reaction mechanism consists of a hydraulic piston reaction plate and a series of reaction levers. An air filter, air silencer, and filter retainer are assembled around the valve operating rod, filling the cavity inside the hub of the power piston. The pushrod that operates the air valve projects out of the end. See Figure 80–10.

Released-Position Operation At the released position (brake pedal up), the air valve is seated on the floating control valve, which shuts off the air. The floating control valve is held away from the valve seat in the power-piston insert. Vacuum from the engine is present in the space on both sides of the power piston. Any air in the system is drawn through a small passage in the power piston, over the

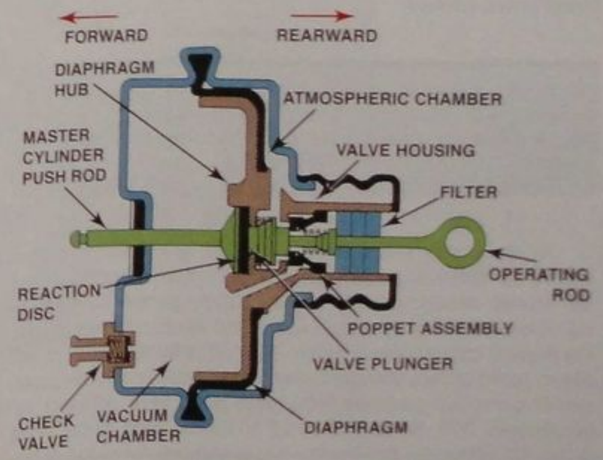


Figure 80–10 Cross-sectional view of a typical vacuum brake booster assembly.

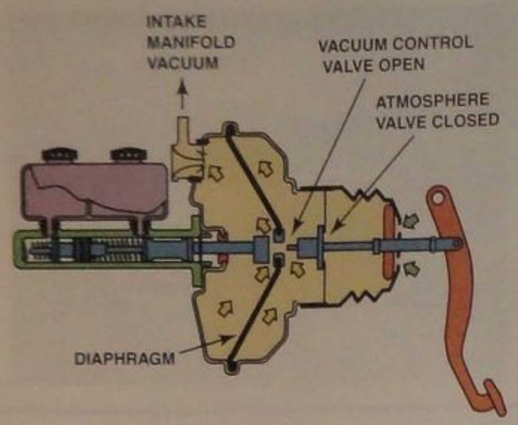


Figure 80–11 In the release position (brake pedal up), the vacuum is directed to both sides of the diaphragm.

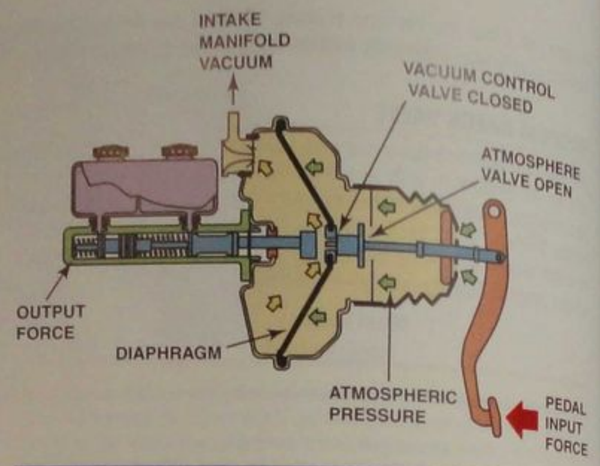


Figure 80–12 Simplified diagram of a vacuum brake booster in the apply position. Notice that the atmospheric valve is open and air pressure is being applied to the diaphragm.

seat in the power-piston insert, and through a passage in the power-piston insert. There is a vacuum on both sides of the power piston, and it is held against the rear of the housing by the power-piston return spring. At rest, the hydraulic reaction plate is held against the reaction retainer. The air-valve spring holds the reaction lever against the hydraulic reaction plate and holds the air valve against its stop in the tube of the power piston. The floating control-valve assembly is held against the air-valve seat by the floating control-valve spring. See Figure 80–11.

Applied-Position Operation As the brake pedal is depressed, the floating control valve is moved toward its seat in the power piston, away from the rear of the booster. The smaller air valve spring causes the air valve to stretch out toward the retreating floating control valve until it bottoms out on the lip of the power piston's vacuum passage. This closes off the vacuum supply to the rear section of the housing. Since the floating control valve travels farther than the sealing end of the air valve, atmospheric air is allowed to enter between the air valve and the floating control valve pressurizing the rear section of the housing. At this point, the rear section of the housing is pressurized and the front section is under vacuum. Atmospheric pressure can then force the power piston forward.

NOTE: This movement of air into the rear chamber of the brake booster may be heard inside the vehicle as a hissing noise. The loudness of this airflow varies from vehicle to vehicle and should be considered normal.

As the power piston travels forward, the pushrod pushes against the hydraulic reaction plate in the master cylinder pushing the master cylinder primary and secondary pistons forward. As back-pressure builds up on the end of the master cylinder piston, the floating control valve is pushed back off of its seat in the power piston applying back pressure to the brake pedal. The power piston return spring also generates some brake pedal force. All in all, approximately 30% of the brake load is applied back to the brake pedal. This gives the driver a feel that is proportional to the degree of brake application. See Figure 80–12.

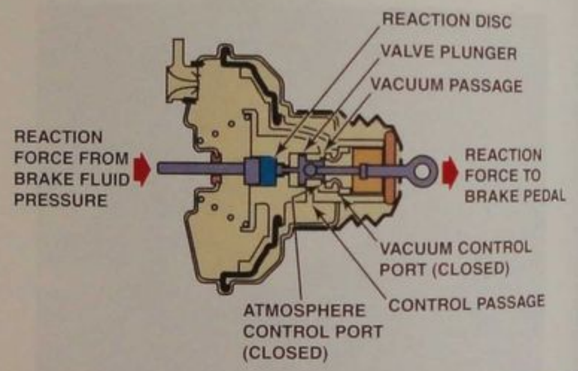


Figure 80–13 Cross section of a vacuum brake booster in the hold position with both vacuum and atmospheric valves closed. Note that the reaction force from the brake fluid pressure is transferred back to the driver as a reaction force to the brake pedal.

Hold-Position Operation When the desired brake pedal force is reached and there is balance between the opposing forces of the brake pedal and the master cylinder, the power piston moves forward "around" the floating control valve and reaction disc until the air valve sealing end "catches up" with the floating control valve. At this point, the air valve is once again sealed against the floating control valve and is no longer blocking the vacuum passage in the power piston. The floating control valve is again held away from its seat. Vacuum once again is present on both sides of the diaphragm and power piston. The status of the booster is almost exactly as it was in the released state except that the positions of the power piston and subsequently the master cylinder pistons are farther forward. Brake pedal force is keeping the power piston in its position. If additional braking is required (brake pedal pushed farther), the floating control valve moves away from the air valve permitting the power of atmospheric pressure to push the power piston and master cylinder pistons forward. If the pedal is released, since vacuum is then present on both sides of the diaphragm, the power piston return spring moves the power piston to its released state. See Figure 80–13.

Vacuum-Failure Mode In case of vacuum source interruption, the brake operates as a standard brake as follows. As the pedal is pushed down, the operating rod forces the floating control valve against the power piston and reaction disc. This force is then applied to the pushrod and subsequently the hydraulic reaction plate fastened to the master cylinder piston rod, which applies pressure in the master cylinder. For safety in the event of a stalled engine and a loss of vacuum, a power brake booster should have adequate storage of vacuum for several power-assisted stops.

TECH TIP ✓ **A Low, Soft Brake Pedal Is Not a Power Booster Problem**

Some service technicians tend to blame the power-brake booster if the vehicle has a low, soft brake pedal. A defective power-brake booster causes a hard brake pedal, not a soft brake pedal. A soft or spongy brake pedal is usually caused by air being trapped somewhere in the hydraulic system.

Many times, the technician has bled the system and, therefore, thinks that the system is free of any trapped air. According to remanufacturers of master cylinders and power-brake boosters, most of the returned parts under warranty are not defective. Incorrect or improper bleeding procedures account for much of the problem.

DUAL- (TANDEM-) DIAPHRAGM VACUUM BOOSTERS

To provide power assist, air pressure must work against a rubber diaphragm. The larger the area of the diaphragm, the more force can be exerted. The usual method of increasing the area of the vacuum diaphragm was to increase the diameter of the vacuum booster. However, a larger vacuum booster took up too much room under the hood of many vehicles. Instead of increasing the diameter, vacuum booster manufacturers used two smaller-diameter diaphragms and placed one in front of the other. These designs increased the total area without increasing the physical diameter of the booster. This style is called a **dual-diaphragm** or **tandem-diaphragm vacuum booster.** See Figure 80–14.

BRAKE ASSIST SYSTEM

Some vehicles are equipped with a **brake assist system (BAS)** that applies the brakes with maximum force if the system detects that the driver is making a panic stop. Tests performed by brake engineers have indicated that it is normal for a person to first apply the brakes rapidly during a panic situation. However, it was also found that the driver would tend to reduce the force applied to the brake pedal. As a result, the vehicle did not brake with the maximum effort.

Operation The brake assist system opens an air valve on the rear part of the vacuum booster assembly. As a result, more air at atmospheric pressure can flow into the rear chamber of the vacuum booster, thereby increasing the force applied to the master cylinder. The BAS function works with the electronic stability control (ESC) system to ensure maximum braking efficiency during evasive or emergency situations.

If the speed of the brake pedal application exceeds a predetermined limit as determined by the brake pedal travel sensor, the ABS controller energizes the BAS solenoid valve. When the solenoid valve opens, additional air at atmospheric pressure enters the driver's side of the booster. The additional pressure applies the brakes faster and with more force. The BAS solenoid is de-energized when the brake pedal is released and normal braking returns. See Figures 80–15 and 80–16.

VACUUM BOOSTER OPERATION TEST

With the engine "off," apply the brakes several times to deplete the vacuum. With your foot on the brake pedal, start the engine. The brake pedal *should* drop. If the brake pedal does *not* drop, check for proper vacuum source to the booster. If there is proper vacuum, repair or replacement of the power booster is required.

VACUUM BOOSTER LEAK TEST

To test if the vacuum booster can hold a vacuum, run the engine to build up a vacuum in the booster, then turn the engine off. Wait

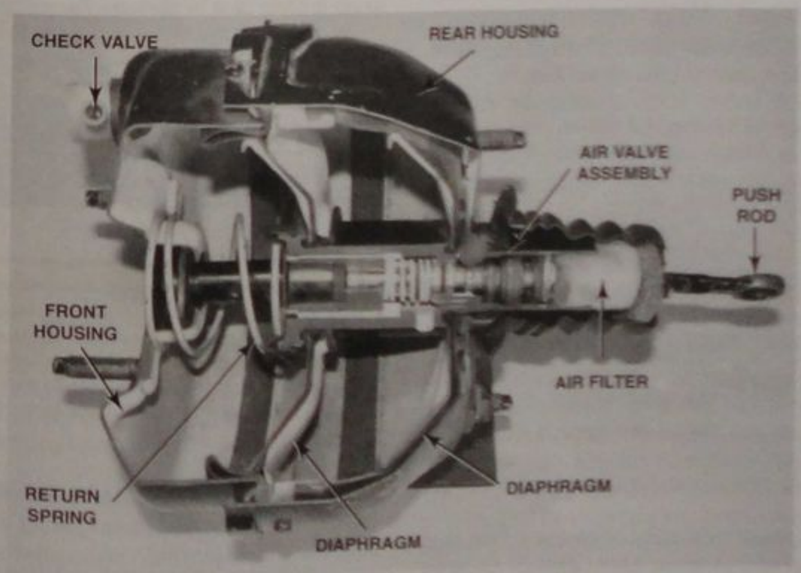


Figure 80–14 Cutaway showing a dual-diaphragm (tandem) vacuum brake booster.

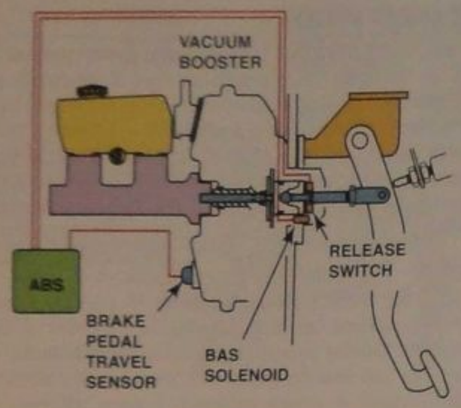


Figure 80–15 A typical brake assist system uses a brake pedal travel sensor and a BAS solenoid to apply the brakes during a panic condition.

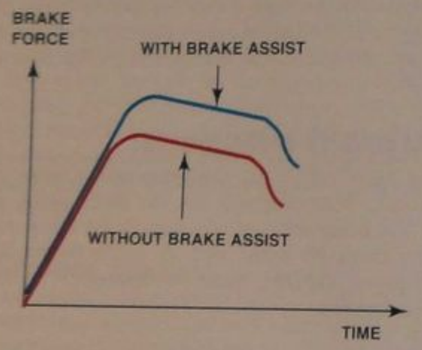


Figure 80–16 When the brake assist function operates, the brake force is much higher than normal.

one minute, then depress the brake pedal several times. There should be two or more power-assisted brake applications.

If applications are not power assisted, either the vacuum check valve or the booster is leaking. To test the check valve, remove the valve from the booster and blow through the check valve. If air passes through, the valve is defective and must be replaced. If the check valve is okay, the vacuum booster is leaking and should be repaired or replaced based on the manufacturer's recommendations.

HYDRAULIC SYSTEM LEAK TEST

An internal or external hydraulic leak can also cause a brake system problem. To test if the hydraulic system (and not the booster) is leaking, depress and release the brake pedal (service brakes) several times. This should deplete any residual power assist. On some ABS units, this may require depressing the brake pedal 20 or more times!

After depleting the power-assist unit, depress and then hold the brake pedal depressed with medium force (20 to 35 lb. or 88 to 154 N). The brake pedal should *not* fall away. If the pedal falls, the hydraulic brake system is leaking. Check for external leakage at wheel cylinders, calipers, hydraulic lines, and hoses. If there is no external leak, there may be an internal leak inside the master cylinder. Repair or replace components as needed to correct the leakage.

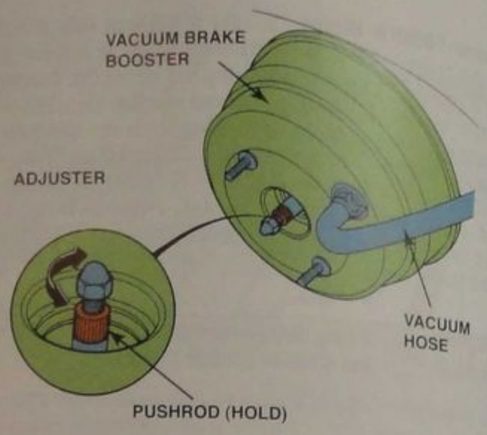


Figure 80–17 Typical adjustable pushrod. This adjustment is critical for the proper operation of the braking system. If the pushrod is too long, the brakes may be partially applied during driving. If the rod is too short, the brake pedal may have to be depressed farther down before the brakes start to work.

PUSHROD CLEARANCE ADJUSTMENT

Whenever the vacuum brake booster or the master cylinder is replaced, the pushrod length should be checked. The length of the pushrod must match correctly with the master cylinder. See Figure 80–17.

If the pushrod is too long and the master cylinder is installed, the rod may be applying a force on the primary piston of the master cylinder even though the brake pedal is not applied. This can cause the brakes to overheat, causing the brake fluid to boil. If the brake fluid boils, a total loss of braking force can occur. Obviously, this pushrod clearance check and adjustment is very important. A gauge is often used to measure the position of the master cylinder piston, and then the other end of the gauge is used to determine the proper pushrod clearance. See Figure 80–18.

VACUUM BOOSTER DISASSEMBLY AND SERVICE

Some vehicle manufacturers recommend that the vacuum brake booster be disassembled and overhauled if defective.

CAUTION: Some vehicle manufacturers recommend that the vacuum brake booster be replaced as an assembly if tested to be leaking or defective. Always follow the manufacturer's recommendations.

A special holding fixture should be used before rotating (unlocking) the front and rear housing because the return spring is strong. See Figure 80–19.

Disassemble the vacuum brake booster according to the manufacturer's recommended procedures for the specific unit being serviced. See Figure 80–20.

A rebuilding kit is available that includes all necessary parts and the proper silicone grease. The manufacturer warns that all parts included in the kit be replaced.

FREQUENTLY ASKED QUESTION ???

What Is Supplemental Brake Assist?

Supplemental brake assist, SBA, is a motor-driven vacuum pump that can supplement engine vacuum to the vacuum brake booster. This unit is used on some General Motors vehicles. When a vehicle is driven under a heavy load, engine vacuum is low. To meet the brake standards, some vehicles are equipped with the brake assist system that consists of the following components:

- A pressure sensor that is used to measure the vacuum in the vacuum booster.
- An intake manifold check valve that is used to prevent vacuum from escaping the vacuum boost.
- A motor-driven vacuum pump.

The vacuum pump motor will start and run if the pressure sensor detects no vacuum in the booster is below 7 in. Hg and will shut off after the vacuum level increases to 9 in. Hg.

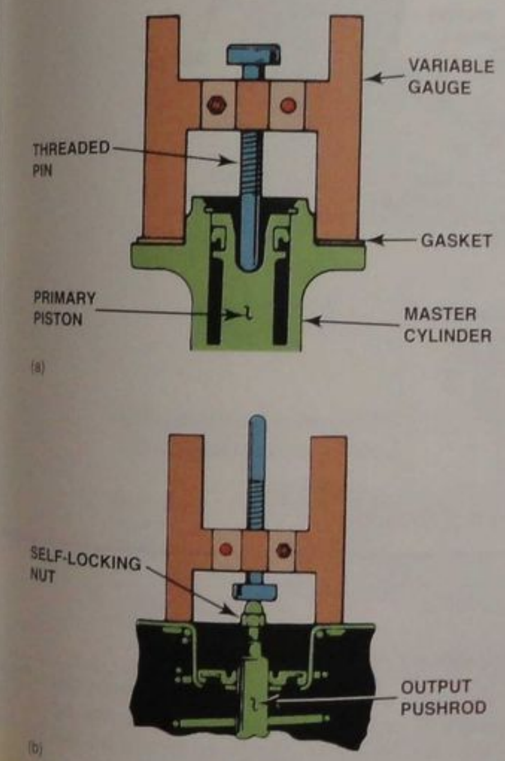


Figure 80–18 Typical vacuum brake booster pushrod gauging tool. (a) The tool is first used against the mounting flange of the master cylinder and the depth of the piston determined. (b) The gauge is then turned upside down and used to gauge the pushrod length. Some vacuum brake boosters do not use adjustable pushrods. If found to be the incorrect length, a replacement pushrod of the correct length should be installed.

HYDRO-BOOST HYDRAULIC BRAKE BOOSTER

Hydro-boost is a hydraulically operated power-assist unit built by Bendix. The hydro-boost system uses the pressurized hydraulic fluid from the vehicle's power steering pump as a power source rather than using engine vacuum as is used with vacuum boosters. See Figures 80–21 and 80–22.

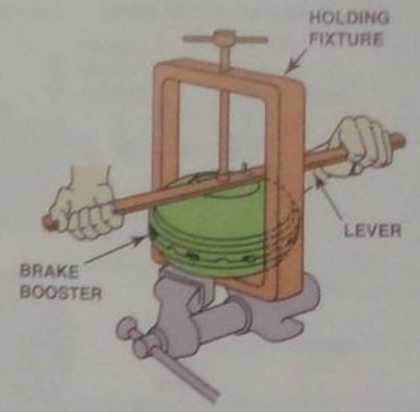


Figure 80–19 A holding fixture and a long tool being used to rotate the two halves of a typical vacuum brake booster.

The hydro-boost unit is used on vehicles that lack enough engine vacuum, such as turbo-charged or diesel engine vehicles. During operation, diesel engines do not produce vacuum in the intake manifold. As a result, diesel engines must use accessory engine-driven vacuum pumps to operate vacuum accessories. Turbocharged and supercharged engines do not create engine vacuum during periods of acceleration. Even though vacuum is available when the engine is decelerating, some vehicle manufacturers elect to install a hydro-boost system rather than equip the vehicle with an accessory engine-driven vacuum pump.

Operation Fluid pressure from the power steering pump enters the unit and is directed by a spool valve. See Figure 80–23 on page 987.

When the brake pedal is depressed, the lever and primary valve are moved. The valve closes off the return port, causing pressure to build in the boost pressure chamber. The hydraulic pressure pushes on the power piston, which then applies force to the output rod that connects to the master cylinder piston. In the event of a power steering pump failure, power assist is still available for several brake applications. See Figure 80–24 on page 988.

During operation, hydraulic fluid under pressure from the power steering pump pressurizes an accumulator. See Figure 80–25.

While some units use a spring inside the accumulator, most hydro-boost units use nitrogen gas. The fluid trapped in the accumulator under pressure is used to provide power-assisted stops in the event of a hydraulic system failure.

Diagnosis The power source for hydro-boost units comes from the power steering pump. The first step of troubleshooting is to perform a thorough visual inspection, including the following:

1. Checking for proper power steering fluid level
2. Checking for leaks from the unit or power steering pump
3. Checking the condition and tightness of the power steering drive belt
4. Checking for proper operation of the base brake system

After checking all of the visual components, check for proper pressure and volume from the power steering pump using a power steering pump tester, as shown in Figures 80–26 and 80–27 on page 988.

The pump should be capable of producing a minimum of 2 gallons (7.5 liters) with a maximum pressure of 150 PSI (1000 kPa) with the steering in the straight-ahead position. With the engine "off," the accumulator should be able to supply a minimum of two power-assisted brake applications.

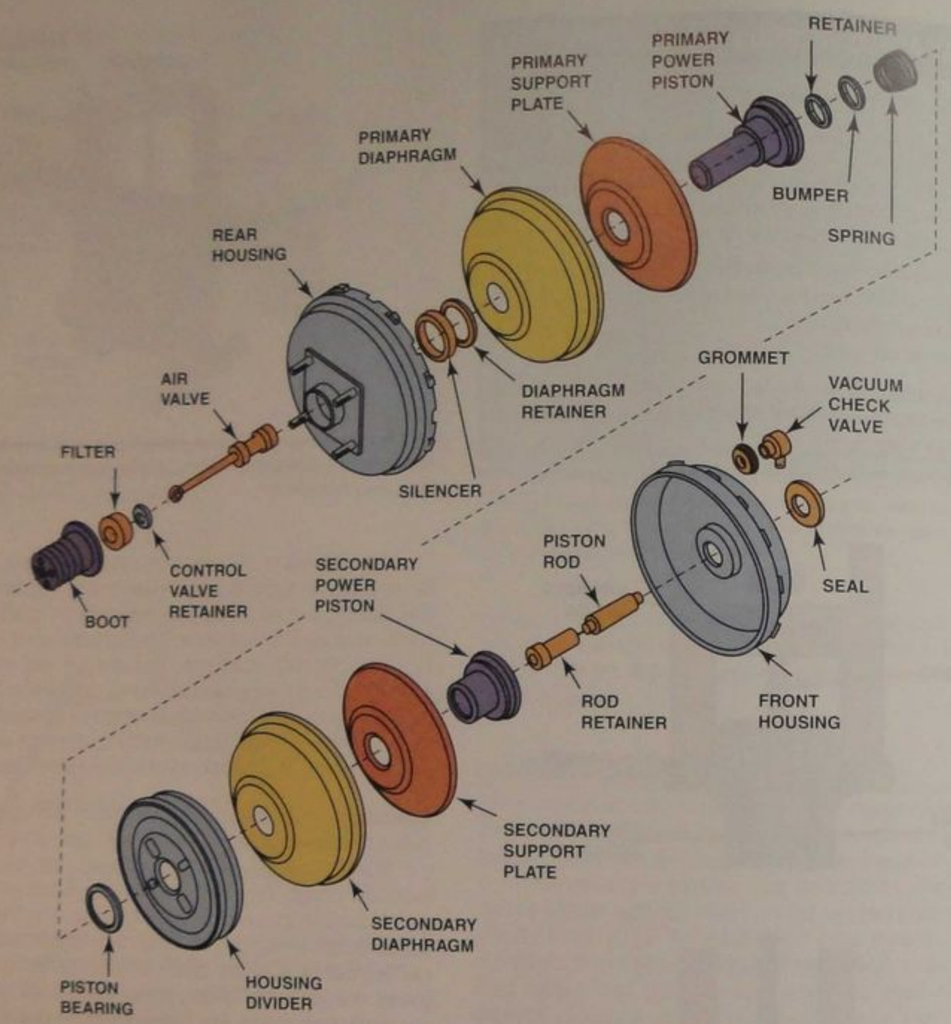


Figure 80–20 Exploded view of a typical dual-diaphragm vacuum brake booster assembly.

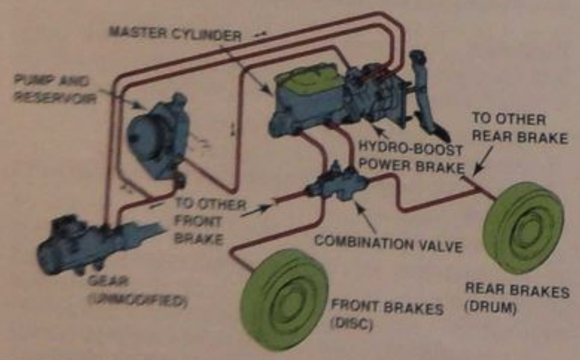


Figure 80–21 Hydro-boost unit attaches between the bulkhead and the master cylinder and is powered by the power steering pump. (Courtesy of Allied Signal Automotive Aftermarket)

HYDRO-BOOST FUNCTION TEST

With the engine off, apply the brake pedal several times until the accumulator is depleted completely. Depress the service brake pedal and start the engine. The pedal should fall and then push back against the driver's foot.

TECH TIP ✔ **The Hydro-Boost Accumulator Test**

The accumulator stores hydraulic fluid under pressure to provide a reserve in the event of a failure of the power steering system. The accumulator is designed to provide three or more power-assisted stops with the engine off. See Figure 80–28 on page 988

If the accumulator fails, it does not hold pressure. To easily check whether the accumulator has lost its charge, simply grasp the accumulator with your hand and try to twist or move it. The accumulator should have so much pressure on it that it should not move or wiggle. If the accumulator moves, it has lost its ability to hold pressure and the hydro-boost unit should be replaced.

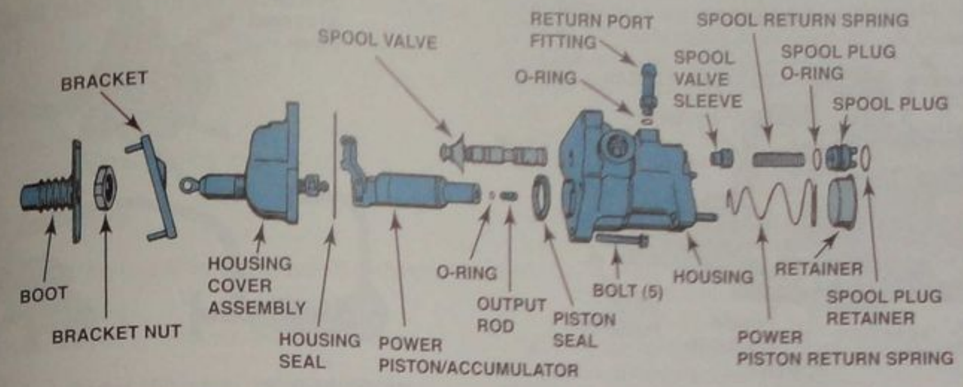


Figure 80–22 Exploded view of the hydro-boost unit. *(Courtesy of Allied Signal Automotive Aftermarket)*

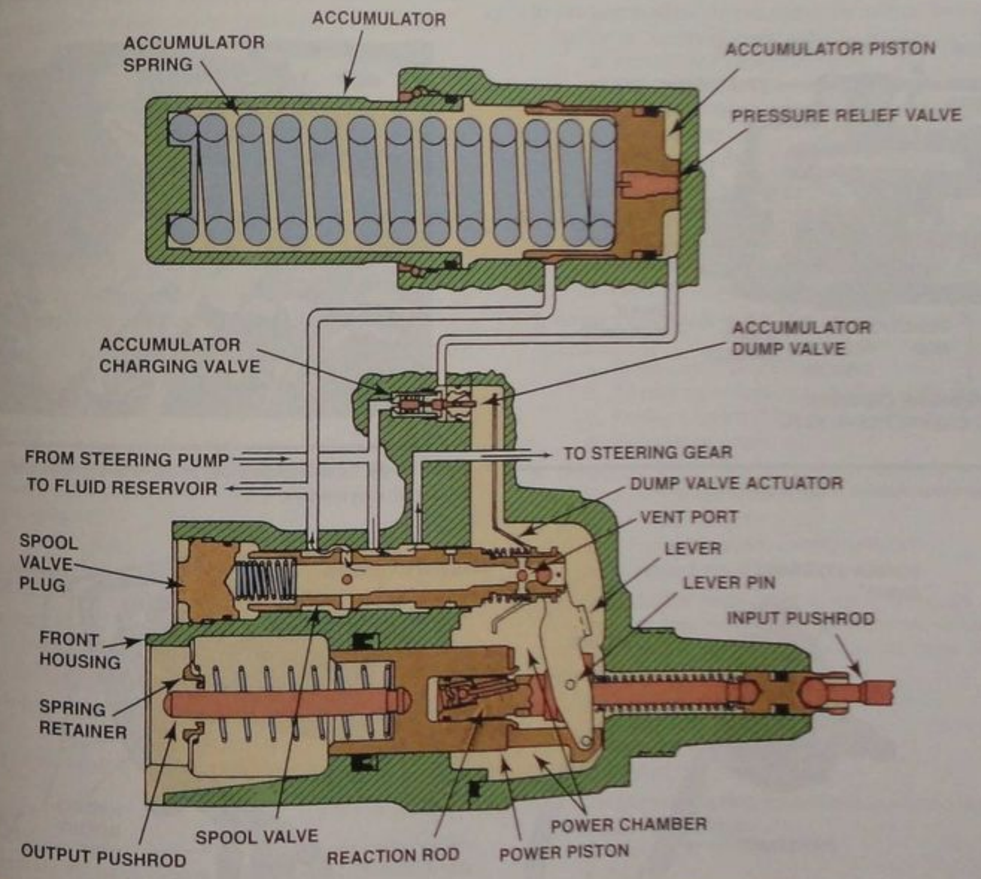


Figure 80–23 A hydro-boost hydraulic booster in the unapplied position.

HYDRO-BOOST SYMPTOM-BASED GUIDE

Excessive Brake Pedal Effort Possible causes for this include the following:

1. Loose or broken power steering pump belt
2. No fluid in the power steering reservoir
3. Leaks in the power steering, booster, or accumulator hoses
4. Leaks at tube fittings, power steering, booster, or accumulator connections
5. External leakage at the accumulator
6. Faulty booster piston seal, causing leakage at the booster flange vent
7. Faulty booster cover seal with leakage between the housing and cover
8. Faulty booster spool plug seal

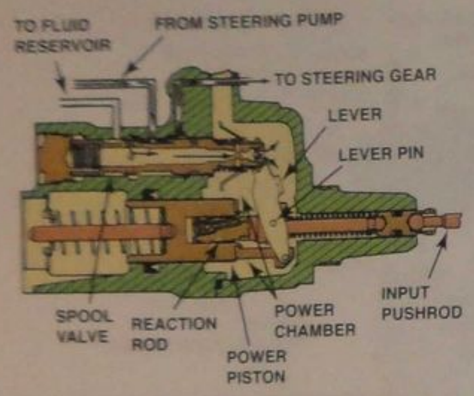


Figure 80–24 A hydro-boost hydraulic booster as the brakes are applied.

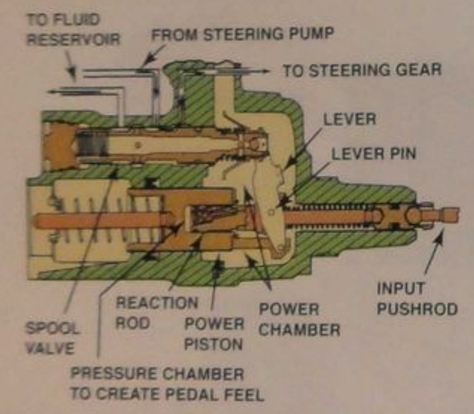


Figure 80–25 A hydro-boost hydraulic booster in the holding position.

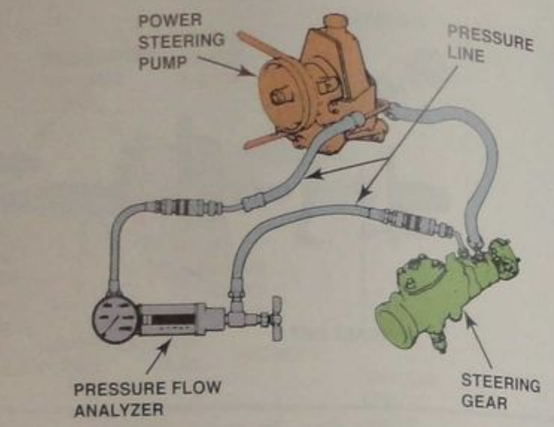


Figure 80–27 Pressure and flow analyzer installation to check the power steering pump output.



Figure 80–28 The accumulator should be able to hold pressure and feel tight when hand force is used to try to move it.

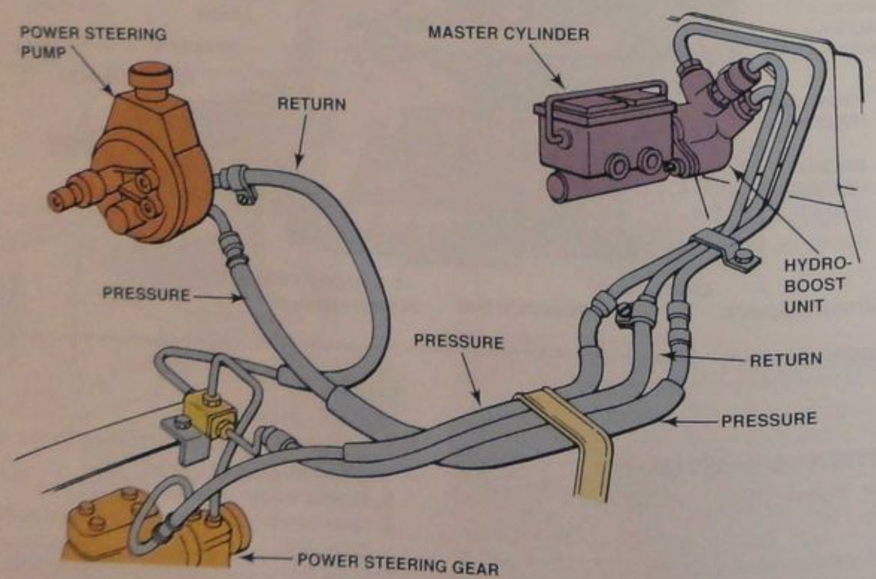


Figure 80–26 A typical hydro-boost hydraulic line arrangement showing the pump, steering gear, and brake booster assembly.

Slow Brake Pedal Return Possible causes for this include the following:

1. Excessive seal friction in the booster
2. Faulty spool action
3. Broken piston return spring
4. Restriction in the return line from the booster to the pump reservoir
5. Broken spool return spring

Grabby Brakes Possible causes for this include the following:

1. Broken spool return spring
2. Faulty spool action caused by contamination in the system

Booster Chatters—Pedal Vibrates Possible causes for this include the following:

1. Power steering pump belt slipping
2. Low fluid level in the power steering pump reservoir
3. Faulty spool operation caused by contamination in the system

SUMMARY

1. Vacuum brake boosters use air pressure acting on a diaphragm to assist the driver's force on the brake master cylinder.
2. At rest, there is vacuum on both sides of the vacuum booster diaphragm. When the brake pedal is depressed, atmospheric air pressure is exerted on the back side of the diaphragm.
3. The use of two diaphragms in tandem allows a smaller-diameter booster with the same area. The larger the area of the booster diaphragm, the more air pressure force can be applied to the master cylinder.
4. Hydraulic-operated brake boosters use either an electric motor-driven pump or the engine-driven power steering pump.
5. When replacing a vacuum brake booster, always check for proper pushrod clearance.
6. To be assured of power-assisted brake application in the event of failure, hydraulic power-assisted brake systems use an accumulator to provide pressure to the system.

REVIEW QUESTIONS

1. Describe the purpose and function of the one-way check valve used on vacuum brake booster units.
2. Explain how vacuum is used to assist in applying the brakes.
3. Describe how to perform a vacuum booster leak test and hydraulic system leak test.
4. Explain how a hydro-boost system functions.

CHAPTER QUIZ

1. Two technicians are discussing vacuum brake boosters. Technician A says that a low, soft brake pedal is an indication of a defective booster. Technician B says that there should be at least two power-assisted brake applications after the engine stops running. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that to check the operation of a vacuum brake booster, the brake pedal should be depressed until the assist is depleted and then start the engine. Technician B says that the brake pedal should drop when the engine starts, if the booster is okay. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Brake pedal feedback to the driver is provided by the _____.
   a. Vacuum check-valve operation
   b. Reaction system
   c. Charcoal filter unit
   d. Vacuum diaphragm
4. The proper operation of a vacuum brake booster requires that the engine be capable of supplying at least _____.
   a. 15 in. Hg vacuum
   b. 17 in. Hg vacuum
   c. 19 in. Hg vacuum
   d. 21 in. Hg vacuum
5. The purpose of the charcoal filter in the vacuum hose between the engine and the vacuum brake booster is to _____.
   a. Filter the air entering the engine
   b. Trap gasoline vapors to keep them from entering the booster
   c. Act as a one-way check valve to help keep a vacuum reserve in the booster
   d. Direct the vacuum
6. A defective vacuum brake booster will cause a _____.
   a. Hard brake pedal
   b. Soft (spongy) brake pedal
   c. Low brake pedal
   d. Slight hiss noise when the brake pedal is depressed
7. An accumulator such as that used on electric or hydraulic brake boosters _____.
   a. Reduces brake pedal noise
   b. Provides higher force being fed back to the driver's foot
   c. Provides a reserve in the event of a failure
   d. Works against engine vacuum
8. The first step in diagnosing a hydro-boost problem is _____.
   a. A pressure test of the pump
   b. A volume test of the pump
   c. To tighten the power steering drive belt
   d. A thorough visual inspection
9. A brake pedal feels spongy when depressed. Technician A says that a defective hydraulic brake booster could be the cause. Technician B says that a defective vacuum brake booster could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. If the engine stops running, the hydro-boost will not be able to provide any power assist for the brakes.
    a. True
    b. False

CHAPTER

81 ABS Components and Operation

OBJECTIVES: **After studying Chapter 81, the reader will be able to:** Prepare for ASE Brakes (A5) certification test content area "F" (Antilock Brake System Diagnosis and Repair). • Explain the reason for ABS. • Describe the purpose and function of the ABS components, such as wheel speed sensors, electrohydraulic unit, and electronic controller. • Discuss how the ABS components control wheel slippage. • Explain how the ABS components control acceleration traction control.

KEY TERMS: accumulator • active sensor • air gap • antilock braking systems (ABS) • channel • control module • Electronic Stability Control (ESC) • flash codes • integral ABS • isolation solenoid • nonintegral ABS • pressure decay stage • pressure dump stage • pressure holding stage • pressure increase stage • pressure reduction stage • pressure release stage • Rear Antilock Braking System (RABS) • Rear Wheel Anti-Lock (RWAL) • release solenoid • select low principle • solenoid valves • tire slip • tone ring • traction • traction control • wheel speed sensors (WSS)

ABS CHARACTERISTICS

Antilock braking systems (ABS) help prevent the wheels from locking during sudden braking, especially on slippery surfaces. This helps the driver maintain control.

Antilock brakes increase safety because they eliminate lockup and minimize the danger of skidding, allowing the vehicle to stop in a straight line. ABS also allows the driver to maintain steering control during heavy braking so the vehicle can be steered to avoid an obstacle or another vehicle.

ABS can optimize braking when road conditions are less than ideal, as when making a sudden panic stop or when braking on a wet or slick road. ABS does this by monitoring the relative speed of the wheels to one another. It uses this information to modulate brake pressure as needed to control slippage and maintain traction when the brakes are applied.

ABS and Tire Traction Preventing brake lockup is important because of the adverse effect a locked wheel has on tire **traction.** The brakes slow the rotation of the wheels, but it is friction between the tire and road that stops the vehicle and allows it to be steered. If tire traction is reduced, stopping distances increase, and the directional stability of the vehicle suffers.

Traction is defined in terms of **tire slip,** which is the difference between the actual speed and the rate at which the tire tread moves across the road. A free-rolling wheel has nearly zero tire slip, while a locked wheel has 100% tire slip. See Figure 81–1.

When the brakes are applied, the rotational speed of the wheel drops, and tire slip increases because the tread moves across the road slower than the actual vehicle speed. This slip creates friction that converts kinetic energy into braking and cornering force.

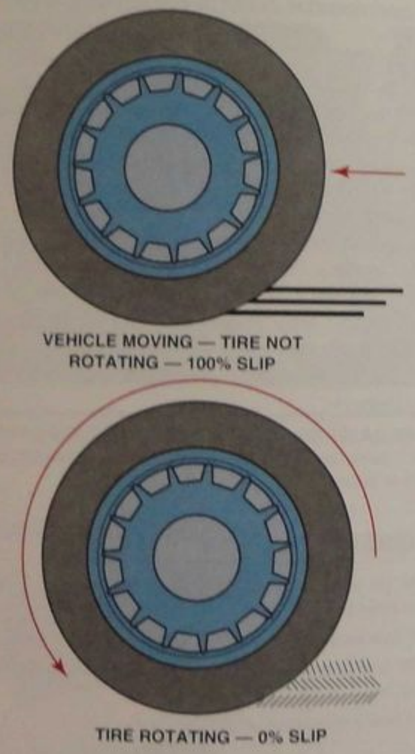


Figure 81–1 Maximum braking traction occurs when tire slip is between 10% and 20%. A rotating tire has 0% slip and a locked-up wheel has 100% slip.

Tire Slip and Braking Distance On dry or wet pavement, maximum braking traction occurs when tire slip is held between approximately 15% and 30%. See Figure 81–2.

On snow- or ice-covered pavement, the optimum slip range is 20% to 50%. In each case, if tire slip increases beyond these levels, the amount of traction decreases. A skidding tire with 100% slip provides 20% to 30% less braking traction on dry pavement, and this is generally true on slippery roads as well. In nearly all cases, the shortest stopping distances are obtained when the brakes are applied with just enough force to keep the tire slip in the range where traction is greatest.

Tire Slip and Vehicle Stability A tire's contact patch with the road can provide only a certain amount of traction. When a vehicle is stopped in a straight line, nearly all of the available traction can be used to provide braking force. Only a small amount of traction is required to generate lateral force that keeps the vehicle traveling in a straight line. However, if a vehicle has to stop and turn at the same time, the available traction must be *divided* to provide both cornering (lateral) and braking force.

No tire can provide full cornering power and full braking power at the same time. When a brake is locked and the tire has

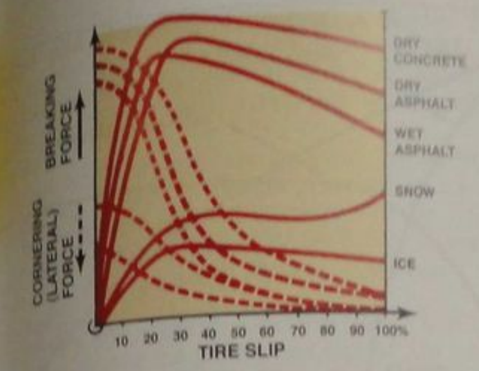


Figure 81–2 Traction is determined by pavement conditions and tire slip.

100% slip, all of the available traction is used for braking, and none is left for steering. As a result, a skidding tire follows the path of least resistance. This means that if the rear brakes lock, the back end of the vehicle will tend to swing around toward the front causing a spin. If the front brakes lock, steering control will be lost and the vehicle will slide forward in a straight line until the brakes are released to again make traction available for steering.

ABS and Base Brakes An antilock braking system is only an "add-on" to the existing base brake system. ABS only comes into play when traction conditions are marginal or during sudden panic stops when the tires lose traction and begin to slip excessively. The rest of the time ABS has no effect on normal driving, handling, or braking.

ABS also makes no difference in the maintenance, inspection, service, or repair of conventional brake system components. A vehicle with ABS brakes uses the same brake linings, calipers, wheel cylinders, and other system components as a vehicle without ABS brakes. The only exception being the master cylinder on certain applications.

All ABS are also designed to be as "fail-safe" as possible. Should a failure occur that affects the operation of the ABS, the system will deactivate itself and the vehicle will revert to normal braking. Therefore, an ABS failure will not prevent the vehicle from stopping.

ABS Limitations There are two situations in which an antilock brake system will *not* provide the shortest stopping distances. The first involves straight stops made on smooth, dry pavement by an expert driver. Under these conditions, a skilled driver can hold the tires consistently closer to the ideal slip rate than the ABS can. See Figure 81–3.

This is possible because current antilock braking systems may allow the amount of tire slip to drop as low as 5%, which is somewhat below the point where maximum tire traction is achieved. However, for the average driver, or under less than ideal conditions, antilock brakes will almost always stop the vehicle in a shorter distance.

The other situation in which antilock brakes will not provide the shortest stops is when braking on loose gravel or dirt, or in deep, fluffy snow. Under these conditions, a locked wheel will stop the vehicle faster because loose debris builds up and forms a wedge in front of the tire that helps stop the vehicle. See Figure 81–4.

An antilock braking system will prevent this wedge from forming so some vehicles with antilock brakes have a switch on the instrument panel that allows the system to be deactivated when driving on these kinds of road surfaces.

No ABS can overcome the laws of physics. The weight and speed of a moving vehicle give it a great deal of kinetic energy, and

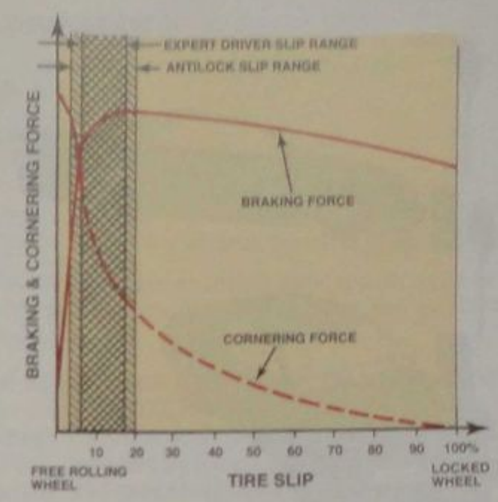


Figure 81–3 A good driver can control tire slip more accurately than an ABS if the vehicle is traveling on a smooth, dry road surface.

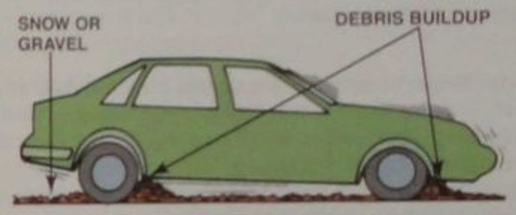


Figure 81–4 A wedge of gravel or snow in the front of a locked wheel can help stop a vehicle faster than would occur if the wheel brakes were pulsed on and off by an antilock braking system.

only so much of that energy can be converted into braking or cornering force at any given time. The limiting factor in this conversion is the traction between the tires and road.

Although a vehicle with four-wheel antilock brakes will stop in very nearly the shortest possible distance, this will still not prevent an accident if the brakes are applied too late to bring the vehicle to a complete stop before impact. However, because steering control is retained with four-wheel antilock brakes, it may be possible to drive the vehicle around a potential accident while in the process of braking.

Another situation where antilock brakes cannot defy the laws of physics occurs when a vehicle enters a corner traveling faster than it is physically possible to negotiate the turn. In this situation, antilock brakes will not prevent the vehicle from leaving the road. However, they will allow the vehicle to be slowed and steered in the process, thus lessening the severity of the eventual impact. See Figure 81–5.

ABS OPERATION

All ABS control tire slip by monitoring the relative deceleration rates of the wheels during braking. Wheel speed is monitored by one or more wheel speed sensors. If one wheel starts to slow at a faster rate than the others, or at a faster rate than that which is programmed in the antilock **control module,** it indicates a wheel is starting to slip and is in danger of losing traction and locking. The ABS responds by momentarily reducing hydraulic pressure to the brake on the affected wheel or wheels. This allows the wheel to

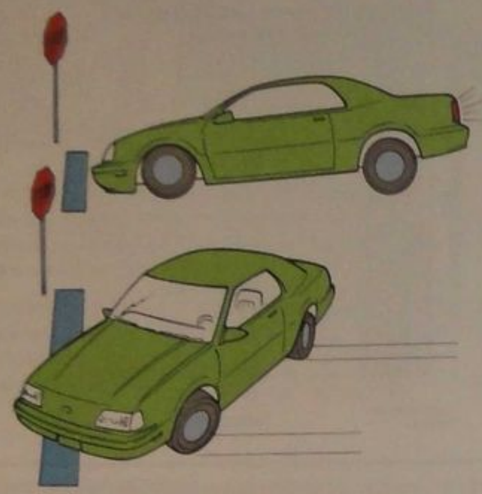


Figure 81–5 Being able to steer and control the vehicle during rapid braking is one major advantage of an antilock braking system.

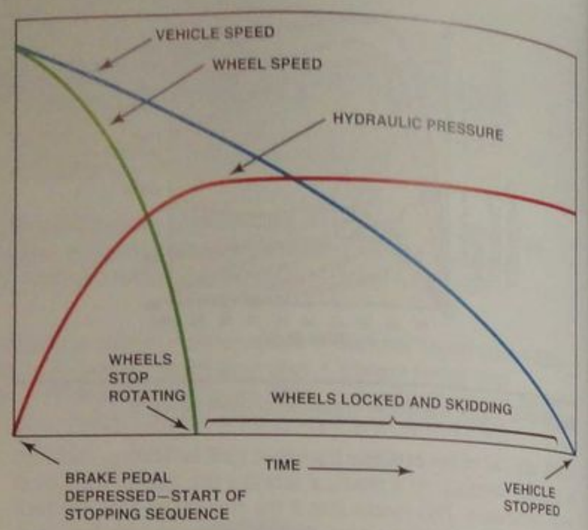


Figure 81–6 A typical stop on a slippery road surface without antilock brakes. Notice that the wheels stopped rotating and skidded until the vehicle finally came to a stop.

speed up momentarily so it can regain traction. As traction is regained, brake pressure is reapplied to again slow the wheel. The cycle is repeated over and over until the vehicle stops or until the driver eases pressure on the brake pedal.

Electrically operated **solenoid valves** (or motor-driven valves in the case of Delphi ABS-VI applications) are used to hold, release, and reapply hydraulic pressure to the brakes. This produces a pulsating effect, which can be felt in the brake pedal during hard braking. The rapid modulation of brake pressure in a given brake circuit reduces the braking load on the affected wheel and allows it to regain traction to prevent lockup. The effect is much the same as pumping the brakes, except that the ABS does it automatically for each brake circuit, and at speeds that would be humanly impossible—up to dozens of times per second depending on the system (some cycle faster than others). See Figure 81–6.

Once the rate of deceleration for the affected wheel catches up with the others, normal braking function and pressure resume, and antilock reverts to a passive mode.

SYSTEM CONFIGURATIONS

All ABS keep track of wheel deceleration rates with wheel speed sensors. The various ABS use a different number of sensors, depending on how the system is configured. See Figure 81–7.

Four-Channel ABS On some applications, each wheel is equipped with its own speed sensor. This type of arrangement is called a "four-wheel, four-channel" system since each wheel speed sensor provides input for a separate hydraulic control circuit or "channel."

The term **channel** always refers to the number of separate or individually controlled ABS hydraulic circuits in an ABS, not the number of wheel speed sensor electrical circuits.

NOTE: For vehicle stability systems to function, there has to be four wheel speed sensors and four channels so the hydraulic control unit can pulse individual wheel brakes to help achieve vehicle stability.

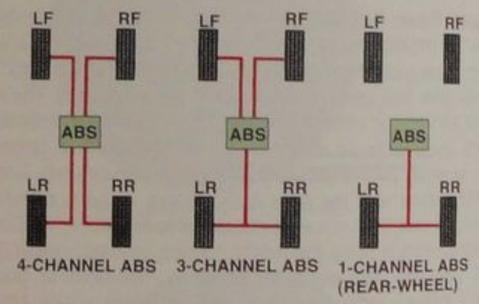


Figure 81–7 ABS configuration includes four-channel, three-channel, and single-channel.

Three-Channel ABS Some four-wheel ABS have a separate wheel speed sensor for each front wheel but use a common speed sensor for both rear wheels. These are called "three-channel" systems. The rear wheel speed sensor is mounted in either the differential or the transmission. The sensor reads the combined or average speed of both rear wheels. This type of setup saves the cost for an additional sensor and reduces the complexity of the system by allowing both rear wheels to be controlled simultaneously. This is known as the **select low principle.** Three-channel systems are the most common type of ABS setup used on rear-wheel-drive applications.

Single-Channel ABS The single-channel rear-wheel-only ABS is used on many rear-wheel-drive pickups and vans. Ford's version is called **Rear Antilock Braking System (RABS),** while General Motors and Chrysler call theirs **Rear Wheel Anti-Lock (RWAL).** The front wheels have no speed sensors, and only a single speed sensor mounted in the differential or transmission is used for both rear wheels. Rear-wheel antilock systems are typically used on applications where vehicle loading can affect rear wheel traction, which is why it is used on pickup trucks and vans. Because the rear-wheel antilock systems have only a single channel, they are much less complex and costly than their multichannel, four-wheel counterparts.

Integral and Nonintegral Another distinction between ABS is whether they are **integral** or **nonintegral ABS.** Integral systems combine the brake master cylinder and ABS hydraulic modulator, pump, and accumulator into one assembly. See Figure 81–8.

Integral systems do not have a vacuum booster for power assist and rely instead on pressure generated by the electric pump for this purpose. Most of the older ABS applications are integral systems. Integral ABS include the Bendix 10 and Bendix 20 (deep) ABS, Bosch 3, Delco Moraine Powermaster III, and Teves Mark 2.

Nonintegral ABS, which are sometimes referred to as "add-on" systems, have become the predominant type of ABS because of their lower cost and simplicity. See Figure 81–9.

Nonintegral ABS have a conventional brake master cylinder and vacuum power booster with a separate hydraulic modulator unit. Some also have an electric pump for ABS braking (to reapply pressure during the ABS hold-release-reapply cycle), but do not use the pumps for normal power assist.

Nonintegral (add-on) systems include Bendix 3, Bendix 6, Bendix ABX-4, Bendix Mecatronic, Bosch 2, Bosch 2S Micro, Bosch 2S, Bosch 2E, Bosch 5, Delco Moraine ABS-VI, Kelsey-Hayes RABS/RWAL, 4WAL, EBC-5 and EBC-10, Sumitomo ABS, Teves Mark 4 ABS and MK20, and Toyota rear-wheel ABS.

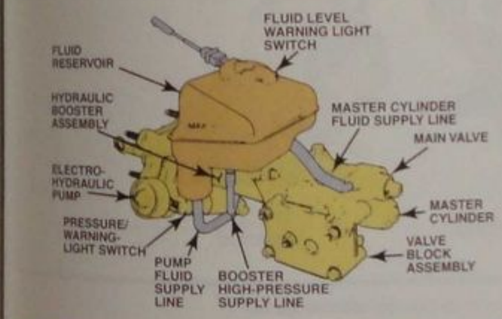


Figure 81–8 A typical integral ABS unit that combines the function of the master cylinder, brake booster, and antilock braking system in one assembly.

ABS COMPONENTS

Basic components that are common to all antilock brake systems include the following:

- Wheel speed sensors
- Electronic control unit
- ABS warning lamp
- Hydraulic modulator assembly with electrically operated solenoid valves (or motor-driven valves in the case of Delphi ABS-VI)

Some systems also have an electric pump and accumulator to generate hydraulic pressure for power assist as well as ABS braking. See Figure 81–10.

Wheel Speed Sensors The **wheel speed sensors WSS** consist of a magnetic pickup and a toothed sensor ring (usually called a **tone ring**). The sensor may be mounted in the steering knuckle, wheel hub, brake backing plate, transmission tailshaft, or differential housing. See Figure 81–11.

On some applications, the sensor is an integral part of the wheel bearing and hub assembly. The sensor rings may be mounted on the axle hub behind the brake rotors, on the brake rotors or drums, on the outside of the outboard constant velocity joints on a front-wheel-drive vehicle, on the transmission tailshaft, or inside the differential on the pinion gear shaft.

Sensor Operation The sensor pickup has a magnetic core surrounded by coil windings. See Figure 81–12.

As the wheel turns, teeth on the sensor ring move through the pickup's magnetic field. This reverses the polarity of the magnetic field and induces an alternating current (AC) voltage in the sensor windings. The number of voltage pulses per second induced in the pickup changes frequency. See Figure 81–13.

The frequency of the signal is therefore proportional to wheel speed. The higher the frequency, the faster the wheel is turning.

The signals are sent to the ABS control module (or an intermediate module in some General Motors rear-wheel ABS applications), where the AC signal is converted into a digital signal for processing. The control module then monitors wheel speed by counting the pulses from each of the wheel speed sensors. If the frequency signal from one wheel starts to change abruptly with respect to the others, it tells the module that wheel is starting to lose traction. The module then applies antilock braking if needed to maintain traction.

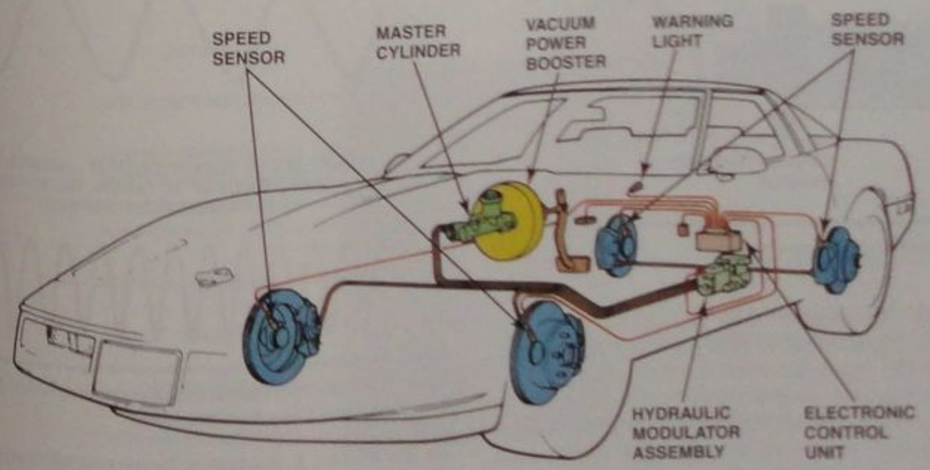


Figure 81–9 A typical nonintegral-type (remote) ABS.

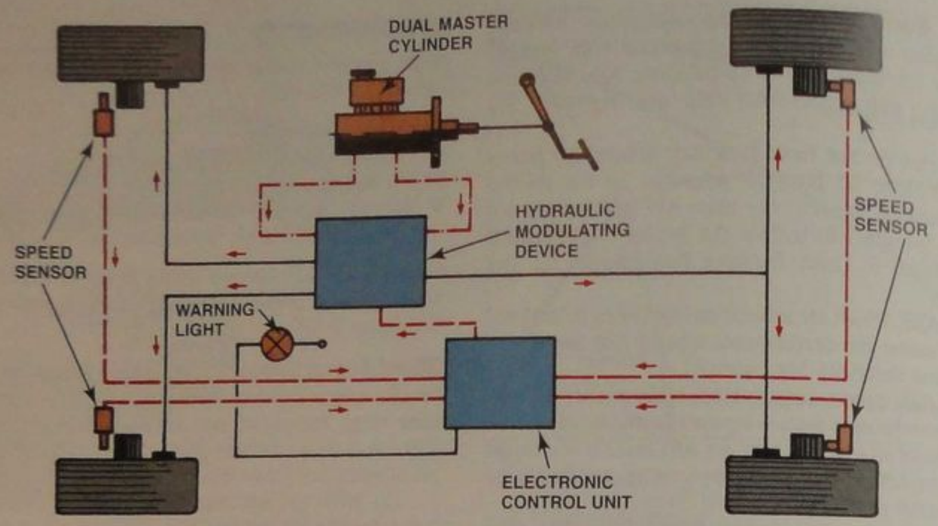


Figure 81–10 A schematic drawing of a typical antilock braking system.

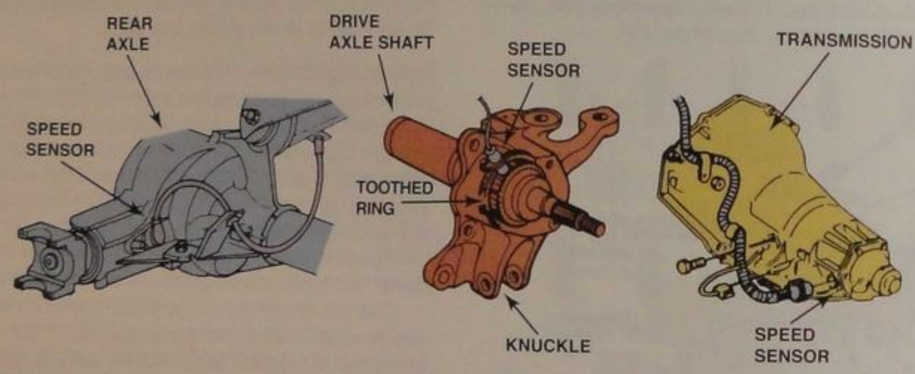


Figure 81–11 Wheel speed sensors for the rear wheels may be located on the rear axle, on the transmission, or on the individual wheel knuckle.

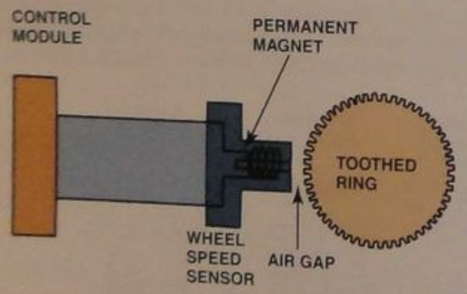


Figure 81–12 A schematic of a typical wheel speed sensor.

Sensor Air Gap The distance or **air gap** between the end of the sensor and its ring is critical. A close gap is necessary to produce a strong, reliable signal. But metal-to-metal contact between the sensor and its ring must be avoided since this would damage both. The air gap must not be too wide or a weak or erratic signal (or no signal) may result. The air gap on some wheel speed sensors is adjustable, and is specified by the vehicle manufacturer.

Sensor Applications and Precautions Wheel speed sensor readings are affected by the size of the wheels and tires on the vehicle. A tire with a larger overall diameter will give a slower speed reading than one with a smaller diameter. Because the ABS is calibrated to a specific tire size, vehicle manufacturers warn against changing tire sizes. A different tire size or aspect ratio could have an effect on the operation of the ABS.

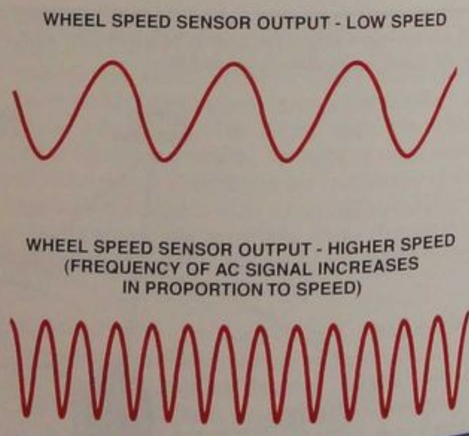


Figure 81–13 Wheel speed sensors produce an alternating current (AC) signal with a frequency that varies in proportion to wheel speed.

Wheel speed sensors are also magnetic, which means they can attract metallic particles. These particles can accumulate on the end of the sensor and reduce its ability to produce an accurate signal. Removing the sensor and cleaning the tip may be necessary if the sensor is producing a poor signal.

Digital Wheel Speed Sensors A conventional wheel speed sensor uses a permanent magnet with a surrounding coil of wire to produce an AC voltage signal that is proportional to wheel speed. The major problem with this type of sensor is that the voltage output and frequency are very low at slow speeds and therefore, cannot produce accurate wheel speed for ABS and traction control.

A digital wheel speed sensor, also called an **active sensor**, uses either a Hall-effect or a variable-reluctance circuit to produce a square waveform where the frequency is proportional to the wheel speed. A digital wheel speed sensor can also detect direction and can therefore be used by the controller for hill holding. The accuracy of these digital sensors also makes correlation to global positioning used in navigational systems more accurate, especially when the vehicle is being driven at slow speeds.

The typical digital wheel speed sensor uses two wires:

- A 12-volt supply
- A DC signal from the sensor

The sensor voltage toggles between about 0.8 V and 1.9 V. See Figure 81–14.

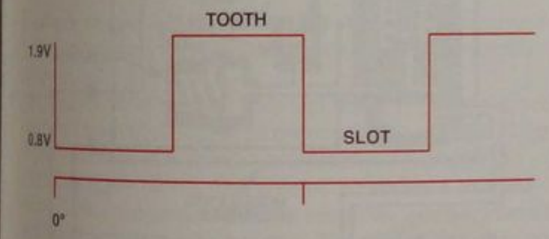


Figure 81–14 A digital wheel speed sensor produces a square wave output signal.

ABS Control Module The ABS electronic control module, which may be referred to as an "electronic brake control module" (EBCM), "electronic brake module" (EBM), or "controller antilock brakes" (CAB) module, is a digital microprocessor that uses inputs from its various sensors to regulate hydraulic pressure during braking to prevent wheel lockup. The module may be located on the hydraulic modulator assembly (as it is on many of the newer compact ABS), or it may be located elsewhere in the vehicle, such as the trunk, passenger compartment, or under the hood.

Module Inputs The key inputs for the ABS control module come from the wheel speed sensors and the brake pedal switch. See Figure 81–15.

The brake pedal switch signals the control module when the brakes are being applied, which causes it to go from a "standby" mode to an active mode. At the same time, the wheel speed sensors provide information about what is happening to the wheels while the brakes are being applied.

NOTE: A fault with the brake switch will not prevent ABS operation. The brake switch allows the controller to react faster to an ABS event.

Module Operation If the control module detects a difference in the deceleration rate between one or more wheels when braking, or if the overall rate of deceleration is too fast and exceeds the limits programmed into the control module, it triggers the ABS control module to momentarily take over. The control module cycles the solenoid valves in the modulator assembly to pulsate hydraulic pressure in the affected brake circuit (or circuits) until sensor information indicates that the deceleration rates have returned to normal and braking is under control. Normal braking resumes. When the brake pedal is released or when the vehicle comes to a stop, the control module returns to a standby mode until it is again needed.

ABS Warning Lamp Every ABS has an amber indicator lamp on the instrument panel that warns the driver when a problem occurs within the ABS. The lamp comes on when the ignition is

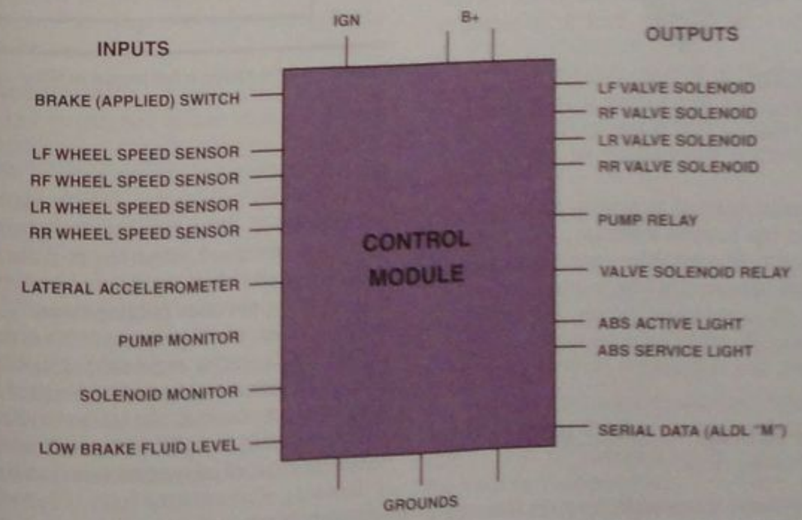


Figure 81–15 Typical inputs and outputs for brake control modules.

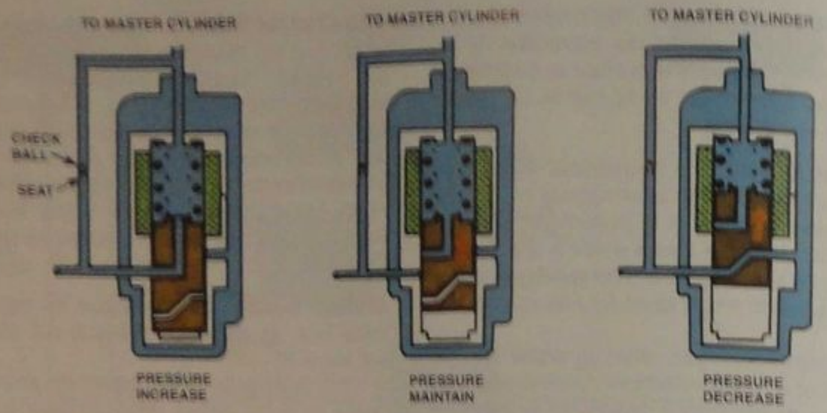


Figure 81–16 An ABS 3-way solenoid can increase, maintain, or decrease brake pressure to a given brake circuit.

turned on for a bulb check, then goes out after the engine starts. If the warning light remains on or comes on while driving, it usually indicates a fault in the ABS that will require further diagnosis. On most applications, the ABS disables if the ABS warning light comes on and remains on. This should have no effect on normal braking, unless the red brake warning lamp is also on. The ABS warning light is also used for diagnostic purposes when retrieving **flash codes** (trouble codes) from the ABS module.

Hydraulic Modulator Assembly The modulator valve body is part of the master cylinder assembly in nonintegral antilock systems but separate in nonintegral systems. It contains solenoid valves for each brake unit (in Delphi ABS-VI applications, however, motor-driven valves are used instead of solenoids). The exact number of valves per circuit depends on the ABS and the application. Some use a pair of on-off solenoid valves for each brake circuit while others use a single valve that can operate in more than one position.

ABS Solenoid A solenoid consists of a wire coil with a movable core and a return spring. When current from the ABS control module energizes the coil, it pulls on the movable core. Depending on how the solenoid is constructed, this may open or close a valve that's attached to the movable core. When the control current is shut off, the solenoid snaps back to its normal or rest position.

Some solenoids are designed to do more than just switch on or off to open or close a valve. Some pull a valve to an intermediate position when a certain level of current is applied to the coil, then pull the valve to a third position when additional current is provided. See Figure 81–16.

This design allows a single solenoid to perform the same functions as two or even three single position solenoids.

The solenoids in the hydraulic modulator assembly are used to open and close passageways between the master cylinder and the individual brake circuits. By opening or closing the modulator valves to which they're attached, brake pressure within any given circuit can be held, released, and reapplied to prevent lockup during hard braking.

ABS Control Pressure Strategy The standard ABS control strategy that's used is a three-step cycle:

- The first step is to hold or isolate the pressure in a given brake circuit by closing an **isolation solenoid** in the modulator assembly.

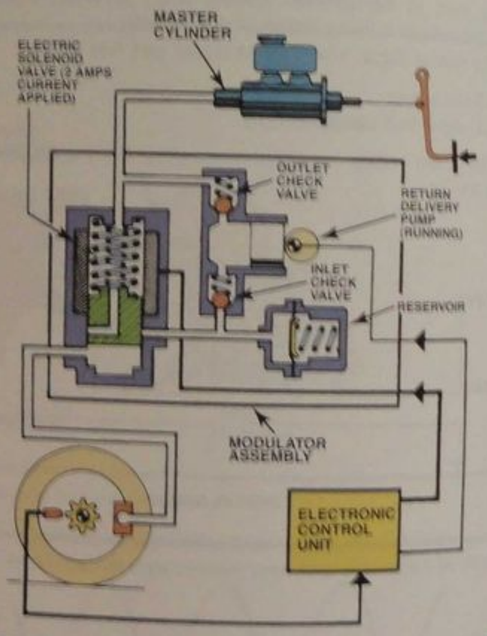


Figure 81–17 The isolation or hold phase of an ABS on a Bosch 2 system.

This solenoid is normally electrically and hydraulically opened. See Figure 81–17. When the solenoid is electrically closed, it becomes hydraulically closed, which blocks off the line and prevents any further pressure from the master cylinder reaching the brake. This is called the **pressure holding stage.**

- If the wheel speed sensor continues to indicate the wheel is slowing too quickly and is starting to lock, the same solenoid or a second **release solenoid** is energized to open a vent port that releases pressure from the brake circuit. See Figure 81–18. The fluid is usually routed into a spring-loaded or pressurized storage reservoir (called an **accumulator**) so it can be reused as needed. Releasing pressure in the brake circuit allows the brake to loosen its grip so the wheel can speed up and regain traction. This is called **pressure reduction, pressure release,**

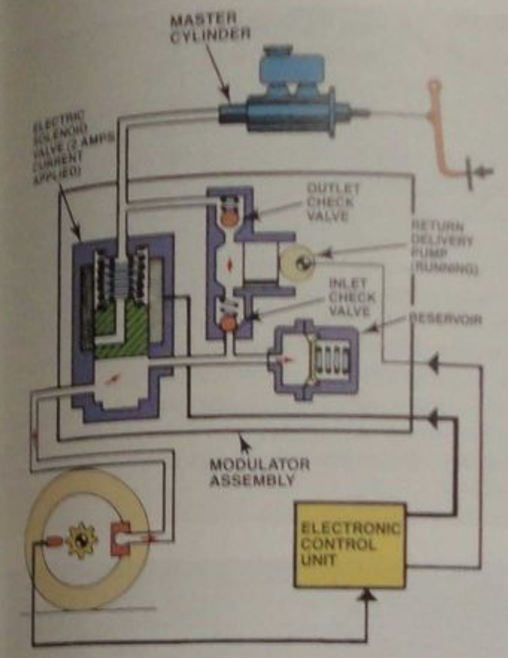


Figure 81–18 During the pressure reduction stage, pressure is vented from the brake circuit so the tire can speed up and regain traction.

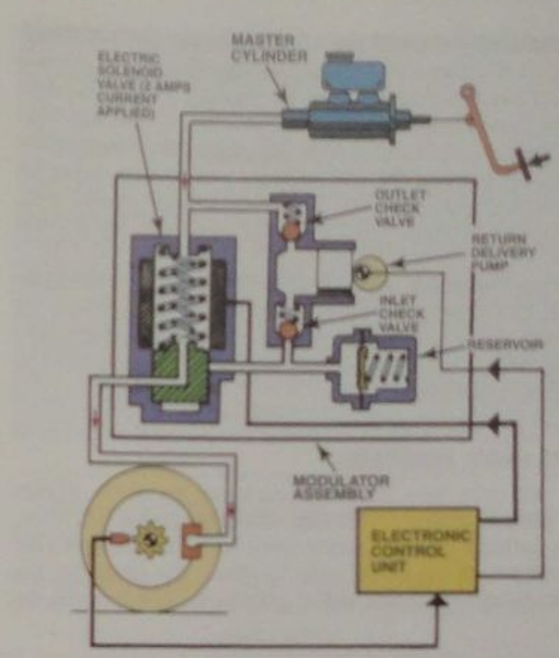


Figure 81–19 The control module reapplies pressure to the affected brake circuit once the tire achieves traction so that normal braking can continue.

pressure decay, or **pressure dump stage.** The pressure reduction solenoid is normally hydraulically closed and electrically opened.

- The release and/or isolation solenoid(s) are then closed and/or the additional solenoid energized so pressure can be reapplied to the brake from the master cylinder or accumulator to reapply the brake. See Figure 81–19. This is called the **pressure increase stage.** During the pressure increase stages, the isolation solenoid is electrically and hydraulically opened. The pressure reduction solenoid is electrically opened and hydraulically closed.

The hold-release-reapply cycle repeats as many times as needed until the vehicle either comes to a halt or the driver releases the brake pedal. The speed at which this occurs depends on the particular ABS that is on the vehicle, but can range from a few times per second up to dozens of times per second.

Pump Motor and Accumulator A high-pressure electric pump is used in some ABS to generate power assist for normal braking as well as the reapplication of brake pressure during ABS braking. See Figure 81–20. In some systems, it is used only for the reapplication of pressure during ABS braking.

The pump motor is energized by a relay, which is switched on and off by the ABS control module. The fluid pressure generated by the pump is stored in the accumulator. Some ABS have more than one accumulator. The accumulator on ABS, where the hydraulic modulator is part of the master cylinder assembly, consists of a pressure storage chamber filled with nitrogen gas. A thick rubber diaphragm forms a barrier between the nitrogen gas and brake fluid. As fluid is pumped into the accumulator, it compresses the gas and stores pressure. When the brake pedal is depressed, pressure from the accumulator flows to the master cylinder to provide power assist.

A pair of pressure switches mounted in the accumulator circuit signals the ABS control module to energize the pump when pressure

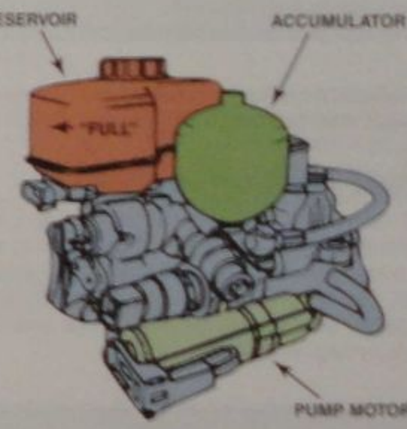


Figure 81–20 An integral ABS unit with a pump motor to provide power assist during all phases of braking and brake pressure during ABS stops.

falls below a preset minimum, then to shut the pump off once pressure is built back up.

Should the pump fail (a warning lamp comes on when reserve pressure drops too low), there is usually enough reserve pressure in the accumulator for 10 to 20 power-assisted stops. After that, there is no power assist. The brakes still work, but with greatly increased effort.

On ABS that have a conventional master cylinder and vacuum booster for power assist, a small accumulator or pair of accumulators may be used as temporary storage reservoirs for brake fluid during the hold-release-reapply cycle. This type of accumulator typically uses a spring-loaded diaphragm rather than a nitrogen-charged chamber to store pressure.

Accumulator Precautions A fully charged accumulator in an integral ABS can store up to 2,700 PSI (19,000 kPa) of pressure for power-assist braking and for reapplying the brakes during the hold-release-reapply cycle for antilock braking. This stored pressure represents a potential hazard for a brake technician who is servicing the brakes, so the accumulator should be depressurized prior to doing any type of brake service work by pumping the brake pedal 25 to 40 times with the ignition key off.

In nonintegral ABS where an accumulator is used to temporarily hold fluid during the release phase of the hold-release-reapply ABS cycle, the accumulator consists of a spring-loaded diaphragm. This type of accumulator does not have to be depressurized prior to performing brake service.

BRAKE PEDAL FEEDBACK

Many ABS units force brake fluid back into the master cylinder under pressure during an ABS stop. This pulsing brake fluid return causes the brake pedal to pulsate. Some vehicle manufacturers use the pulsation of the brake pedal to inform the driver that the wheels are tending toward lockup and that the ABS is pulsing the brakes.

NOTE: A pulsating brake pedal may be normal only during an ABS stop. It is not normal for a vehicle with ABS to have a pulsating pedal during normal braking. If the brake pedal is pulsating during a non-ABS stop, the brake drums or rotor may be warped.

Some manufacturers use an isolation valve that prevents brake pedal pulsation even during an ABS stop.

BRAKE PEDAL TRAVEL SWITCH (SENSOR)

Some ABS, such as the Teves Mark IV system, use a brake pedal travel switch (sensor). The purpose of the switch is to turn on the hydraulic pump when the brake pedal has been depressed to 40% of its travel. The pump runs and pumps brake fluid back into the master cylinder, which raises the brake pedal until the switch closes again, turning off the pump.

NOTE: Some early ABS did not use a brake switch. The problem occurred when the ABS could be activated while driving over rough roads. The brake switch can be the same as the brake light switch or a separate switch.

The brake pedal switch is an input for the electronic controller. When the brakes are applied, the electronic controller "gets ready" to act if ABS needs to "initialize" the starting sequence of events.

CAUTION: If the driver pumps the brakes during an ABS event, the controller will reset and initialization starts over again. This resetting process can disrupt normal ABS operation. The driver need only depress and hold the brake pedal down during a stop for best operation.

TECH TIP ✓ **Keep the Tires the Same Outside Diameter**

It is important to remember when replacing tires, to keep the same outside diameter as the original tire. Vehicles equipped with antilock brakes are "programmed" to pulse the brakes at just the right rate for maximum braking effectiveness. A larger tire rotates at a slower speed and a smaller-than-normal tire rotates at a faster speed. Therefore, tire size affects the speed and rate of change in speed of the wheels as measured by the wheel speed sensors.

While changing tire size will not prevent ABS operation, it will cause less effective braking during hard braking with the ABS activated. Using the smaller spare tire can create such a difference in wheel speed compared with the other wheels that a false wheel speed sensor code may be set and an amber ABS warning lamp on the dash may light. However, most ABS will still function with the spare tire installed, but the braking performance will not be as effective. For best overall performance, always replace tires with the same size and type as specified by the vehicle manufacturer.

TRACTION CONTROL

Traction control allows an ABS to control wheel lockup during deceleration can be adopted to control wheel spin during acceleration.

Low-speed traction control uses the braking system to limit positive slip up to a vehicle speed of about 30 mph (48 km/h). See Figure 81–21.

All-speed traction control systems are capable of reducing positive wheel slip at all speeds. Most speed traction control systems use accelerator reduction and engine power reduction to limit slip. For example, if a vehicle were being driven on an icy or snow-covered road, the brakes may become overheated if heavy acceleration is attempted. To help take the load off the brakes, the acceleration and power output from the engine is reduced. Many systems use accelerator pedal reduction and fuel injector cutout or ignition timing retardation individually or in combination to help match engine power output to the available tire traction. Traction control is also called acceleration slip regulation (ASR). See Figures 81–22 and 81–23.

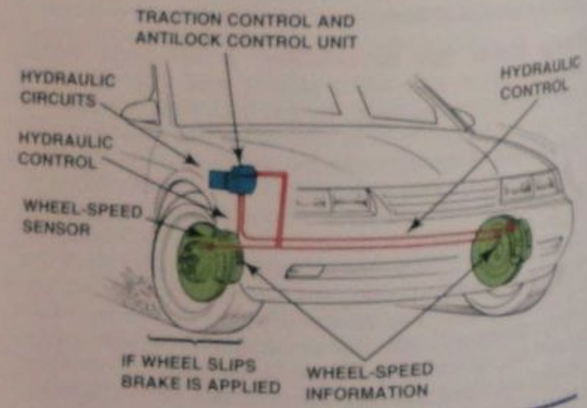


Figure 81–21 Typical low-speed traction control design that uses wheel speed sensor information and the application of the drive-wheel brakes to help reduce tire slippage during acceleration.

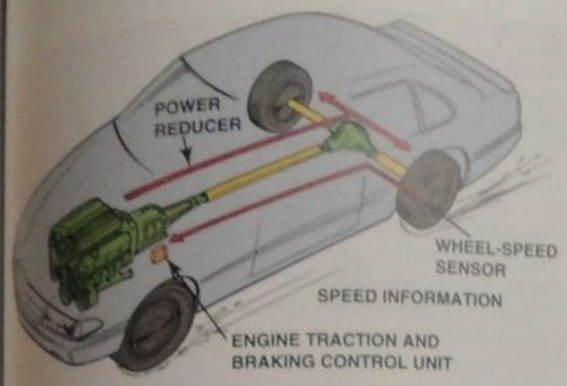


Figure 81–22 Typical all-speed traction control system that uses wheel speed sensor information and the engine controller to not only apply the brakes at lower speeds but also reduce engine power.



Figure 81–23 A cutaway of an ABS/traction control assembly used on a Honda.

NOTE: The ABS controller supplies to the wheel brake only the pressure that is required to prevent tire slipping during acceleration. The amount of pressure varies according to the condition of the road surface and the amount of engine power being delivered to the drive wheels. A program inside the controller will disable traction control if brake system overheating is likely to occur. The driver should either wait for the brakes to cool down or use less accelerator pedal while driving.

Inputs and Outputs The input signals used for traction control include:

- Throttle position (TP) sensor—This indicates the position of the throttle.
- Wheel speed sensor (WSS)—The ABS controller (computer) monitors all four wheel speed sensors. If one wheel is rotating faster than the other, this indicates that the tire is slipping or has lost traction.
- Engine speed (RPM)—This information is supplied from the engine controller (power train control module) and indicates the speed of the engine.
- Transmission range switch—Determines which gear the driver has selected so that the PCM can take corrective action.

FREQUENTLY ASKED QUESTION ???

I Thought Traction Control Meant Additional Drive Wheels Were Engaged

When the term *traction control* is used, many people think of four-wheel-drive or all-wheel-drive vehicles and power trains. Instead of sending engine torque to other drive wheels, it is the purpose and function of the traction control system to prevent the drive wheel(s) from slipping during acceleration. A slipping tire has less traction than a non slipping tire—therefore, if the tire can be kept from slipping (spinning), more traction will be available to propel the vehicle. Traction control works with the engine computer to reduce torque delivery from the engine, as well as the ABS controller to apply the brakes to the spinning wheel if necessary to regain traction.

The outputs of the traction control system can include one or more of the following:

- Retard ignition timing to reduce engine torque.
- Decrease the fuel injector pulse-width to reduce fuel delivery to the cylinder to reduce engine torque.
- Reduce the amount of intake air if the engine is equipped with an electronic throttle control. Reduced airflow will reduce engine torque.
- Upshift the automatic transmission/transaxle. If the transmission is shifted into a higher gear, the torque applied to the drive wheels is reduced.
- Lights a low traction or traction control warning light on the dash. See Figure 81–24.

Traction Control Operation Traction control uses the same wheel speed sensors as ABS, but requires additional programming in the control module so the system monitors wheel speed continuously, not just when braking. Traction control also requires additional solenoids in the hydraulic modulator so the brake circuits to the drive wheels can be isolated from the nondrive wheels when braking is needed to control wheel spin. An ABS with traction control capability must also have a pump and accumulator to generate and store pressure for traction control



Figure 81–24 A traction control or low traction light on the dash is confusing to many drivers. When this lamp is on, the traction control system has either been turned off or a low traction condition is forcing the traction control system to take action.

braking. If a wheel speed sensor detects wheel spin in one of the drive wheels during acceleration, the control module energizes a solenoid that allows stored fluid pressure from the accumulator to apply the brakes on the wheel that is spinning. This slows the wheel that is spinning and redirects engine torque through the differential to the opposite drive wheel to restore traction. It works just as well on front-wheel-drive vehicles as it does rear-wheel-drive vehicles.

Traction Active Lamp On most applications, a "TRAC CNTL" indicator light or "TRACTION CONTROL ACTIVE" message flashes on the instrumentation when the system is engaging traction control. This helps alert the driver that the wheels are losing traction. In most applications, the message does not mean there is anything wrong with the system—unless the ABS warning lamp also comes on, or the traction control light remains on continuously.

Traction Deactivation Switch Many vehicles with traction control have a dash-mounted switch that allows the driver to deactivate the system when desired (as when driving in deep snow). An indicator light shows when the system is on or off, and may also signal the driver when the traction control system is actively engaged during acceleration.

ELECTRONIC CONTROLLER OPERATION

The electronic controller is the computer in the system that controls all parts of ABS operation, including the following:

1. **A Self-Test.** The controller runs a self-test of all its components every time the ignition is turned on.

NOTE: Since an antilock braking system is a safety-related system, if it malfunctions, people can be injured. This is one reason why the system does a complete "system check" every time the ignition is cycled.

2. **The Wheel Hydraulic Controls.** The controller looks at the rate of wheel deceleration and compares it with normal stopping rates using an internal computer program that is based on vehicle weight, tire size, and so on. If a wheel is slowing down too fast, the controller activates the necessary hydraulic pressure controls.

FREQUENTLY ASKED QUESTION ???

Is Tire Chirp Normal with ABS?

Some owners of vehicles complain that their ABS is not working correctly because their tires chirp and occasionally experience tire lockup during hard braking, especially at low speed. These conditions are perfectly normal because, for maximum braking, between 12% and 20% of slip means that the tire will slip or skid slightly during an ABS stop.

It is also normal for vehicles with ABS to have the tires lock and skid slightly when the speed of the vehicle is below 5 mph (8 km/h). This occurs because the wheel speed sensors cannot generate usable speed signals for the electronic controller. This low-speed wheel lockup seldom creates a problem.

Before attempting to troubleshoot or diagnose an ABS problem, be sure that the problem is not just normal operation of the system.

TECH TIP ✓ Stop on a Dime?

Vehicles that are equipped with ABS help the driver avoid skidding and losing total control during braking. This is especially true for road surfaces that are slippery. However, vehicles equipped with ABS must still have traction between the tire and the road to stop.

This author had an experience with ABS on a snow-covered road. I applied the brakes while approaching a stop sign and the brake pedal started to pulsate, the electrohydraulic unit started to run, and the vehicle continued straight through the intersection! Luckily, no other vehicles were around. The vehicle did not stop for a long distance through the intersection, but it did stop straight—avoiding skidding. Because of the ice under the snow, the vehicle did not have traction between the tires and the road.

A common complaint is that the ABS did not stop the vehicle, while in reality, it did stop the vehicle from skidding or traveling out of control, even though short stops are not always possible. The service technician should explain the purpose and function of ABS before attempting to repair a problem that may be normal on the vehicle being inspected.

Remember—*The primary purpose of ABS is vehicle control—not short stopping distance!*

ELECTRONIC STABILITY CONTROL

Electronic Stability Control (ESC) uses the steering wheel position sensor and G-force and/or yaw sensor to determine if a vehicle is not under control. The ESC system, also called Electronic Stability Program (ESP), then applies individual wheel brakes to bring the vehicle under control. The following occurs if the vehicle is oversteering or understeering.

Oversteering In this condition, the rear of the vehicle breaks loose resulting in the vehicle spinning out of control. This condition is also called *loose*. If the condition is detected during a left turn, the ESC system would apply the right front brake to bring the vehicle back under control.

Understeering In this condition, the front of the vehicle continues straight ahead when turning, a condition that is also called *plowing* or *tight*. If this condition is detected during a right turn, the ESC system would apply the right rear wheel brake to bring the vehicle back under control. See Figure 81–25.

NOTE: When the brakes are applied during these corrections, a thumping sound and vibration may be sensed.

Stability control systems are offered under the following names:

- Acura: Vehicle Stability Assist (VSA)
- Audi: Electronic Stabilization Program (ESP)
- BMW: Dyanmic Stability Control (DSC), including Dynamic Traction Control
- Chrysler: Electric Stability Program (ESP)
- Dodge: Electronic Stability Program (ESP)
- Chrysler: Electronic Stability Program (ESP)
- Ferrari: Controllo Stabilita (CST)
- Ford: AdvanceTrac and Interactive Vehicle Dynamics (IVD)
- General Motors: StabiliTrak (Except Corvette—Active Handling)
- Hyundai: Electronic Stability Program (ESP)

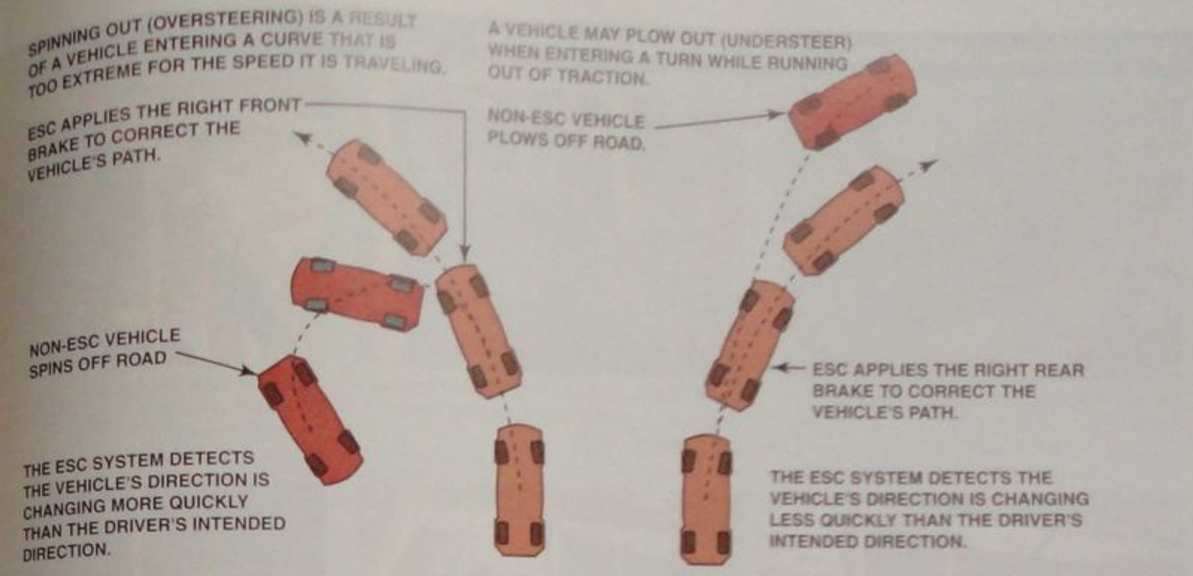


Figure 81–25 The electronic stability control (ESC) system applies individual wheel brakes to keep the vehicle under control of the driver.

- Honda: Electronic Stability Control (ESC), Vehicle Stability Assist (VSA), and Electronic Stability Program (ESP)
- Infiniti: Vehicle Dynamic Control (VDC)
- Jaguar: Dynamic Stability Control (DSC)
- Jeep: Electronic Stability Program (ESP)
- Kia: Electronic Stability Program (ESP)
- Land Rover: Dynamic Stability Control (DSC)
- Lexus: Vehicle Dynamics Integrated Management (VDIM) with Vehicle Stability Control (VSC) and Traction Control (TRAC) systems
- Lincoln: Advance Trak
- Maserati: Maserati Stability Program (MSP)
- Mazda: Dynamic Stability Control
- Mercedes: Electronic Stability Program (ESP)
- Mercury: Advance Trak
- Mini Cooper: Dynamic Stability Control
- Mitsubishi: Active Skid and Traction Control MULTIMODE
- Nissan: Vehicle Dynamic Control (VDC)
- Porsche: Porche Stability Management (PSM)
- Rover: Dynamic Stability Control (DSC)
- Saab: Electronic Stability Program (ESP)
- Saturn: Stabili Trak
- Subaru: Vehicle Dynamics Control Systems (VDCS)
- Suzuki: Electronic Stability Program (ESP)
- Toyota: Vehicle Dynamics Integrated Management (VDIM) with Vehicle Stability Control (VSC)
- Volvo: Dynamic Stability and Traction Control (DSTC)
- VW: Electronic Stability Program (ESP)

The purpose of the vehicle stability enhancement system along with the antilock brake system (ABS) is to provide vehicle stability enhancement during oversteer or understeer conditions.

PHOTO SEQUENCE Wheel Speed Sensor Step-by-Step



P81–1 A tone ring and a wheel speed sensor on the rear of a Dodge Caravan.



P81–2 The wiring from the wheel speed sensor should be inspected for damage.



P81–3 To test a wheel speed sensor, disconnect the sensor connector to gain access to the terminals.

(continued)

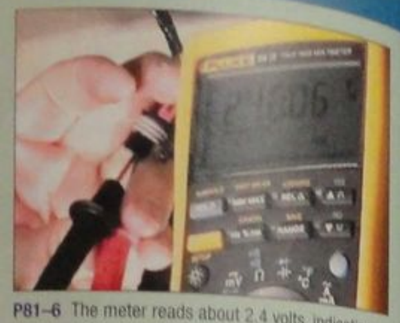
PHOTO SEQUENCE Wheel Speed Sensor Step-by-Step—continued



P81–4 Pulling down the rubber seal reveals the connector.



P81–5 The ABS controller (computer) on this vehicle supplies a 2.5-volt reference signal to the wheel speed sensors.



P81–6 The meter reads about 2.4 volts, indicating that the ABS controller is supplying the voltage to the wheel speed sensor.



P81–7 The test probes are touched to the terminals leading to the wheel speed sensor and the resistance is 1.1032 k ohms or 1,103.2 ohms.



P81–8 The meter should (and does) read "OL," indicating that the wheel speed sensor and pigtail wiring is not shorted to ground.



P81–9 To measure the output of the wheel speed sensor, select AC volts on the digital multimeter.



P81–10 Rotate the wheel and tire assembly by hand while observing the AC voltage output on the digital multimeter.



P81–11 A good wheel speed sensor should be able to produce at least 100 mV (0.1 V) when the wheel is spun by hand.



P81–12 After testing, carefully reinstall the wiring connector into the body and under the rubber grommet.

SUMMARY

1. Antilock braking systems are designed to limit the amount of tire slip by pulsing the wheel brake on and off up to 20 times per second.
2. Steering control is possible during an ABS stop if the tires maintain traction with the road surface.
3. The three stages of ABS operation are pressure buildup, pressure holding, and pressure reduction.
4. The heart of an antilock braking system is the electronic controller (computer). Wheel speed sensors produce an electrical frequency that is proportional to the speed of the wheel. If a wheel is slowing down too fast, the controller controls the pressure of the wheel brake through an electrohydraulic unit.
5. Both integral and nonintegral antilock braking systems control the rear wheels only, both front wheels individually and the rear as one unit (three-channel), or all four wheel brakes independently (four-channel).
6. Antilock braking systems that control the drive-wheel brakes can be used for acceleration traction control.

REVIEW QUESTIONS

1. Describe how an antilock braking system (ABS) works.
2. List the three stages of ABS operation.
3. Explain how wheel speed sensors work.
4. Describe the difference between a three- and a four-channel system.
5. Explain how ABS can be used to prevent wheel slippage during acceleration.

CHAPTER QUIZ

1. Technician A says that the ABS is designed so that the pressure to the wheel brakes is never higher than the pressure the driver is applying through the brake pedal. Technician B says that a pulsating brake pedal during normal braking is a characteristic feature of most ABS-equipped vehicles. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. The maximum traction between a tire and the road occurs when the tire is _____.
   a. Locked and skidding
   b. Rotating freely
   c. Slipping 10% to 20%
   d. Slipping 80% to 90%
3. Technician A says that ABS-equipped vehicles can stop quickly and without skidding on all road surfaces even if covered with ice. Technician B says that steering is possible during an ABS stop. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. A customer wanted the ABS checked because of tire chirp noise during hard braking. Technician A says that the speed sensors may be defective. Technician B says that tire chirp is normal during an ABS stop on dry pavement. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Two technicians are discussing ABS wheel speed sensors. Technician A says that some ABS use a sensor located in the rear-axle pinion gear area. Technician B says that all ABS use a wheel speed sensor at each wheel. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Technician A says that it may be normal for the hydraulic pump and solenoids to operate after the vehicle starts to move after a start. Technician B says that the ABS is disabled (does not function) below about 5 mph (8 km/h). Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Technician A says that a scan tool may be necessary to bleed some ABS hydraulic units. Technician B says that only DOT 3 brake fluid should be used with an ABS. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Technician A says that many traction control systems reduce engine torque to help the drive wheels achieve traction. Technician B says that hydraulic pressure from the electrohydraulic unit supplies brake fluid pressure to the wheel brake that is spinning during a traction control event. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. The faster a wheel rotates, the higher the frequency produced by a wheel speed sensor.
   a. True
   b. False
10. Technician A says that some wheel speed sensors are enclosed in a wheel bearing assembly. Technician B says that some wheel speed sensors are exposed to possible damage from road debris. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 82 ABS Diagnosis and Service

OBJECTIVES: After studying Chapter 82, the reader will be able to: Prepare for ASE Brakes (A5) certification test content area "F" (Antilock Brake System Diagnosis and Repair). • Describe normal ABS dash lamp operation. • Discuss visual inspection of the various types and brands of ABS. • Explain how to retrieve trouble codes. • List the methods used to clear trouble codes. • Explain the various methods for bleeding ABS. • Discuss methods and tools needed to diagnose an ABS-equipped vehicle.

KEY TERMS: amber ABS warning lamp • breakout box (BOB) • red brake warning lamp (RBWL)

ABS DIAGNOSTIC PROCEDURE

Customer concerns about a fault with the antilock braking system can be best handled by performing the following:

Step #1 Verify the customer concern. This step is very important because often a problem with the base brakes is thought by the customer to be a fault with the antilock braking system. It is helpful for the owner to drive the vehicle with a service technician if the problem is not readily apparent.

Step #2 Perform a visual inspection. If both the red and the amber brake warning lights are on, look for a fault in the hydraulic system, including leaks at the following locations:

- Master cylinder
- Electrohydraulic control unit
- Flexible brake hoses
- Brake lines and fittings
- Calipers and/or wheel cylinders

Step #3 Check for stored diagnostic trouble codes (DTCs). Use a scan tool or other necessary methods to retrieve diagnostic trouble codes. If found, follow the specified factory procedures to isolate and determine the cause.

Step #4 Complete the repair. This step may involve replacing a hydraulic component. If so, then the hydraulic system should be bled using the factory specified procedure. Clear all diagnostic trouble codes.

Step #5 Verify the repair. Always test-drive the vehicle under the same conditions that were needed to verify the problem to be sure that the cause has been corrected.

BRAKE WARNING LAMP OPERATION

The first step in the visual diagnosis of an antilock braking system problem is to check the status of the brake warning lamps.

Red Brake Warning Lamp A **red brake warning lamp** (RBWL) warns of a possible dangerous failure in the base brakes, such as low brake fluid level or low pressure in half of the hydraulic system. The red brake warning lamp will also light if the parking brake is applied and may light due to an ABS failure, such as low brake pressure on an integral system. See Figure 82–1.

Amber ABS Warning Lamp The **amber ABS warning lamp** usually comes on after a start during the initialization or startup self-test sequence. The exact time the amber lamp remains on after the ignition is turned on varies with the vehicle and the ABS design. See Figure 82–2.

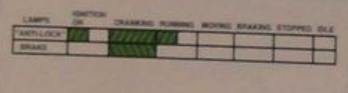
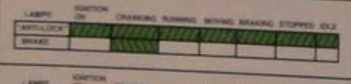
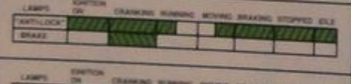
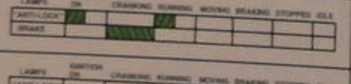
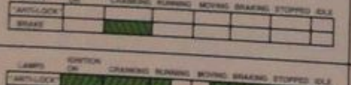
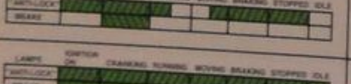
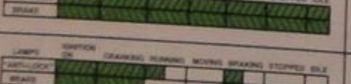
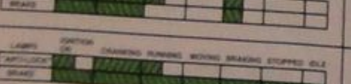
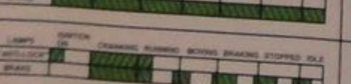
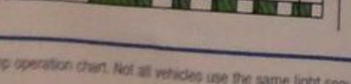
SEQUENCE NUMBER	LAMP SEQUENCE	SYMPTOM DESCRIPTION	PERFORM TEST
1		NORMAL LAMP SEQUENCE WITH -EXCESSIVE PEDAL TRAVEL OR SPONGY PEDAL -ANTILOCK BRAKING OPERATION OR VALVE CYCLING DURING NORMAL STOPS ON DRY PAVEMENT -POOR VEHICLE TRACKING DURING ANTILOCK BRAKING	H C D
2		CONTINUOUS "ANTILOCK" LAMP NORMAL "BRAKE" LAMP	A
3		"ANTILOCK" LAMP COMES ON AFTER VEHICLE STARTS MOVING NORMAL BRAKE LAMP	C
4		NO "ANTILOCK" LAMP WHILE CRANKING NORMAL "BRAKE" LAMP	E
5		NO "ANTILOCK" LAMP NORMAL "BRAKE" LAMP	F
6		INTERMITTENT "ANTILOCK" LAMP WHILE DRIVING NORMAL "BRAKE" LAMP	G
7		CONTINUOUS "ANTILOCK" LAMP CONTINUOUS "BRAKE" LAMP	B
8		"ANTILOCK" AND "BRAKE" LAMPS COME ON WHILE BRAKING	B
9		NORMAL "ANTILOCK" LAMP CONTINUOUS "BRAKE" LAMP	B
10		NORMAL OR CONTINUOUS "ANTILOCK" LAMP FLASHING "BRAKE" LAMP	B

Figure 82–1 Typical brake warning lamp operation chart. Not all vehicles use the same light sequence. The top of the chart indicates normal warning lamp operation if the system is okay.

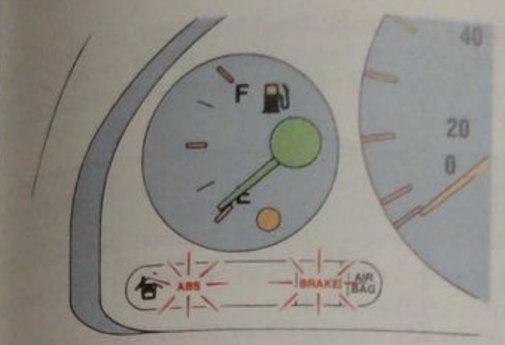


Figure 82–2 On most vehicles equipped with ABS, the ABS and the BRAKE warning lamp should come on as a bulb check when the ignition is first switched on.

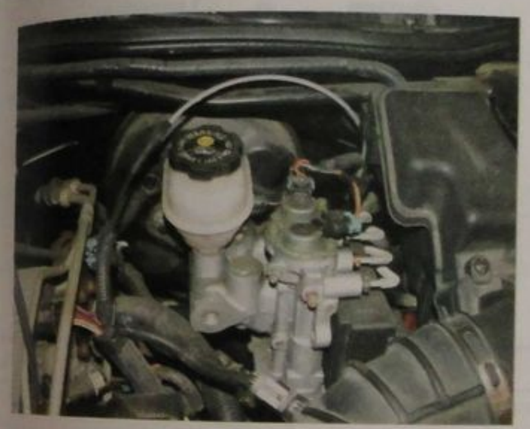


Figure 82–3 A thorough visual inspection should include carefully inspecting around the electrohydraulic unit for signs of obvious problems or the installation of aftermarket devices such as alarm systems.

THOROUGH VISUAL INSPECTION

Many ABS-related problems can be diagnosed quickly if all the basics are carefully inspected. See Figure 82–3.

A thorough visual inspection should include the following items:

Brake fluid leaks	Check for cracks in flexible lines or other physical damage.
Fuses and fusible links	Check all ABS-related fuses.
Wiring and connections	Check all wiring, especially wheel speed sensor leads, for damage.
Wheel speed sensors	Check that the sensor ring teeth are not damaged. Clean debris from the sensor if possible.

NOTE: Most wheel speed sensors are magnetic and therefore can attract and hold metallic particles. Be sure to remove any metallic debris from around the magnetic wheel speed sensor.

Base brake components	All base brake components, such as disc brake calipers, drum brake wheel cylinders, and related components, must be in proper working condition.
Parking brake	Check that the parking brake is correctly adjusted and fully released.
Wheel bearings	All wheel bearings must be free of defects and adjusted properly.
Tires and tires	Check for correct size, proper inflation, and legal tread depth.

TECH TIP ✓ **Quick and Easy Wheel Speed Sensor Diagnosis**

A fault in a wheel speed sensor (WSS) is a common ABS problem. A quick and easy test that works on most Bosch ABS (and perhaps others) involves the following steps:

Step #1 Hoist the vehicle safely.

Step #2 Turn the ignition on (engine off).

Step #3 Spin a tire by hand as fast as possible.

Step #4 The ABS amber warning light should come on, indicating that a speed was detected but not by all the wheel speed sensors.

Step #5 Turn the ignition off to reset the ABS warning light.

Step #6 Repeat the test on each of the remaining wheels.

If any wheel fails to turn on the ABS light, carefully inspect the wheel speed sensor for proper resistance and the tone ring and wiring. If the ABS light is on all the time and does not reset when the ignition is turned off, the problem is not caused by a wheel speed sensor.

TEST-DRIVE AND VERIFY THE FAULT

A test-drive is a very important diagnostic procedure. Many ABS and diagnostic trouble codes (DTCs) will not set unless the vehicle is moving. Often, the driver has noticed something like the self-test while driving and believed it to be a fault in the system.

NOTE: Some ABS units, such as the Delphi VI, will cause the brake pedal to move up and down slightly during cycling of the valves during the self-test. Each system has unique features. The service technician will have to learn to avoid attempting to repair a problem that is not a fault of the system.

Before driving, start the engine and observe the red and amber brake warning lamps. If the red brake warning lamp is on, the base brakes may not be functioning correctly. Do not drive the vehicle until the base brakes are restored to proper operation.

FREQUENTLY ASKED QUESTION ???

What's That Noise and Vibration?

Many vehicle owners and service technicians have been disturbed to hear and feel an occasional groaning noise. It is usually heard and felt through the vehicle after first being started and driven. Because it occurs when first being driven in forward or reverse, many technicians have blamed the transmission or related drive line components. This is commonly heard on many ABS vehicles as part of a system check. As soon as the ABS controller senses speed from the wheel speed sensors after an ignition cycles on, the controller will run the pump either every time or whenever the accumulator pressure is below a certain level. This can occur while the vehicle is being backed out of a driveway or being driven forward because wheel sensors can only detect speed—not direction. Before serious and major repairs are attempted to "cure" a noise, make sure that it is not the normal ABS self-test activation sequence of events.

General Motors ABS Diagnostic Guide

Type of ABS	Code Clearing Procedure	Scan Tool* Code Retrieval
Teves IV Nonintegral	Yes	Yes
Bosch 2U Nonintegral	Yes	Yes
Delphi (Delco) VI	Yes	Yes
Bosch 2S	Yes	Yes
Delco Powermaster III	Yes	Yes
Kelsey-Hayes RWAL	Yes or disconnect the ABS fuse	Yes or flash codes
Kelsey-Hayes 4WAL	Yes	Yes

*A jumper wire can be used on some systems. Not all scan tools can perform all functions.

NOTE: Some systems are diagnosed by "antilock" and "brake" warning lamps, vehicle symptoms, and the use of a breakout box.

Ford ABS Diagnostic Guide

Type of ABS	Code Clearing Procedure	Scan Tool* Code Retrieval
Teves IV Nonintegral	Drive the vehicle after the repair.	Yes
Kelsey-Hayes RABS	Drive the vehicle after the repair.	Flash codes
Teves 4WABS	Drive the vehicle after the repair.	Yes

*A jumper wire can be used on some systems. Not all scan tools can perform all functions.

Chrysler ABS Diagnostic Guide

Type of ABS	Code Clearing Procedure	Scan Tool* Code Retrieval
Bendix 6 Nonintegral	Yes or disconnect the battery	Yes
Bosch MMC	Yes	Yes
Bosch 2U Nonintegral	No codes available on this system	No codes available on this system
Teves Mark IV	Yes	Yes
Kelsey-Hayes RWAL	Disconnect the battery	Flash codes
Kelsey-Hayes 4WAL	Yes	Yes

*A jumper key can be used for some systems. Not all scan tools can perform all functions.

RETRIEVING DIAGNOSTIC TROUBLE CODES

After performing a thorough visual inspection and after verifying the customer's complaint, retrieve any stored ABS-related diagnostic trouble codes (DTCs). The exact procedure varies with the type of ABS and with the make, model, and year of the vehicle.

Always consult factory service information for the vehicle being diagnosed. Some systems can only display flash codes (flashing ABS or brake lamp in sequence), whereas other systems can perform self-diagnosis and give all information to the technician through a scan tool.

NOTE: With some antilock braking systems, the diagnostic trouble code is lost if the ignition is turned "off" before grounding the diagnostic connector.

KELSEY-HAYES ANTILOCK (NONINTEGRAL)

The Kelsey-Hayes rear-wheel antilock uses two solenoids and valves to control the rear-wheel brakes. Kelsey-Hayes four-wheel antilock uses the computer to pulse the valves rather than turning them on or off. The pulsing is called pulse-width modulated (PWM) and the valve is called a PWM valve.

Retrieving Diagnostic Trouble Codes GM trucks' (RWAL) DTCs are retrieved by flash codes or scan data through the use of a scan tool or connect H to A at the data link connector (DLC). See Figure 82–4.

NOTE: Be sure that the brake warning lamp is on before trying to retrieve DTCs. If the lamp is not on, a false code 9 could be set.

Ford trucks' (RABS) DTCs are retrieved by jumper lead flash codes only. See Figure 82–5.

Chrysler light trucks' DTCs are retrieved by ground diagnostic connections. See Figure 82–6.

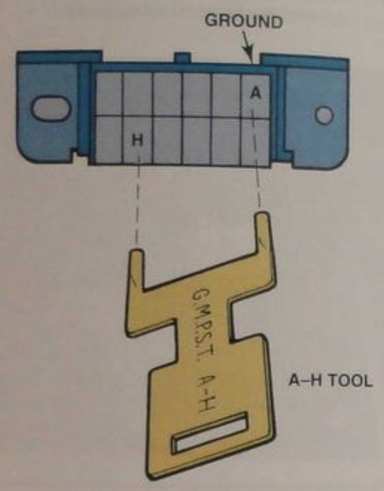


Figure 82–4 General Motors diagnostic connector. Flash codes are available by using a jumper wire to ground (terminal A) to terminal H. This connector is located under the dash near the steering column on most General Motors vehicles.

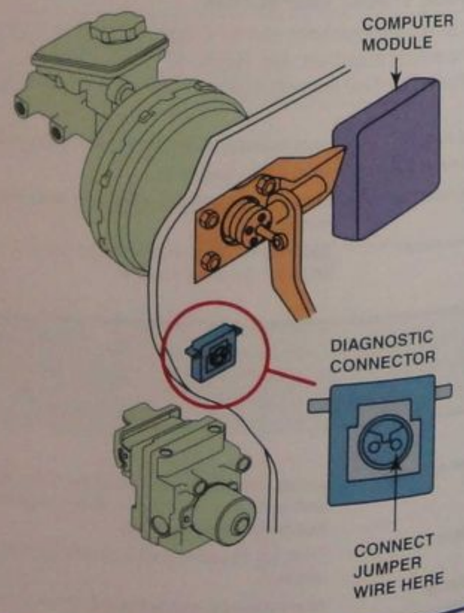


Figure 82–5 Connecting a jumper wire from the diagnostic connector to ground. The exact location of this diagnostic connector varies with the exact vehicle model and year.

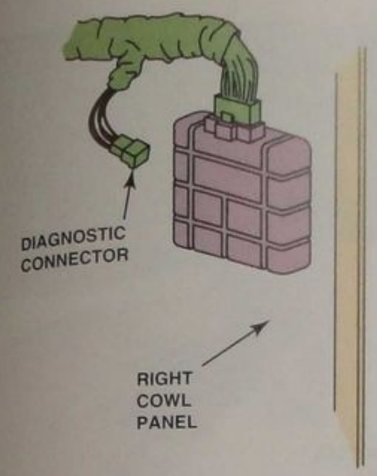


Figure 82–6 Chrysler diagnostic connector location varies with the model and year.

Kelsey-Hayes Diagnostic Trouble Codes

NOTE: If the ignition is turned off, the failure code will be lost unless it is a hard code that will be present when the ignition is turned back on.

RWAL Diagnostic Codes

Code	Description
	Open isolation valve solenoid circuit or malfunctioning EBCM/VCM
	Open dump valve solenoid circuit or malfunctioning EBCM/VCM
	Grounded valve reset switch circuit
	Excessive actuations of dump valve during antilock braking
	Erratic speed signal
	Shorted isolation valve circuit or faulty EBCM/VCM
	Shorted dump valve circuit or faulty EBCM/VCM
	Open or grounded circuit to vehicle speed sensor
	Brake switch circuit
17 to 17	Computer malfunction

REAL WORLD FIX **RWAL Diagnosis**

The owner of an S-10 pickup truck complained that the red brake warning lamp on the dash remained on even when the parking brake was released. The problem could be one of the following:

1. A serious hydraulic problem
2. Low brake fluid
3. A stuck or defective parking brake switch
4. If the brake lamp is dim, RWAL trouble is indicated.

The technician found that the brake lamp was on dimly, indicating that an antilock braking problem was detected. The first step in diagnosing an antilock braking problem with a dash lamp on is to check for stored trouble codes. The technician used a jumper between terminals A and H on the DLC (ALCL), and four flashes of the brake lamp indicated a code 4.

Checking a service manual, code 4 was found to be a grounded switch inside the hydraulic control unit. The hardest part about the repair was getting access to, and the replacement of, the defective (electrically grounded) switch. After bleeding the system and a thorough test-drive, the lamp sequence and ABS functioned correctly.

NOTE: A scan tool may or may not be able to retrieve or display diagnostic trouble codes. Check with the technical literature for the specific vehicle being scanned.

4WAL Diagnostic Trouble Codes

Code	Description
12	System normal (2WD applications)
13	System normal—brake applied (2WD applications)
14	System normal (4WD/AWD applications)
15	System normal—brake applied (4WD/AWD applications)
21 RF	Speed sensor circuit open
25 LF	
31 RR	
35 LR	
35	VSS circuit open
22 RF	Missing speed sensor signal
26 LF	
32 RR	
36 LR	
36	Missing VSS signal
23 RF	Erratic speed sensor signal
27 LF	
33 RR	
37 LR	
37	Erratic VSS signal
28	Simultaneous dropout of front-wheel speed sensors
29	Simultaneous dropout of all speed sensors
35	Vehicle speed sensor circuit open
36	Missing LR or vehicle speed sensor signal
37	Erratic LR or vehicle speed sensor signal
38	Wheel speed error
41 to 66	Malfunctioning BPMV/EHCU
67	Open motor circuit or shorted EBCM output
68	Locked motor or shorted motor circuit
71 to 74	Memory failure
81	Open or shorted brake switch circuit
86	Shorted ABS warning lamp
88	Shorted red brake warning lamp (RBWL)

BOSCH 2 ABS (NONINTEGRAL)

The Bosch 2U/2S ABS is used on many domestic and imported brands of vehicles.

Retrieving Diagnostic Trouble Codes On General Motors vehicles, DTCs can be retrieved by connecting A to H at the data link connector (DLC). On most Bosch 2 systems, a scan tool can and should be used if available to retrieve DTC.

TEVES MARK IV

The Teves Mark IV is a nonintegral (remote) ABS.

Retrieving Diagnostic Trouble Codes Trouble codes are accessed only by a bidirectional scan tool connected to the data link connector (DLC). See Figure 82–7.

Bosch 2U/2S ABS Diagnostic Trouble Codes

Code	Description
12	Diagnostic system operational
21 RF	Wheel speed sensor fault
25 LF	
32 RR	
35 LR	
35	Rear-axle speed sensor fault
22 RF	Toothed wheel frequency error
26 LF	
32 RR	
36 LR	
36	Rear-axle toothed wheel frequency error
41 RF	Valve solenoid fault
45 LF	
55	Rear valve solenoid fault
61	Pump motor or motor relay fault
63	Solenoid valve relay fault
71	Electronic brake control module (EBCM) fault
72	Serial data link fault
74	Low voltage
75	Lateral acceleration sensor fault
76	Lateral acceleration sensor fault

Teves Mark IV ABS Diagnostic Trouble Codes

Code	Description
21	RF speed sensor circuit open
22	RF speed sensor signal erratic
23	RF wheel speed is 0 mph
25	LF speed sensor circuit open
26	LF speed sensor signal erratic
27	LF wheel speed is 0 mph
31	RR speed sensor circuit open
32	RR speed sensor signal erratic
33	RR wheel speed is 0 mph
35	LR speed sensor circuit open
36	LR speed sensor signal erratic
37	LR wheel speed is 0 mph
41	RF inlet valve circuit
42	RF outlet valve circuit
43	RF speed sensor noisy
45	LF inlet valve circuit
46	LF outlet valve circuit
47	LF speed sensor noisy
51	RR inlet valve circuit
52	RR outlet valve circuit
53	RR speed sensor noisy
55	LR inlet valve circuit
56	LR outlet valve circuit
57	LR speed sensor noisy
61	Pump motor test fault
62	Pump motor fault in ABS stop
71	EBCM check sum error
72	TCC/antilock braking switch circuit
73	Fluid level switch circuit

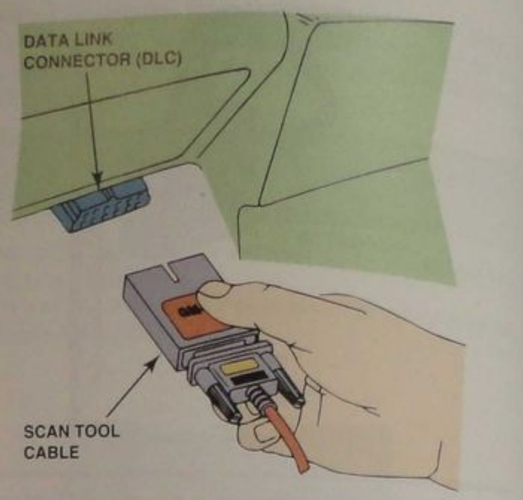


Figure 82–7 A scan tool is the recommended method to use to access General Motors Teves Mark IV systems.

Clearing Diagnostic Trouble Codes A scan tool is required to clear DTCs on some vehicles. Driving the vehicle over 20 mph (32 km/h) will clear the codes on some vehicles. Disconnecting the battery will also clear the codes but will cause other "keep-alive" functions of the vehicle to be lost.

DELPHI (DELCO) ABS VI (NONINTEGRAL)

The Delphi (Delco) ABS VI is unique from all other antilock systems because it uses motor-driven ball screws and pistons for brake pressure to reduce, hold, and apply. See Figures 82–8 and 82–9 on page 1010.

REAL WORLD FIX — **The Nervous Taurus**

A customer complained that, sometimes during normal braking, the ABS would be activated just before coming to a stop. However, the ABS light would not come on. The service technician was able to duplicate the condition and there were no DTCs stored. Using a scan tool to monitor the wheel speed sensors, the technician discovered that the left front wheel speed was slightly different than the others. A thorough visual inspection revealed that the tone wheel (sensor ring) was cracked. This crack created a different wheel speed signal to the ABS controller than the other wheels and the controller activated the ABS as it would normally—that was why there were no DTCs.

Other things that could have caused this problem, which is often called "false modulation," include a bent wheel, mismatched tire sizes, or metal debris around the sensor.

Retrieving Diagnostic Codes The Delphi (Delco) VI antilock braking system has extensive self-diagnostic capability. Access to this vast amount of information requires the use of a scan tool designed to interface (work) with the Delphi VI system.

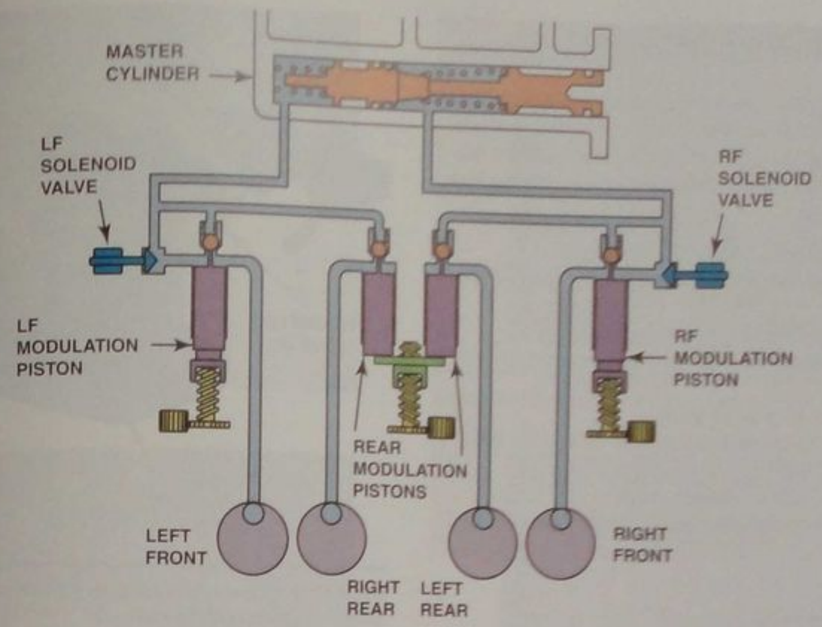


Figure 82–8 Delphi (Delco) VI system components. Notice that each front brake is controlled by a separate piston, whereas the rear brakes are controlled by the same piston.

Delphi (Delco) ABS VI Diagnostic Trouble Codes

Code	Description
	ABS lamp open or shorted to ground
	ABS lamp circuit shorted to battery
	Enable relay contacts open, fuse open
	Enable relay contacts shorted to battery
	Enable relay coil circuit open
	Enable relay coil shorted to ground
	Enable relay coil shorted to B1 or 0 ohms
	Left-front wheel speed
	Left-rear wheel speed
	Right-rear wheel speed
	Excessive left-front wheel acceleration
	Excessive right-front wheel acceleration
	Excessive left-rear wheel acceleration
	Excessive right-rear wheel acceleration
	Two-wheel speed sensors open
	System voltage is low
	System voltage is high
	Left-front EMB will not hold motor
	Right-front EMB will not hold motor
	Rear-axle ESB will not hold motor
	Left-front EMB will not release motor, gears frozen
	Right-front EMB will not release motor, gears frozen
	Rear-axle ESB will not release motor, gears frozen
	Left-front nut failure (motor free-spins)
	Right-front nut failure (motor free-spins)
	Rear-axle nut failure (motor free-spins)
	Left-front channel in release too long
	Right-front channel in release too long
	Rear axle in release too long

Delphi (Delco) ABS VI Diagnostic Trouble Codes

Code	Description
55	Motor driver interface (MDI) fault detected
56	Left-front motor circuit open
57	Left-front motor circuit shorted to ground
58	Left-front motor circuit shorted to battery
61	Right-front motor circuit open
62	Right-front motor circuit shorted to ground
63	Right-front motor circuit shorted to battery
64	Rear-axle motor circuit open
65	Rear-axle motor circuit shorted to ground
66	Rear-axle motor circuit shorted to battery
67	Left-front EMB release circuit open or shorted to ground
68	Left-front EMB release circuit shorted to battery or driver open
71	Right-front EMB release circuit open or shorted to ground
72	Right-front EMB release circuit shorted to battery or driver open
76	Left-front solenoid circuit open or shorted to battery
77	Left-front solenoid circuit shorted to ground or driver open
78	Right-front solenoid circuit open or shorted to battery
81	Right-front solenoid circuit shorted to battery or driver open
82	Calibration memory failure
86	ABS controller turned "on"; red brake telltale
87	Red brake telltale circuit open
88	Red brake telltale circuit shorted to battery or driver open
91	Open brake switch contacts (deceleration detected)
92	Open brake switch contacts
93	Test 91 or 92 failed last or current ignition cycle
94	Brake switch contacts shorted
95	Brake switch circuit open
96	Brake lamps open, brake lamp ground open, center high-mounted stop lamp open during four-way flasher operations

HOW TO **Look for Flood Damage If Electrical Problems**

These can often diagnose electrical problems that can occur including false DTCs or intermittent operation of electrical sensors, ABS, accessories, or gauges. Sometimes the root of these problems is due to rust and corrosion after a vehicle is involved in a flood. Here are some telltale signs that a vehicle may have been in a flood or in deep water.

- Mud, silt, or rotted trash under the dash and inside the doors
- Corroded electrical connectors on the computer, fuse box, or ABS controller connectors
- Visible water line in the doors or behind panels
- Rust in abnormal places such as seat springs or brackets behind the dash
- Moisture in lenses
- Musty smell and/or strong air freshener smell
- Powdery corrosion on aluminum parts such as intake manifold and inside the throttle bore
- Rust on insulators inside electrical switches or relays
- Areas that are normally dusty such as an ashtray or glove box are very clean

REAL WORLD FIX **The Mystery ABS Amber Warning Light**

The owner of an Acura Legend complained to a service technician that the ABS warning light would come on but only while driving down from a parking garage. When the driver turned off the ignition and restarted the engine, the ABS amber light was not on and did not come on again until the vehicle was again driven down the spiral parking garage ramp. The service technician used a scan tool and found that no DTCs had been stored.

NOTE: Some ABS will not retain a DTC unless the problem is currently present and the ABS amber warning light is on.

All of the brakes were in excellent condition, but the brake fluid level was down a little. After topping off the master cylinder with clean DOT 3 brake fluid, the vehicle was returned to the customer with the following information:

- The ABS amber warning light may have been triggered by the brake fluid level switch. While driving down the steep parking garage ramp, the brake fluid moved away from the fluid level sensor.

NOTE: While the brake fluid level sensor normally would turn on the red brake warning light, in some systems it turns on the amber ABS light if the brake fluid falls below a certain level in the ABS reservoir.

- The difference in wheel speed between the outboard and the inboard wheels could have triggered a fault code by a wheel speed sensor during the drive down the spiral parking garage ramp.

WHEEL SPEED SENSOR DIAGNOSIS

Wheel speed sensor (WSS) circuits are often the cause of many ABS problems. See Figure 82–10. These components may suffer from physical damage, build-up of metallic debris on the sensor tip, corrosion, poor electrical connections, and damaged wiring.

See a WSS for measuring resistor voltage and circuit continuity. A **breakout box (BOB)** cable connects to the ABS harness near the ABS module. All WSS resistance checks, including the wiring to the sensors, can be measured at this location. See Figure 82–11. Follow the equipment manufacturer's instructions for connecting the breakout box to the vehicle, and for probing the appropriate pins on the breakout box.

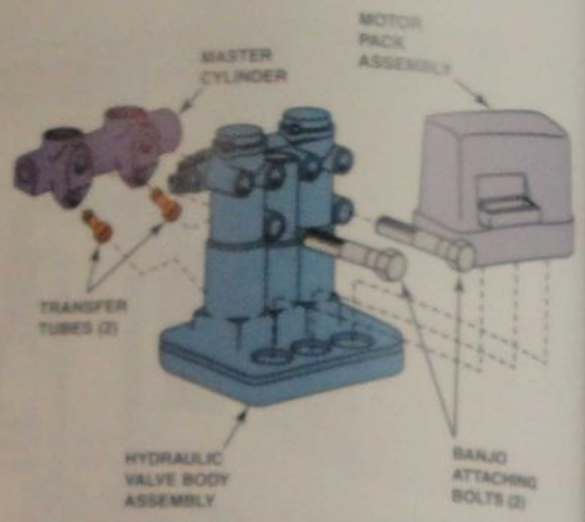


Figure 82–9 The Delphi (Delco) VI attaches to the side of the master cylinder and connects hydraulically through transfer tube assemblies.

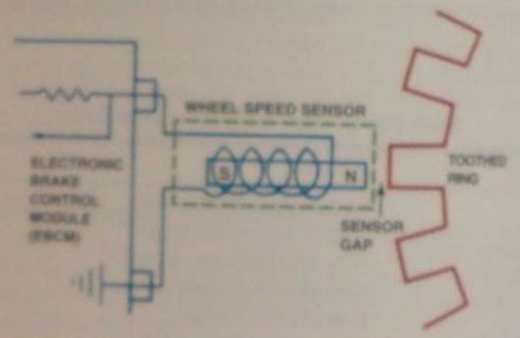
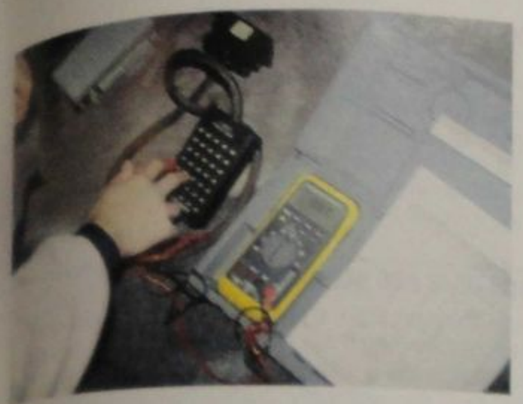


Figure 82–10 Typical wheel speed sensor. When a tooth on the sensor ring is close to the sensor, the strength of the magnetic field is stronger because the metal of the tooth conducts magnetic lines of force better than air. When the tooth moves away, the magnetic field strength is reduced. It is this changing magnetic field strength that produces the changing voltage. Frequency of the signal is determined by the speed of the rotating sensor.

Resistance Measurement The resistors of most WSS range from 800 Ω to 1,400 Ω. Therefore, a reading of about 1,000 ohms or 1 KΩ would indicate proper sensor coil resistance. See Figure 82–12.

Checking for Short-to-Ground Connect either lead of the ohmmeter to one of the WSS wires and the other to a good, clean chassis ground. The resistance should be infinity (OL). If a low resistance reading is obtained, the sensor or sensor wiring is shorted-to-ground and must be replaced.

AC Voltage Check Connect a digital meter to the WSS terminals or input to the controller in the breakout box and set the meter to read AC volts. Rotate the wheel by hand at a rate of one revolution per second. A good WSS should produce voltage of at least 0.1 volt (100 mV). A sensor voltage of lower than 0.1 volt (100 mV) may be caused by three things:



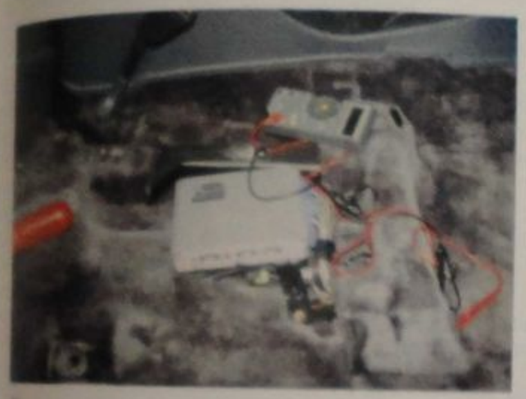


Figure 82–11 (a) A breakout box is being used to diagnose an ABS problem. The controller (module) is located in the trunk of this vehicle, and a digital multimeter is being used to measure resistance and voltage at various points in the system, following the service manual procedure. (b) Interior vehicle being tested for an ABS fault. In this vehicle, the computer is located under the passenger seat, which has been removed to gain better access to the wiring and terminals.

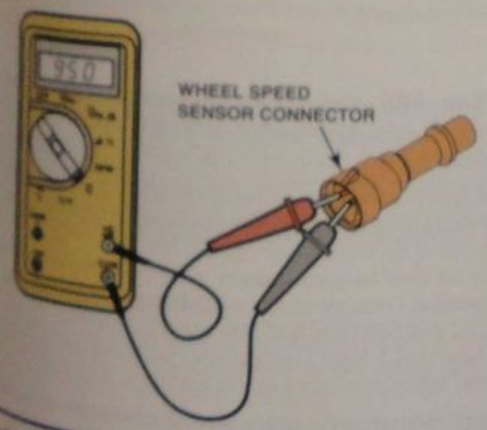


Figure 82–12 Measuring the resistance of a wheel speed sensor.

1. Excessive clearance between the sensor and the tone ring.
2. Buildup of debris on the end of the sensor. Most WSSs are magnetic and can attract metallic particles, which can affect the operation of the sensor.
3. Excessive resistance in the sensor or sensor wiring, which can also cause a weak signal to be produced by the WSS.

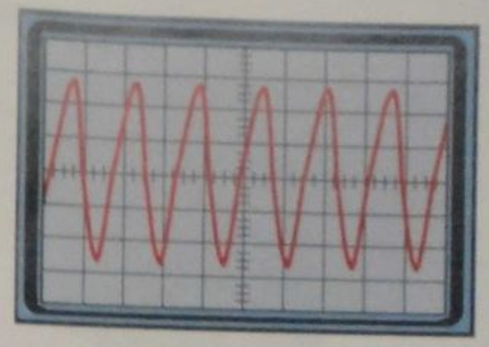


Figure 82–13 A scope can be used to check for proper operation of a wheel speed sensor.

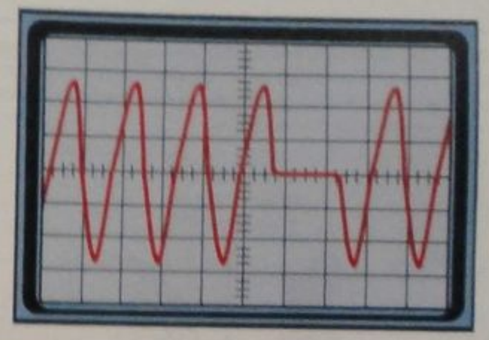


Figure 82–14 A broken tooth on a wheel speed sensor tone ring shows on the scope trace as a missing wave.

Scope Testing Attach the scope leads to the sensor terminals or to the input connector on the breakout box. Rotate the wheel by hand or by using engine power with the vehicle safely hoisted with all four wheels off the ground. A good WSS should produce an alternating current (AC) sine wave signal that increases in frequency and amplitude with increasing wheel speed. See Figure 82–13.

Damaged or missing teeth on the tone ring will cause flat spots or gaps in the sine wave pattern. See Figure 82–14.

A bent axle or hub will produce a wavelike pattern that fluctuates as the strength of the sensor signal changes with each revolution.

Scan Tool Testing A scan tool can be used to check for the proper operation of the WSS. As an assistant drives the vehicle, connect the scan tool and monitor the speed of all of the sensors. All of the sensors should indicate the same speed. If a sensor shows a slower or faster speed than the others, carefully check the tone ring for damage such as a crack.

WHEEL SPEED SENSOR ADJUSTMENT

Some ABS applications use adjustable WSSs. Most sensors adjust by first loosening a set screw, then inserting a nonmagnetic brass or plastic feeler gauge between the tip of the sensor and a high point on the tone ring. See Figure 82–15. Adjust the position of the sensor so there is a slight drag on the feeler gauge, and then tighten the setscrew to lock the sensor in place.

When installing new sensors, look for a piece of paper or plastic on the tip end of the unit. This is more than a protective covering and must be left in place during installation. The paper or plastic is the precise thickness to guarantee a correct air gap between the tip of the sensor and the tone ring. Adjust the sensor so

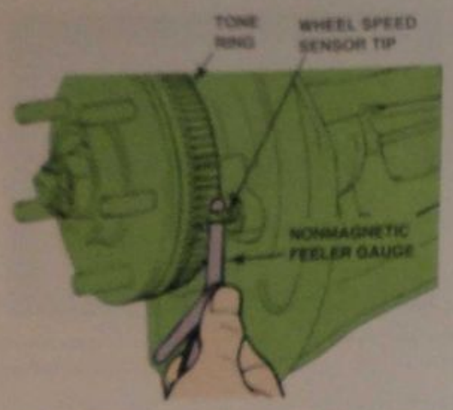
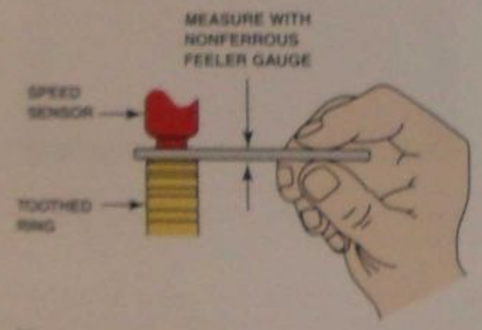


Figure 82–15 Use a nonmagnetic brass or plastic feeler gauge to check wheel speed sensor gap. A steel gauge would be attracted by the magnet in the sensor and would produce a drag on the gauge as it is moved between the sensor and the tone ring. This drag could be interpreted as a correct clearance reading.



(A)



(B)

Figure 82–16 (A) Always use a nonferrous (brass or plastic) feeler (thickness) gauge when measuring the gap between the toothed ring and the wheel speed sensor. (B) Sometimes a sensor is equipped with a paper spacer that is the exact thickness of the spacing required between the toothed ring and the sensor. If equipped, the sensor is simply installed with the paper touching the toothed wheel. A typical gap ranges from 0.020 to 0.050 in. (0.5 to 1.3 mm).

the tip just touches the tone ring and you can slip the paper or plastic out without ripping it. Tighten the setscrew and the air gap is properly set. See Figure 82–16.

Some manufacturers recommend leaving a paper covering in place. The action of the tone ring removes it after the vehicle is driven for several miles.

Digital Wheel Speed Sensor Diagnosis Test a digital WSS by first checking that battery voltage is available at the sensor with the key on, engine off. If the sensor does not have 12 volts, then the problem is most likely in the ABS controller or the wiring between the controller and the sensor.

If there are 12 volts at the sensor, measure the signal voltage. The voltage should switch from about 0.8 V to about 1.9 V as the wheel is rotated by hand.

HYDRAULIC ABS SERVICE

Before doing any brake work on a vehicle equipped with antilock brakes, always consult the appropriate service information for the exact vehicle being serviced. For example, some manufacturers recommend discharging the hydraulic accumulator by depressing the brake pedal many times before opening bleeder valves. Many service checks require that a pressure gauge be installed in the system.

Air can easily get trapped in the ABS electronic hydraulic (E-H) assembly whenever the hydraulic system is opened. Even though the master cylinder and all four wheel cylinders/calipers have been bled, sometimes the brake pedal will still feel spongy. Some E-H units can be bled through the use of a scan tool where the valves are pulsed in sequence by the electronic brake controller (computer). Some units are equipped with bleeder valves while others must be bled by loosening the brake lines. Bleeding the E-H unit also purges out the older brake fluid, which can cause rust and corrosion damage. Only DOT 3 brake fluid is specified for use in an antilock braking system. Always check the label on the brake fluid reservoir and/or service manual or owner's manual.

CAUTION: Some ABS units require that the brake pedal be depressed as many as 40 times to discharge brake fluid fully from the accumulator. Failure to discharge the accumulator fully can show that the brake fluid level is too low. If additional brake fluid is added, the fluid could overflow the reservoir during an ABS stop when the accumulator discharges brake fluid back into the reservoir.

Bleeding ABS During routine brake service, attempt to keep the air from entering the hydraulic system by doing the following:

1. Do not allow the brake system to run dry. Use a brake pedal depressor or plug any open brake line to keep brake fluid from flowing out of the brake master cylinder reservoir.
2. Do not allow the master cylinder to run dry during the bleeding operation. Check the master cylinder reservoir often and keep it filled with fresh brake fluid from a sealed container.
3. Always bench bleed a replacement master cylinder to help prevent against introducing air into the hydraulic system.

After depressing the unit as per manufacturer's recommended procedures, the brakes can be bled using the same procedure as for a vehicle without ABS. Air trapped in the ABS hydraulic unit may require that a scan tool be used to cycle the valves. See Figures 82–17 and 82–18.

The bleeding procedure for vehicles equipped with antilock brakes is often different than vehicles without ABS. Consult the service information for the specified bleeding procedure and sequence.

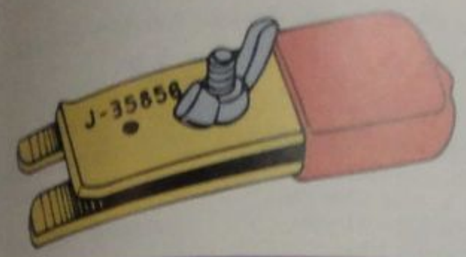


Figure 82–17 Special bleed valve tools are often required when bleeding some ABS units such as the Kelsey Hayes 4WAL system.

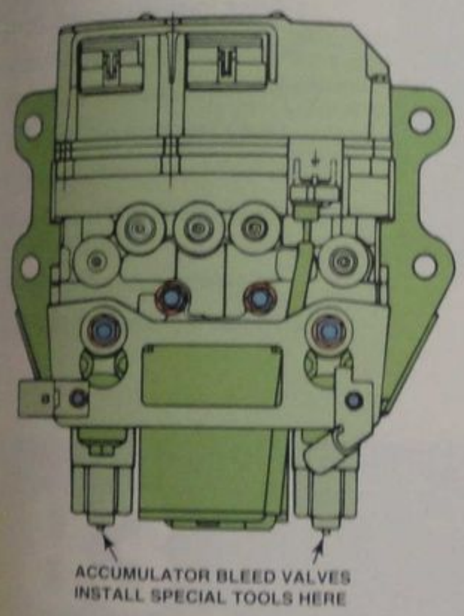


Figure 82–18 Two bleed valve tools are needed to bleed the Kelsey-Hayes 4WAL system. Hoses attaches to the bleed valves on the accumulator.

NOTE: To avoid having to bleed the hydraulic unit, use a brake pedal depressor during brake service to avoid losing brake fluid. This simple precaution keeps air from getting into the hard-to-bleed passages of the hydraulic unit.

ABS SAFETY PRECAUTIONS

1. Avoid mounting the antenna for the transmitting device near the ABS control unit. Transmitting devices include cellular (cell) telephones, citizen-band radios, and so on.
2. Avoid mounting tires of different diameter than that of the original tires. Different size tires generate different wheel speed sensor frequencies which may not be usable by the ABS controller.
3. Never open a bleeder valve or loosen a hydraulic line while the ABS is pressurized. The accumulator must be depressurized according to the manufacturer's recommended procedures.
4. If arc welding on a vehicle, disconnect all computers (electronic control modules) to avoid possible damage due to voltage spikes.
5. Do not pry against or hit the wheel speed sensor ring.

SUMMARY

1. ABS diagnosis starts with checking the status of both the red brake warning lamp and the amber ABS warning lamp.
2. The second step in diagnosis of an ABS problem is to perform a thorough visual inspection.
3. The third step in diagnosis of an ABS problem is to test-drive the vehicle and verify the fault.
4. Always consult the factory service information for the specific vehicle being serviced for the proper procedure to use to retrieve and clear diagnostic trouble codes (DTCs).
5. A breakout box is used with a digital multimeter to diagnose electrical ABS components.
6. Hydraulic service on most integral ABS units requires that the brake pedal be depressed as many as 40 times with the ignition key "off" to depressurize the hydraulic system.

REVIEW QUESTIONS

1. Describe the proper operation of the red and amber brake warning lamps.
2. List the items that should be checked as part of a thorough visual inspection.
3. Explain how to retrieve a diagnostic trouble code from a General Motors vehicle equipped with Kelsey Hayes RWAL ABS.
4. Describe how to use a breakout box to check for proper wheel speed sensor operation.

CHAPTER QUIZ

1. The red brake warning lamp is on and the amber ABS lamp is off. Technician A says that a fault is possible in the base brake system. Technician B says that the red brake warning lamp can be turned on by a low brake fluid level in the master cylinder. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Two technicians are discussing magneto-type wheel speed sensors. Technician A says that wheel speed sensors are magnetic. Technician B says that the toothed sensor ring is magnetic. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that using the space-saving small spare tire may trigger an ABS amber warning lamp. Technician B says the use of the small spare tire may trigger the red brake warning lamp. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that, with some antilock braking systems, the diagnostic trouble code may be lost if the ignition is turned off before retrieving the code. Technician B says that some antilock braking systems require that a terminal be grounded to cause the amber ABS warning lamp to flash diagnostic trouble codes. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

5. Technician A says that a scan tool may be required to retrieve data and diagnostic trouble codes from some antilock braking systems. Technician B says that a jumper wire can be used to retrieve diagnostic trouble codes on some antilock braking systems. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

6. Technician A says that a breakout box is sometimes required to diagnose an antilock braking system. Technician B says that a breakout box requires the use of a digital multimeter. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. Technician A says that a dim red brake warning lamp could indicate a fault in the antilock braking system on some vehicles. Technician B says that the ABS fuse may have to be removed to erase some ABS diagnostic codes if a scan tool is not used. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. The ABS computer uses what signal characteristic from a wheel speed sensor?
   a. Voltage
   b. Frequency
   c. Resistance
   d. Electromagnetic

9. Most wheel speed sensors should measure how much resistance?
   a. 800 to 1,300 ohms
   b. 100 to 300 ohms
   c. 1 to 3 ohms
   d. 0.1 to 1 ohm

10. Technician A says that the ABS electrohydraulic unit can be bled using bleeder screws and the manual method. Technician B says that a scan tool is often required to bleed the ABS electrohydraulic unit. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

SECTION XII Suspension and Steering

83 Tires and Wheels
84 Tire and Wheel Service
85 Suspension System Components and Operation
86 Front Suspension and Service
87 Rear Suspension and Service
88 Electronic Suspension Systems
89 Steering Columns and Gears
90 Steering Linkage and Service
91 Power-Assisted Steering Operation and Service
92 Wheel Alignment Principles
93 Alignment Diagnosis and Service



CHAPTER 83 Tires and Wheels

OBJECTIVES: After studying Chapter 83, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "E" (Wheel and Tire Diagnosis and Repair). • Discuss tire sizes and ratings. • Describe tire purchasing considerations and maintenance. • Explain the construction and sizing of steel and alloy wheels and attaching hardware. • Demonstrate the correct lug nut tightening procedure and torque.

KEY TERMS: aspect ratio • back spacing • bead • belt • body ply • bolt circle • carcass ply • center section • conicity • DOT tire code • E-metric tire • green tire • high-flotation tires • hydroplaning • inner liner • JWL • LLR • load index • lug nuts • major splice • offset • ply steer • rim width • run-flat tires • Schrader valve • sidewall • speed ratings • spider • TPC • TPMS • tread • TREAD Act • unsprung weight • UTQGS • wear bars

The friction (traction) between the tire and the road determines the handling characteristics of any vehicle. Think about this statement for a second. The compounding, construction, and condition of tires are some of the most important aspects of the steering, suspension, alignment, and braking systems of any vehicle. A vehicle that handles poorly or that pulls, darts, jumps, or steers "funny" may be suffering from defective or worn tires. Understanding the construction of a tire is important for the technician to be able to identify tire failure or vehicle handling problems.

Tires are mounted on wheels that are bolted to the vehicle to provide the following:

1. Shock absorber action when driving over rough surfaces
2. Friction (traction) between the wheels and the road

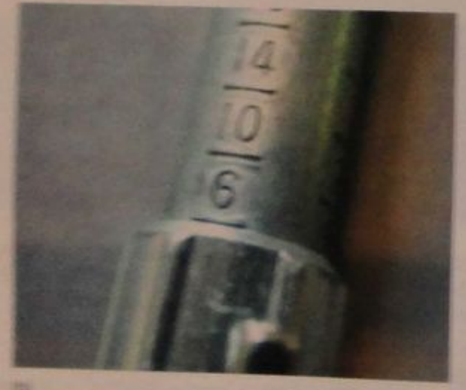
All tires are assembled by hand from many different component parts consisting of various rubber compounds, steel, and various types of fabric material. Tires are also available in many different designs and sizes.

PARTS OF A TIRE

Tread **Tread** refers to the part of the tire that contacts the ground. *Tread rubber* is chemically different from other rubber parts of a tire, and is compounded for a combination of traction and tire wear. *Tread depth* is usually 11/32 in. deep on new tires (this could vary, depending on manufacturer, from 9/32 to 15/32 in.). Figure 83–1 shows a tread depth gauge.



(a)



(b)

Figure 83–1 (a) A typical tire tread depth gauge. The center movable plunger is pushed down into the groove of the tire. (b) The tread depth is read at the top edge of the sleeve. In this example, the tread depth is 6/32 in.

NOTE: A tread depth is always expressed in 1/32s of an inch, even if the fraction can be reduced to 1/16s or 1/8s.

Wear indicators are also called **wear bars.** When tread depth is down to the legal limit of 2/32", bald strips appear across the tread. See Figure 83–2.

Tie bars are molded into the tread of most all-season-rated tires. These rubber reinforcement bars are placed between tread blocks on the outer tread rows to prevent unusual wear and to reduce tread noise. As the tire wears normally, the tie bars will gradually appear. This should not be mistaken for an indication of

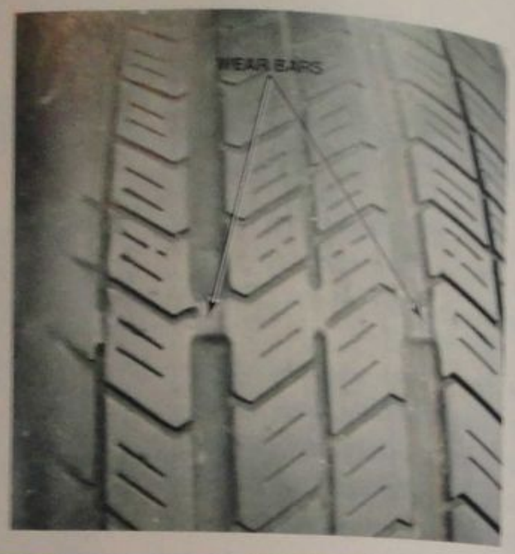


Figure 83–2 Wear indicators (wear bars) are strips of bald tread that show when the tread depth is down to 2/32 in, the legal limit in many states.

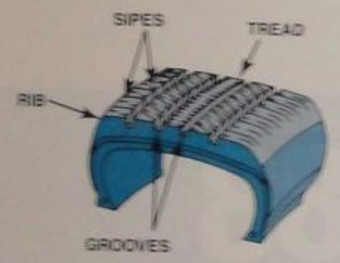


Figure 83–3 The tire tread runs around the circumference of the tire, and its pattern helps maintain traction. The ribs provide grip, while the grooves direct any water on the road away from the surface. The sipes help the tire grip the road.

excess outer edge wear. A tire tread with what appears to be a solid band across the entire width of the tread is what the service technician should consider the wear bar indicator.

Grooves are large, deep recesses molded in the tread and separating the tread blocks. These grooves are called *circumferential grooves* or *kerfs.* Grooves running sideways across the tread of a tire are called *lateral grooves.* See Figure 83–3.

Grooves in both directions are necessary for wet traction. The trapped water can actually cause the tires to ride up on a layer of water and lose contact with the ground, as shown in Figure 83–4. This is called **hydroplaning.** With worn tires, hydroplaning can occur at speeds as low as 30 mph on wet roads. Stopping and cornering is impossible when hydroplaning occurs. *Sipes* are small slits in the tread area to increase wet and dry traction.

Sidewall The **sidewall** is that part of the tire between the tread and the wheel. The sidewall contains all the size and construction details of the tire.

Some tires turn brown on the sidewalls after a short time. This is due to ozone (atmosphere) damage that actually causes the rubber to oxidize. Premium-quality tires contain an anti-oxidizing chemical additive blended with the sidewall rubber to prevent this discoloration.

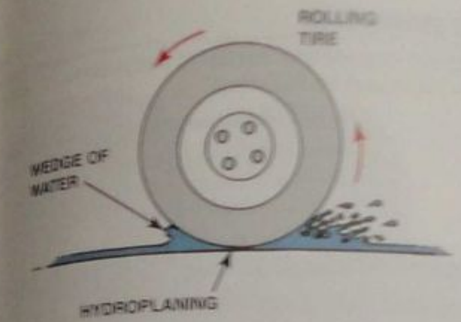


Figure 83–4 Hydroplaning can occur at speeds as low as 30 mph (48 km/h), if the water is deep enough and the tire tread cannot evacuate water through its grooves fast enough, the tire is lifted off the road surface by a layer of water. Hydroplaning occurs at lower speeds as the tire becomes worn.

White Sidewall Lettered When pneumatic tires were first constructed in the early 1900s, only natural rubber was used. The entire tire was white. When it was discovered that carbon black greatly increased the toughness of a tire, it was used. The public did not like the change from white tires to black, so tire manufacturers added carbon black (lamp black) only in the rubber that was to be used for the tread portion of the tire. This tire lasted a lot longer because the black rubber tread that touched the ground was stronger and tougher; it sold well because the sidewalls were white.

White sidewall or white lettered tires actually contain a strip of gum rubber under the black sidewall. This is ground off at the factory to reveal the white rubber. Only whitewalls or white letter lines contain this expensive white rubber. Various widths of whitewalls are also possible simply by changing the width of the grinding wheel.

Bead The **bead** is the foundation of the tire and is located where the tire grips the inside of the wheel rim.

1. The bead is constructed of many turns of copper- or bronze-coated steel wire.
2. The main body plies (layers of material) are wrapped around the bead.

CAUTION: If the bead of a tire is cut or damaged, the tire must be replaced!

3. Most radial-ply tires and all truck tires wrap the bead with additional material to add strength.

Body Ply A tire gets its strength from the layers of material wrapped around both beads under the tread and sidewall rubber. This creates the main framework, or "carcass," of the tire. The **body plies** are often called **carcass plies.** A 4-ply tire has four separate layers of material. If the body plies overlap at an angle to the tire, the tire is called a *bias-ply* tire. If only one or two body plies are used and they do not cross at an angle, but lie directly from bead to bead, then the tire is called *radial ply.* See Figure 83–5.

1. Rayon is a body ply material used in many tires because it provides a very smooth ride. A major disadvantage of rayon is that it must be protected from moisture.
2. Nylon is a strong body ply material. Though it is still used in some tires, it tends to "flat-spot" after sitting overnight.
3. Kevlar® is the generic name for aromatic polyamide fibers developed in 1972. Aramid is several times stronger than steel (pound for pound), and is used in high-performance tire construction.

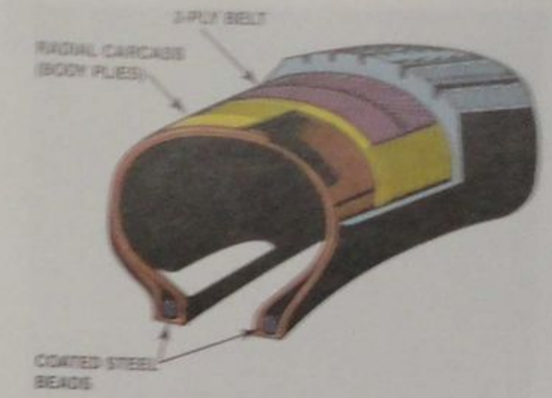


Figure 83–5 Typical construction of a radial tire. Some tires have only one body ply, and some tires use more than two belt plies.

Kevlar is the DuPont brand name for aramid and a registered trademark of E.I. Dupont de Nemours and Co.

4. Polyester is the most commonly used tire material because it provides the smooth ride characteristics of rayon with the tire resistance and strength of nylon.

Belt A tire **belt** is two or more layers of material applied over the body plies and under the tread area only, to stabilize the tread and increase tread life and handling.

1. Belt material can consist of the following:
   a. Steel mesh
   b. Nylon
   c. Rayon
   d. Fiberglass
   e. Aramid
2. **All radial tires are belted.**

NOTE: Most tires used for high speed use a nylon "overlay" or "cap belt" between the 2-ply belt and the tread of the tire. This overlay helps stabilize the belt package and helps hold the tire together at high speeds, when centrifugal force acts to tear it the apart.

Inner Liner The **inner liner** is the soft rubber lining (usually a butyl rubber compound) on the inside of the tire that protects the body plies and helps provide for self-sealing of small punctures.

Major Splice When the tire is assembled by a craftsperson or a tire-building machine, the body plies, belts, and tread rubber are spliced together. The fabric is overlapped approximately five threads. The point where the majority of these overlaps occur is called the **major splice,** which represents the stiffest part of the tire. This major splice is visible on most tires on the inside, as shown in Figure 83–6.

NOTE: On most new vehicles and on new tires, the tire manufacturer paints a dot on the sidewall near the bead, indicating the largest diameter of the tire. The largest diameter of the tire usually is near the major splice. The wheel manufacturer either marks the wheel or drills the valve core hole at the smallest diameter of the wheel. Therefore, the dot should be aligned with the valve core or marked for best balance and minimum radial runout.

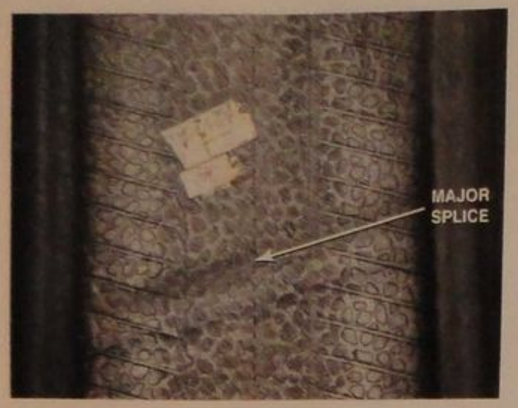


Figure 83–6 The major splice of a tire can often be seen and felt on the inside of the tire. The person who assembles (builds) the tire usually places a sticker near the major splice as a means of identification for quality control.



Figure 83–7 Tire construction is performed by assembling the many parts of a tire together on a tire-building machine.

TIRE MOLDING

After the tire has been assembled by the tire builder, it is called a **green tire.** See Figure 83–7. At this stage in construction, the rubber can be returned and reused because it has not been changed chemically. The completed green tire is then placed in a mold where its shape, tread design, and all sidewall markings are formed. See Figure 83–8.

While in the mold, a steam bladder fills the inside of the tire and forces the tire against the outside of the mold. After approximately 30 minutes at 300°F (150°C), the heat changes the chemistry of the rubber. The tire is no longer called a green tire but a *cured tire,* and after inspection and cleaning, it is ready for shipment.

METRIC DESIGNATION

European and Japanese tires use metric designations. For example, 185SR × 14 denotes the following:

185	the tire is 185 millimeters (mm) wide (cross-sectional width)
S	the speed rating
R	radial design
14	fits a 14-in.-diameter wheel

FREQUENTLY ASKED QUESTION ???

Why Do I Get Shocked by Static Electricity When I Drive a Certain Vehicle?

Static electricity builds up in insulators due to friction of the tires with the road. Newer tires use silica and contain less carbon black in the rubber, which makes the tires electrically conductive. Because the tires cannot conduct the static electricity to the ground, static electricity builds up inside the vehicle and is discharged through the body of the driver and/or passenger whenever the metal door handle is touched.

NOTE: Toll booth operators report being shocked by many drivers as money is being passed between the driver and the toll booth operator.

Newer tire sidewall designs that use silica usually incorporate carbon sections that are used to discharge the static electricity to ground. To help reduce the static charge buildup, spray the upholstery with an antistatic spray available at discount and grocery stores.

The European size indicates the exact physical size (width) of the tire and the speed ratings. Because of the lack of speed limits in many countries, this information is important. Because of tire design changes needed for H- and V-rated tires, their cost is usually much higher. European sizes also include the tire's aspect ratio, for example, 185/70SR × 14. If the aspect ratio of a European-sized tire is not indicated, it is generally 83% for most radials.

American Metric Tire Size Designations After 1980, American tires were also designated using the metric system. For example, P205/75R × 14 denotes the following:

P	passenger vehicle
205	205-mm cross-sectional width
75	75% aspect ratio. The height of the tire (from the wheel to the tread) is 75% as great as its cross-sectional width (the width measured across its widest part). This percentage ratio of height to width is called the **aspect ratio.** (A 60 series tire is 60% as high as it is wide.)
R	radial
14	14-in.-diameter wheel

If a tire is constructed as a bias-ply tire only, then its size designation uses the letter D to indicate *diagonal:* P205/75D × 14.

NOTE: Many "temporary use only" spare tires are constructed with diagonal (bias) plies; the size designation is *T* for *temporary.*

If a tire is constructed as a bias ply with a belt of additional material under the tread area, its size designation uses the letter B to indicate belted: P205/75B × 14. Some tires use letters at the end

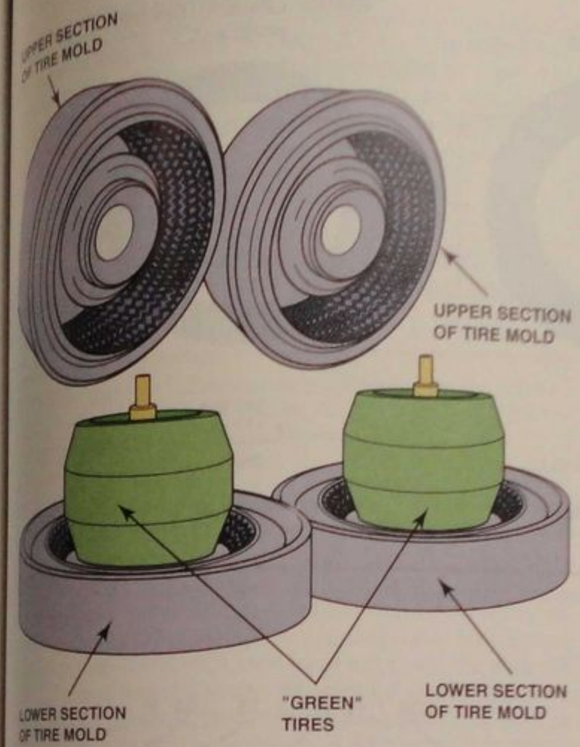


Figure 83–8 After the entire tire has been assembled into a completed "green" tire, it is placed into a tire-molding machine where the tire is molded into shape and the rubber is changed chemically by the heat. This nonreversible chemical reaction is called vulcanization.

FREQUENTLY ASKED QUESTION ???

How Much Does Tire Pressure Change with a Change in Temperature?

As the temperature of a tire increases, the pressure inside the tire also increases. The general amount of pressure gain (when temperatures increase) or loss (when temperatures decrease) is as follows:

10°F increase causes 1 PSI increase

10°F decrease causes 1 PSI decrease

For example, if a tire is correctly inflated to 35 PSI when cold and then driven on a highway, the tire pressure may increase 5 PSI or more.

CAUTION: DO NOT LET AIR OUT OF A HOT TIRE! If air is released from a hot tire to bring the pressure down to specifications, the tire will be underinflated when the tire has cooled. The tire pressure specification is for a cold tire.

Always check the tire pressures on a vehicle that has been driven fewer than 2 miles (3.2 km).

Air pressure in the tires also affects fuel economy. If all four tires are underinflated (low on air pressure), fuel economy is reduced about **0.1 mile per gallon (mpg) for each 1 PSI low.** For example, if all four tires were inflated to 25 PSI instead of 35 PSI, not only is tire life affected but fuel economy is reduced by about 1 mile per gallon (10 × 0.1 = 1 mpg).

FREQUENTLY ASKED QUESTION ???

How Much Bigger Can I Go?

Many owners think they can improve their vehicle by upgrading the tire size over the size that comes from the factory to make their vehicle look sportier and ride and handle better. When changing tire size, there are many factors to consider:

1. The tire should be the same outside diameter as the original to maintain the proper suspension, steering, and ride height specifications.
2. Tire size affects vehicle speed sensor values, ABS brake wheel sensor values that can change automatic transmission operation, and ABS operation.
3. The tire should not be so wide as to contact the inner wheel well or suspension components.
4. Generally, a tire that is 10 mm wider is acceptable. For example, an original equipment tire size 205/75 × 15 (outside diameter = 27.1 in.) can be changed to 215/75 × 15 (outside diameter = 27.6 in.). This much change is less than 1/2 in. in width and increases the outside diameter by 1/2 in.

NOTE: Outside diameter is calculated by adding the wheel diameter to the cross-sectional height of the tire, multiplied by 2. See Figure 83–9.

5. Whenever changing tires, make sure that the load capacity is the same or greater than that of the original tires.
6. If wider tires are desired, a lower aspect ratio is required to maintain the same, or close to the same, overall outside diameter of the tire.

Old	New
P205/75 × 15	P215/70 × 15
205 × 0.75 = 154 mm	215 × 0.70 = 151 mm

Notice that the overall sidewall height is generally maintained.

If even larger tires are needed, then 225/60 × 15s may be OK—let's check the math:

$$225 \times 0.60 = 135 \text{ mm}$$

Notice that this is much too short a sidewall height when compared with the original tire (see no. 6).

7. Use the "plus 1" or "plus 2" concept. When specifying wider tires, the sidewall height must be reduced to maintain the same, or close to the same, original equipment specifications. The "plus 1" concept involves replacing the wheels with wheels 1 in. larger in diameter to compensate for the lower aspect of wider tires.

Original	Plus 1
205/75 × 15	225/60 × 16

The overall difference in outside diameter is only 0.5 in., even though the tire width has increased from 205 mm to 225 mm and the wheel diameter has increased by 1 in. If money is no object and all-out performance is the goal, a "plus 2" concept can also be used (use a P245/50 × 17 tire and change to 17-in.-diameter wheels).

Here the overall diameter is within 1/20" of the original tire/wheel combination, yet the tire width is 1.6 inches (40 mm) wider than the original tire. Refer to the section entitled "Wheels" later in this chapter for proper wheel back spacing and offset when purchasing replacement wheels.

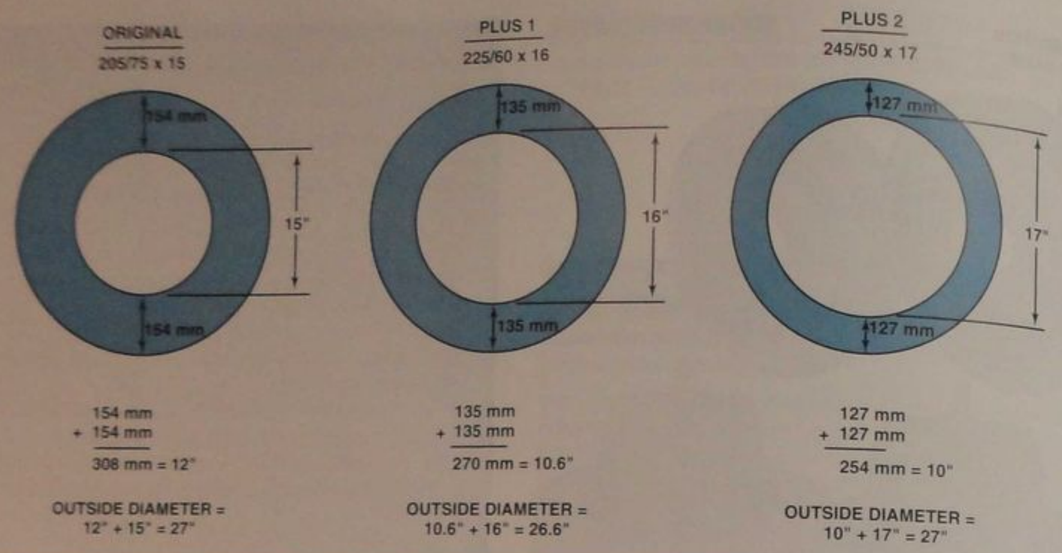


Figure 83–9 Notice that the overall outside diameter of the tire remains almost the same and at the same time the aspect ratio is decreased and the rim diameter is increased.

of the tire size (suffixes) to indicate special applications, including the following:

LT	light truck
ML	mining and logging
MH	mobile home
ST	special trailer
TR	truck

SERVICE DESCRIPTION

Tires built after 1990 use a "service description" method of sidewall information in accordance with ISO 4000 (International Standards Organization) that includes size, load, and speed rating together in one easy-to-read format. See Figure 83–10.

P-Metric Designation	Service Description
P205/75HR × 15	205/75R × 15 92H
P passenger vehicle	205 cross-sectional width in mm
205 cross-sectional width in mm	75 aspect ratio
75 aspect ratio	R radial construction
H speed rating (130 mph/210 km/h)	15 rim diameter in inches
R radial construction	92 load index
15 rim diameter in inches	H speed rating (130 mph/210 km/h)

HIGH-FLOTATION TIRE SIZES

High-flotation tires for light trucks are designed to give improved off-road performance on sand, mud, and soft soil and still provide acceptable hard-road surface performance. These tires are usually larger than conventional tires and usually require a wider-than-normal wheel width. High-flotation tires have a size designation such as 33 × 12.50R × 15LT:

33	approximate overall tire diameter in inches
12.50	approximate cross-sectional width in inches
R	radial-type construction
15	rim diameter in inches
LT	light-truck designation

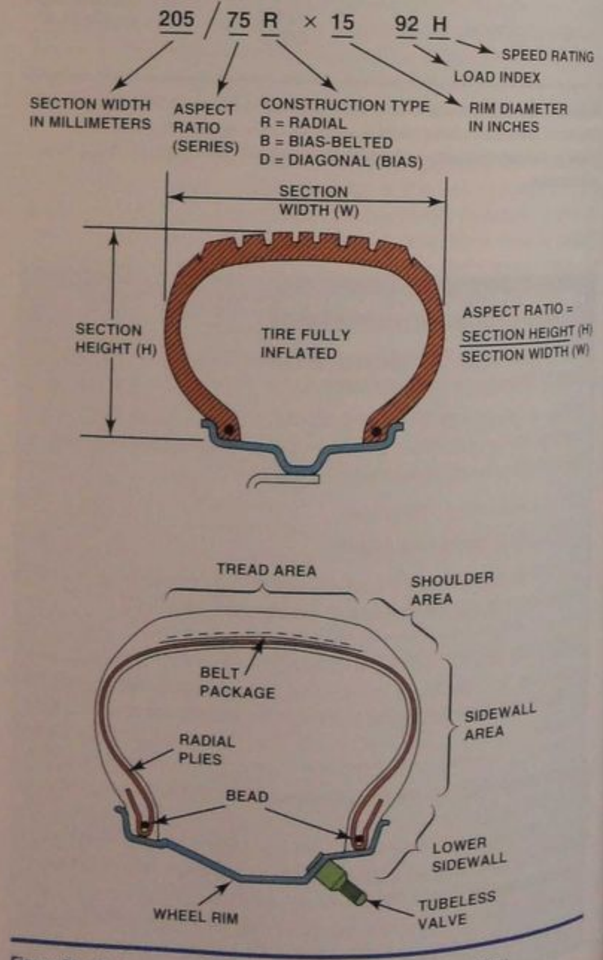


Figure 83–10 Cross-sectional view of a typical tire showing the terminology.

LOAD INDEX AND EQUIVALENT LOADS

The **load index,** as shown in Figure 83–11, is an abbreviated method to indicate the load-carrying capabilities of a tire. The weights listed in the chart represent the weight that *each tire* can safely support. Multiply this amount by 4 to get the maximum that the vehicle should weigh fully loaded with cargo and passengers.

SPEED RATINGS

Tires are rated according to the maximum *sustained* speed. A vehicle should never be driven faster than the **speed rating** of the tires. See chart in first column on page 1023.

CAUTION: A high speed rating does not guarantee that the tires will not fail, even at speeds much lower than the rating. Tire condition, inflation, and vehicle loading also affect tire performance.

As the speed rating of a tire increases, fewer compromises exist for driver comfort and low noise level. The higher speed rating does not mean a better tire. To survive, a high-speed tire must be built with stiff tread compounds, reinforced body (carcass) construction, and fabric angles that favor high speed and high performance over other considerations. For example, a V-rated tire often has less tread depth than a similar tire with an H-speed rating, and therefore will often not give as long of a service life. Since the speed ratings were first developed in Europe, the letters correspond to metric speed in kilometers per hour, with a conversion to miles per hour as noted.

FREQUENTLY ASKED QUESTION ???

What Effect Does Tire Size Have on Overall Gear Ratio?

Customers often ask what effect changing tire size has on fuel economy and speedometer readings. If larger (or smaller) tires are installed on a vehicle, many other factors also will change. These include the following:

1. *Speedometer reading.* **If larger-diameter tires are used, the speedometer will read slower** than you are actually traveling. This can result in speeding tickets!
2. *Odometer reading.* Even though larger tires are said to give better fuel economy, just the opposite can be calculated! Since a larger-diameter tire travels farther than a smaller-diameter tire, the larger tire will cause the odometer to read a shorter distance than the vehicle actually travels. For example, if the odometer reads 100 miles traveled on tires that are 10% oversized in circumference, the actual distance traveled is 110 miles.
3. *Fuel economy.* If fuel economy is calculated on miles traveled, the result will be *lower* fuel economy than for the same vehicle with the original tires.

$$\text{Calculation: mph} = \frac{\text{RPM} \times \text{diameter} \times 3.14}{\text{gear ratio}}$$

$$\text{RPM} = \frac{\text{mph} \times \text{gear ratio}}{\text{diameter} \times 3.14}$$

$$\text{gear ratio} = \frac{\text{RPM} \times \text{diameter} \times 3.14}{\text{mph}}$$

FREQUENTLY ASKED QUESTION ???

If I Have an Older Vehicle, What Size Tires Should I Use?

Newer radial tires can be used on older-model vehicles if the size of the tires is selected that best matches the original tires. See the following cross-reference chart.

Cross-Reference Chart
(This Chart Does Not Imply Complete Interchangeability.)

Pre-1964	1965 to 1972	80 Series Metric	Alpha Numeric 78 Series	P-Metric 75 Series Radial	P-Metric 70 Series Radial
590-13	600-13	165-13	A78-13	P165/75R13	P175/70R13
640-13	650-13	175-13	B78-13	P175/75R13	P185/70R13
725-13	700-13	185-13	D78-13	P185/75R13	P205/70R13
590-14	645-14	155-14	B78-14	P175/75R14	P185/70R14
695-14	695-14	175-14	C78-14	P185/75R14	P195/70R14
735-14	735-14	185-14	E78-14	P195/75R14	P205/70R14
780-14	775-14	195-14	F78-14	P205/75R14	P215/70R14
855-14	825-14	205-14	G78-14	P215/75R14	P225/70R14
890-14	855-14	215-14	H78-14	P225/75R14	P235/70R14
690-15	600-15	165-15	A78-15	P165/75R15	P175/70R15
640-15	685-15	175-15	C78-15	P175/75R15	P185/70R15
670-15	735-15	185-15	E78-15	P195/75R15	P205/70R15
715-15	775-15	195-15	F78-15	P205/75R15	P215/70R15
760-15	815-15	205-15	G78-15	P215/75R15	P225/70R15
800-15	855-15	215-15	H78-15	P225/75R15	P235/70R15
830-15	885-15	230-15	J78-15	P225/75R15	P235/70R15
	900-15	235-15	L78-15	P235/75R15	P255/70R15

NOTE: Vehicles designed for older bias-ply tires may drive differently when equipped with radial tires.

Load Index	Load (kg)	Load (lb)
75	387	853
76	400	882
77	412	908
78	425	937
79	437	963
80	450	992
81	462	1,019
82	475	1,047
83	487	1,074
84	500	1,102
85	515	1,135
86	530	1,168
87	545	1,201
88	560	1,235
89	580	1,279
90	600	1,323
91	615	1,356
92	630	1,389
93	650	1,433
94	670	1,477
95	690	1,521
96	710	1,565
97	730	1,609
98	750	1,653
99	775	1,709
100	800	1,764
101	825	1,819
102	850	1,874
103	875	1,929
104	900	1,934
105	925	2,039
106	950	2,094
107	975	2,140
108	1,000	2,205
109	1,030	2,271
110	1,060	2,337
111	1,090	2,403
112	1,120	2,469
113	1,150	2,535
114	1,180	2,601
115	1,215	2,679

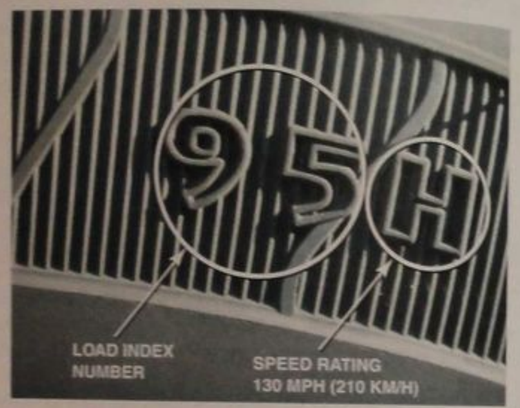


Figure 83–11 Typical sidewall markings for load index and speed rating following the tire size.

FREQUENTLY ASKED QUESTION ??? What Does the Little "e" Mean on the Sidewall?

Most countries have government agencies that regulate standards for motor vehicles sold and/or driven within their jurisdiction. In the United States, the U.S. Department of Transportation and National Highway Traffic Safety Administration are responsible for developing many of the nationwide standards for vehicles. Tires that are certified by their manufacturers to meet U.S. standards are branded with "DOT" (Department of Transportation) preceding the Tire Identification Code on their sidewall.

In Europe, because so much personal and commercial travel extends beyond the borders of any one country, the Economic Commission for Europe (E.C.E.) helps develop uniform motor vehicle standards for its member countries to regulate and standardize passenger and commercial vehicle components.

While sound is a by-product of modern society, it's one thing that most Europeans would enjoy less of. Excessive noise is considered a form of environmental pollution readily apparent to humans. People who express being disturbed by noise during the day and/or night cite truck, motorcycle, and automobile traffic as the most universal sources.

Besides physical specifications, the E.C.E. standards now require tire "pass-by" noise to meet specific limits. These standards were phased-in starting in 2004. The tires must pass noise emission testing, and the standards will continue to expand in scope until 2009, when the standards will be applied to all tires sold in Europe.

The E.C.E. symbol on a tire's sidewall identifies that the manufacturer certifies that the tire meets all regulations, including the load index and speed symbol that appear in its service description. In order to be E.C.E. branded, tires must receive laboratory approval, pass confirmation testing, and have their manufacturing plant pass quality control inspections.

The letter "e" and number code combination (positioned in a circle or rectangle) identify the country originally granting approval, followed by two digits indicating the Regulation Series under which the tire was approved. Tires that have also been tested and meet the "pass-by" noise limits can have a second E.C.E. branding followed by an "-s" (for *sound*). See Figure 83–12.

The following list indicates selected E.C.E. codes and the countries they represent:

Code	Country	Code	Country
E1	Germany	E14	Switzerland
E2	France	E15	Norway
E3	Italy	E16	Finland
E4	Netherlands	E17	Denmark
E5	Sweden	E18	Romania
E6	Belgium	E19	Poland
E7	Hungary	E20	Portugal
E8	Czech Republic	E21	Russian Federation
E9	Spain	E22	Greece
E10	Yugoslavia	E23	Ireland
E11	United Kingdom	E24	Croatia
E12	Austria	E25	Slovenia
E13	Luxembourg	E26	Slovakia



Figure 83–12 The E.C.E. symbol on a sidewall of a tire. Notice the small -s at the end, indicating that the tire meets the "pass-by" noise limits.

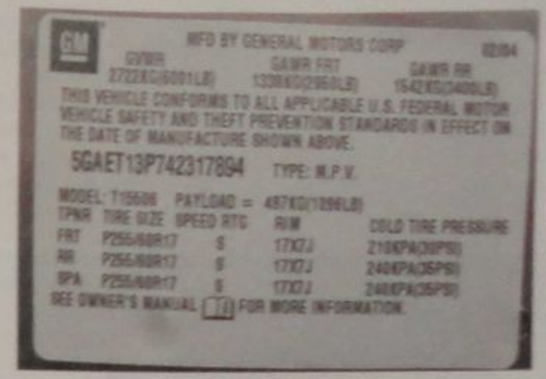


Figure 83–13 A typical door placard used on a General Motors vehicle indicating the recommended tire inflation. Note that the information also includes the tire size and speed rating of the tire as well as the recommended wheel size.

Maximum Rated Speed
120 km/h (75 mph)
130 km/h (81 mph)
140 km/h (87 mph)
150 km/h (93 mph)
160 km/h (99 mph)
170 km/h (106 mph)
180 km/h (112 mph)
190 km/h (118 mph)
200 km/h (124 mph)
210 km/h (130 mph)
240 km/h (149 mph)
270 km/h (168 mph)
300 km/h (186 mph)
open-ended*

*The exact speed rating for a particular Z-rated tire is determined by the tire manufacturer and may vary according to size. For example, not all Brand X Z-rated tires are rated at 186 mph, even though one size may be capable of these speeds.

TIRE PRESSURE AND TRACTION

All tires should be inflated to the specifications given by the vehicle manufacturer. Most vehicles have recommended tire inflation figures written in the owner's manual or on a placard or sticker on the door post or glove compartment. See Figure 83–13.

The pressure number molded into the sidewall of a tire should be considered the maximum pressure when the tire is cold. (Pressures higher than that stated on the sidewall may be measured on a hot tire.)

TIRE CONICITY AND PLY STEER

Conicity can occur during the construction of any radial or belted tire when the parts of the tire are badly positioned, causing the tire to be smaller in diameter on one side. When this tire is installed on a vehicle, it can cause the vehicle to pull to one side of the road due to the cone shape of the tire. See Figure 83–14.

Since the cause of conicity is due to the construction of the tire itself, there is nothing the service technician can do to correct the condition. The exact cause of the conicity is generally due to the slight movement of the belt and tread in the mold during inflation. If a vehicle pulls to one side of the road, the service technician should switch tires left to right (left-side tires to the right side and the right-side tires to the left side of the vehicle). If this swap of tires corrects the pulling condition, then tire conicity was the possible cause.

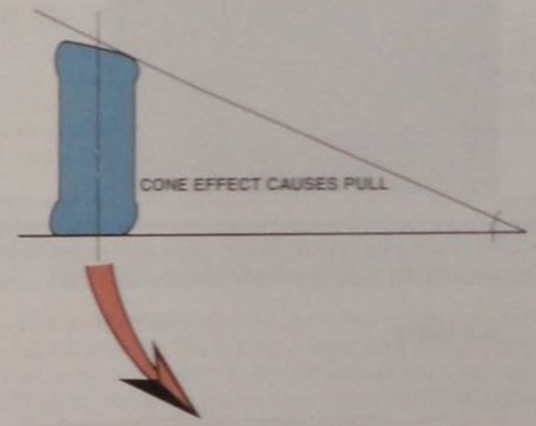


Figure 83–14 Conicity is a fault in the tire that can cause the vehicle to pull to one side due to the cone effect (shape) of the tire.

NOTE: *Radial pull* or *radial tire pull* are other terms often used to describe tire conicity.

Ply steer is another term that describes a slight pulling force on a vehicle due to tire construction. Ply steer is due to the angle of the cords in the belt layers, as seen in Figure 83–15, and not in the ply layer of the carcass (body), as the name implies. Ply steer will cause a slight drift regardless of its direction of rotation. Switching tires left to right will *not* correct a ply steer condition.

NOTE: Whenever a wheel and tire assembly is switched from one side of a vehicle to the other, the tire revolves in the opposite direction.

Ply steer is built into the tire during construction. There is nothing a service technician can do to correct ply steer, except to compensate for it with alignment angles. (See Chapter 93 for details on alignment diagnosis and correction.)

VEHICLE HANDLING AND TIRE SLIP ANGLE

The tire surface contact area or tire patch size is about one-half the area of one page of this book. All accelerating, braking, and



Figure 83–15 Notice the angle of the belt material in this worn tire. The angle of the belt fabric can cause a "ply steer" or slight pulling force toward one side of the vehicle.

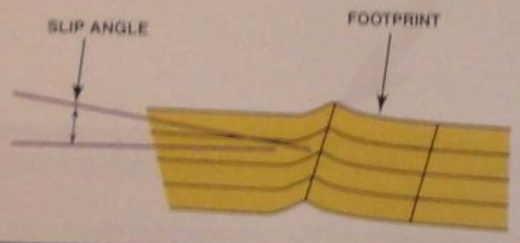


Figure 83–16 Slip angle is the angle between the direction the tire tread is heading and the direction it is pointed.

cornering forces of a vehicle are transferred to the pavement at just four spots. The combined area of these four spots is about equal to the size of this opened book.

Think about this whenever braking or cornering. As a vehicle is turned, the wheels are moved while the tires remain in contact with the road. These actions "twist" the carcass of the tire and create a slip angle between the direction the wheel is pointing and the direction the tread is pointing. See Figure 83–16.

The contact patch is deformed and snaps back into place as the twisted tire carcass returns to its original shape. This movement causes a slight delay in the turning of the vehicle and causes tire wear as the tread rubber moves in relation to the pavement during cornering.

RIM WIDTH AND TIRE SIZE

As a general rule, for a given **rim width** it is best not to change tire width more than 10 mm (either wider or narrower). For a given tire width, it is best not to vary rim width more than 1/2 in. in either direction. For example, if the original tire size is 195/70 × 14, then either a 185/70 × 14 (−10 mm) or a 205/70 × 14 (+10 mm) *could* be used on the original rim (wheel) without undue harm *if* the replacement tire has proper clearance with the body and suspension components.

Installing a tire on too narrow a wheel will cause the tire to wear excessively in the center of the tread. Installing a tire on too wide a wheel will cause excessive tire wear on both edges.

See a tire store representative for recommended tire sizes that can be safely installed on your rims.

FREQUENTLY ASKED QUESTION ???

Is There a Rule-of-Thumb for Rim Size?

According to the Tire and Rim Association, Inc., the answer is no. Each tire size has a designated rim width on which it is designed to be mounted so as to provide the best performance and wear. The width of the specified rim also varies with rim diameter. A 235/45 × 17 tire may require a 7.5-in. rim but a 235/45 × 19 tire may require an 8.0-in. rim. A rule-of-thumb that has been used is to multiply the width of the rim by 33.55 to determine the approximate tire size for the rim. For example, consider the following.

Rim width 5.0 in. × 33.55 = 167.85 (165 mm) tire
Rim width 5.5 in. × 33.55 = 184.50 (185 mm) tire
Rim width 6.0 in. × 33.55 = 201.30 (195 mm) tire
Rim width 6.5 in. × 33.55 = 218.00 (215 mm) tire
Rim width 7.0 in. × 33.55 = 234.90 (235 mm) tire
Rim width 7.5 in. × 33.55 = 252.00 (245 mm) tire
Rim width 8.0 in. × 33.55 = 268.00 (265 mm) tire
Rim width 8.5 in. × 33.55 = 285.00 (285 mm) tire
Rim width 9.0 in. × 33.55 = 302.00 (305 mm) tire
Rim width 10.0 in. × 33.55 = 335.60 (335 mm) tire

Always check with the tire manufacturer as to the specified tire rim width that should be used.

UNIFORM TIRE QUALITY GRADING SYSTEM

The U.S. Department of Transportation (DOT) and the National Highway Traffic Safety Administration (NHTSA) developed a system of tire grading, the **Uniform Tire Quality Grading System (UTQGS),** to help customers better judge the relative performance of tires. The three areas of tire performance are tread wear, traction, and temperature resistance, as shown in Figure 83–17.



Figure 83–17 Typical "Uniform Tire Quality Grading System" (UTQGS) ratings imprinted on the tire sidewall.

NOTE: All tires sold in the United States must have UTQGS ratings molded into the sidewall.

Tread Wear The tread wear grade is a comparison rating based on the wear rate of a standardized tire, tested under carefully controlled conditions, which is assigned a value of 100. A tire rated 200 should have a useful life twice as long as the standard tire's.

NOTE: The standard tire has a rating for tread wear of 100. This value has generally been accepted to mean a useful life of 20,000 miles of normal driving. Therefore, a tire rated at 200 could be expected to last 40,000 miles.

Tread Wear Rating Number	Approximate Number of mi/km
	20,000/32,000
	30,000/48,000
	40,000/64,000
	50,000/80,000
	60,000/96,000
	80,000/129,000
	100,000/161,000

The tread wear life of any tire is affected by driving habits (fast stops, starts, and cornering will decrease tread life), tire rotation (or lack of tire rotation), inflation, wheel alignment, road surfaces, and climate conditions.

Traction Traction performance is rated by the letters AA, A, B, and C, with AA being the highest.

NOTE: The traction rating is for wet braking distance only! It does not include cornering traction or dry braking performance.

The traction rating is only one of many other factors that affect wet braking traction, including air inflation, tread depth, vehicle speed, and brake performance.

Temperature Resistance Temperature resistance is rated by the letters A, B, and C, with A being the highest rating. Tires generate heat while rotating and flexing during normal driving conditions. A certain amount of heat buildup is desirable because tires produce their highest coefficient of traction at normal operating temperatures. For example, race car drivers frequently swerve their cars left and right during the pace laps, causing increased friction between the tire and the road surface, which warms their tires to operating temperature. However, if temperatures rise too much, a tire can start to come apart—the oils and rubber in the tire start to become a liquid! Grade C is the minimum level that all tires must be able to pass under the current Federal Motor Vehicle Safety Standard No. 109.

ALL-SEASON TIRE DESIGNATION

Most all-season tires are rated and labeled as *M & S, MS,* or *M + S,* and therefore must adhere to general design features as specified by the Rubber Manufacturers Association (RMA).

Tires labeled M & S are constructed with an aggressive tread design as well as tread compounds and internal construction that are designed for mud and snow. One design feature is that the tire has at least 25% void area. This means that the tread blocks have enough open space around them to allow the blocks to grab and clean themselves of snow and mud. Block angles, dimensional requirements, and minimum cross-sectional width are also a requirement for the M & S designation.

The tread rubber used to make all-season tires is also more flexible at low temperatures. This rubber compound is low-bounce (called high-hysteresis) and is more likely to remain in contact with the road surface. The rubber compound is also called *hydrophilic,* meaning that the rubber has an affinity for water (rather than being *hydrophobic* rubber, which repels water).

NOTE: Most vehicle manufacturers recommend that the same *type* of tire be used on all four wheels even though the size of the tire may vary between front and rear on some high-performance vehicles. Therefore, if all-season replacement tires are purchased, a complete set of four should be used to be assured of proper handling and uniform traction characteristics. While tire manufacturers have been recommending this for years—since the late 1960s—most vehicle manufacturers are also recommending that all four tires be of the same construction and tread type to help ensure proper vehicle handling.

DOT TIRE CODE

All tires sold in the United States must be approved by the U.S. Federal Department of Transportation (DOT). The **DOT tire code** requirements include resistance to tire damage that could be caused by curbs, chuckholes, and other common occurrences for a tire used on public roads.

NOTE: Most race tires are not DOT-approved and must never be used on public streets or highways.

Each tire that is DOT-approved has a DOT number molded into the sidewall of the tire. This number is usually imprinted on only one side of the tire and is usually on the side *opposite the whitewall.* The DOT code includes letters and numbers, such as **MJP2CBDX264.**

The first two letters identify the manufacturer and location. For this example, the first two letters (MJ) mean that the tire was made by the Goodyear Tire and Rubber Company in Topeka, Kansas. The last three numbers are the build date code. The last of these three numbers is the year (1994), and the 26 means that it was built during the 26th week of 1994. Starting with tires manufactured after January 1, 2000, the tire build date includes four digits rather than three digits. A new code such as "3406" means the 34th week of 2006 ("3406"). See Figure 83–18.

REAL WORLD FIX — Tire Date Code Information Saved Me Money!

The author was looking at a three-year-old vehicle when I noticed that the right rear tire had a build date code newer than the vehicle. I asked the owner, "How badly was this vehicle hit?" The owner stumbled and stuttered a little, then said, "How did you know that an accident occurred?" I told the owner that the right rear tire, while the exact same tire as the others, had a date code indicating that it was only one year old, whereas the original tires were the same age as the vehicle. The last three numbers of the DOT code on the sidewall indicate the week of manufacture (the first two numbers of the three-digit date code) followed by the last number of the year.

The owner immediately admitted that the vehicle slid on ice and hit a curb, damaging the right rear tire and wheel. Both the tire and wheel were replaced and the alignment checked. The owner then dropped the price of the vehicle $500! Knowing the date code helps assure that fresh tires are purchased and can also help the technician determine if the tires have been replaced. For example, if new tires are found on a vehicle with 20,000 miles, then the technician should check to see if the vehicle may have been involved in an accident or may have more miles than indicated on the odometer.



Figure 83–18 Typical DOT date code. This tire was built the sixth week of 2005.

SPARE TIRES

Most vehicles today come equipped with space-saver spare tires that are smaller than the wheels and tires that are on the vehicle. The reason for the small size is to reduce the size and weight of the entire vehicle and to increase fuel economy by having the entire vehicle weigh less by not carrying a heavy spare tire and wheel around. The style and type of these spare tires have changed a great deal over the last several years, and different makes and types of vehicles use various types of spare tires.

CAUTION: Before using a spare tire, always read the warning label (if so equipped) and understand all use restrictions. For example, some spare tires are not designed to exceed 50 mph (80 km/h) or be driven more than 500 miles (800 km).

Many small, space-saving spare tires use a higher-than-normal air inflation pressure, usually 60 PSI (414 kPa). Even though the tire often differs in construction, size, diameter, and width from the vehicle's original tires, it is amazing that the vehicle usually handles the same during normal driving. Obviously, these tires are not constructed with the same durability as a full-size tire and should be removed from service as soon as possible.

NOTE: When was the last time you checked the tire pressure in your spare tire? The spare tire pressure should be checked regularly.

RUN-FLAT TIRES

Run-flat tires (abbreviated RFT) are designed to operate without any air for a limited distance (usually 50 miles at 55 mph). This feature allows vehicle manufacturers to build vehicles without the extra room and weight of a spare tire and jack assembly.

A typical run-flat tire (also called *extended mobility tire* [EMT] *or zero pressure* [ZP] *tire*) requires the use of an air pressure sensor/transmitter and a dash-mounted receiver to warn the driver that a tire has lost pressure. Because of the reinforced sidewalls, the vehicle handles almost the same with or without air pressure. See Figures 83–19 and 83–20.

CAUTION: Tire engineers warn that rapid cornering should be avoided if a run-flat tire has zero air pressure. The handling during quick maneuvers is often unpredictable and could be dangerous.

PAX Run-Flat Tires Michelin developed a run-flat tire that has three unique components:

- A special wheel that has two bead seats that are of different diameters. The outside bead seat is 10 mm smaller in diameter than the inside bead seat. This means that a conventional tire cannot be installed on a PAX-style wheel.
- A urethane support ring that is designed to support the weight of the vehicle in the event of a flat tire.
- A special tire that is designed to operate without air. See Figure 83–21.

The PAX tire design has a unique sizing, such as:

P245/680R 460A 102V

P	= passenger
245	= the cross-section width in millimeters (mm)
680	= the tire diameter in mm (26.77 inches)
R	= radial ply construction
460	= the wheel, diameter in mm (18.1 inches)
A	= asymmetric wheel, meaning that one bead is smaller than the other bead by 10 mm (0.040 in.)
102	= the load index
V	= the speed rating

TECH TIP ✔ **PAX Replacement Tip**

In most cases, the fastest and easiest approach to follow if a PAX tire requires replacement is to purchase a replacement tire/wheel assembly. While more expensive than replacing just the tire, this approach is often used to help the vehicle owner get back on the road faster without any concerns as to whether the replacement tire was properly installed.

Servicing a PAX Wheel/Tire Assembly If a flat tire occurs or when a PAX tire becomes worn and requires replacement, special care should be taken to properly remove the tire from the wheel. Because the urethane support ring prevents the tire bead from entering the dropped center section of the wheel, the outside bead should be broken from the wheel, and then the support ring removed before the tire can be removed from the wheel.

GENERAL MOTORS TPC RATING

All General Motors original equipment (OE) tires have a rating that identifies the size as well as the tread design, wear, traction, and heat resistance factors. All of these factors are combined in a set of numbers and letters that is imprinted in the tire mold. This is referred to as the **Tire Performance Criteria (TPC)** rating of the tire. If a customer wants to have the same tire performance in a replacement tire, then replace the tire with any brand of tire that has the same TPC identification. See Figure 83–22.

TIRE-PRESSURE MONITORING SYSTEM (TPMS)

The **Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act** requires that all vehicles be equipped with a tire-pressure monitoring system that will warn the driver in the event of an underinflated tire.

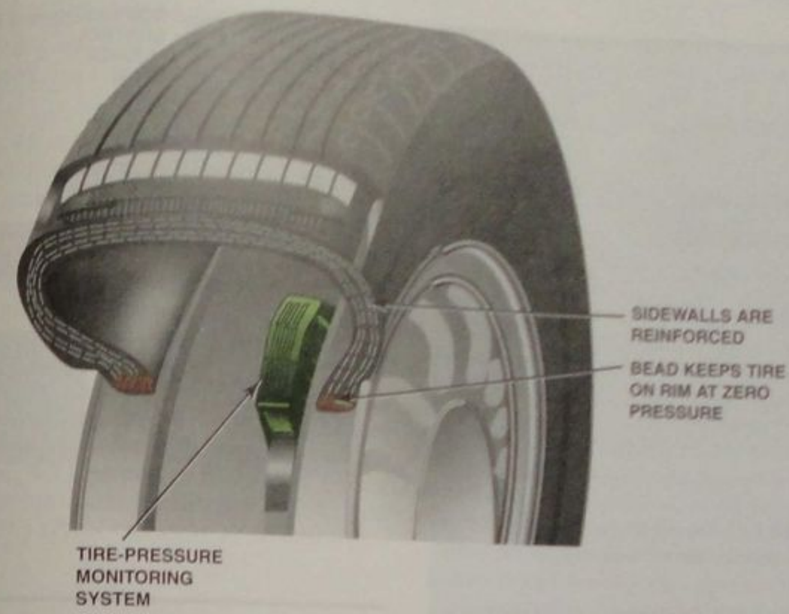


Figure 83–19 Cutaway of a run-flat tire showing the reinforced sidewalls and the required pressure sensor.

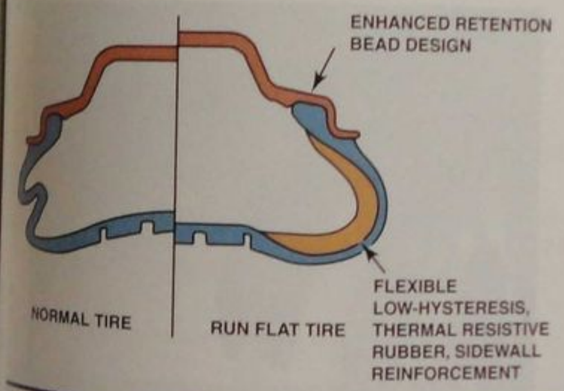


Figure 83–20 A conventional tire on the left and a run-flat tire on the right, showing what occurs when there is no air in the tire.



Figure 83–21 The PAX run-flat tire system is composed of three unique components—a special asymmetrical wheel, a urethane support ring, and special tire.



Figure 83–22 The Tire Performance Criteria (TPC) specification number is imprinted on the sidewall of all tires used on General Motors vehicles from the factory.

The National Highway Traffic Safety Administration (NHTSA) requires the installation of **tire-pressure monitoring systems (TPMS)** in passenger vehicles and light trucks manufactured after November 1, 2003.

The NHTSA ruling is part one of a two-part final ruling. Part one establishes a new Federal Motor Vehicle Safety Standard that requires TPMSs to be installed in passenger vehicles and light trucks to warn the driver when a tire is below specified pressure levels. The requirement to equip vehicles with a tire-pressure monitoring system was phased-in starting in 2004 and requires that 100% of the affected vehicles be equipped in 2007.

Indirect To help compensate for speed variation during cornering, an indirect tire pressure monitoring system checks the rotating speeds of diagonally opposed wheels. The system adds the speeds of the right front and left rear and then subtracts that value from the sum of the left front and right rear tires. If the total is less than or equal to a threshold value, no warning is given. However, if the total is greater than a predetermined value, the TPMS warning light is illuminated. The warning lamp will stay on until air is added to the tire and the ignition is cycled off and on.

NOTE: This system cannot detect if all of the tires are under inflated, only if one tire is under inflated.

FREQUENTLY ASKED QUESTION ???

What Is a Low-Rolling-Resistance Tire?

Low-rolling-resistance (LLR) tires reduce rolling resistance, which is the power-robbing friction between the tire and crown. The **E-metric tire,** designated for use on electric or hybrid vehicles, operates at higher inflation pressures, reduced load percentages, and lower rolling resistance. These tires were first used on the GM EV1 electric vehicle.

To soften the ride of tires pumped with additional air, a new tire profile was developed. Narrower rim width and rounder sidewalls make the tire more shock absorbent.

To make the tires roll more freely, low-rolling-resistant tread compounds are molded into smaller tread elements that flex easily and with less friction when they touch the road. LLR tires are available from most major tire manufacturers, including Michelin the Energy MXV4 Plus and Goodyear VIVA 2. According to tire engineers, the basic tradeoff of low rolling resistance is poor wet traction performance. To improve wet road performance and traction requires the use of more silica in the tread, which increases the cost of the tire. Neither a technician nor a vehicle owner can determine the relative rolling resistance unless the tires are compared using a coast-down test from highway speed to zero or a laboratory testing machine.

The ABS-based indirect-measurement system does not meet a NHTSA requirement stating that the system must be able to sense all four tires being incorrectly inflated. The ABS system can only compare the air pressure in all four tires, and therefore can only determine a difference in tire pressures. If the pressure in all four tires is incorrect, but the difference is still within the programmed range, the ABS-based system cannot determine that inflation pressure is incorrect.

Diagnosis Whenever there is a tire monitoring concern, perform the following:

1. Check tire pressure.
2. Check the tire inflation monitoring function by following the service information chart for Diagnostic System Check Tire Inflation Monitoring. This checks the ability of the EBCM and the body control module (BCM) to communicate with a scan tool and with other electronic control modules in the vehicle.
3. Check for any stored DTCs. The EBCM will request the IPC to turn on the "low tire pressure" lamp if a DTC related to tire inflation is stored.

Reset the Switch Vehicles with the tire inflation monitoring function are equipped with a TPM reset switch. Typically, the switch is housed in the underhood junction block. Always refer to service information for its exact location. The switch provides the body control module (BCM) with a signal requesting that the EBCM begin to auto-learn the tire pressures at each of the four wheels again. A TPM reset is necessary when tires are rotated or one or more tires are replaced. The BCM sends data messages to the EBCM through a Class 2 data circuit.

The reset switch connects to the BCM with a signal circuit and with a ground connection through the vehicle chassis to the BCM ground circuit. Pressing the switch button causes the switch contacts to close momentarily. See Figure 83–23.

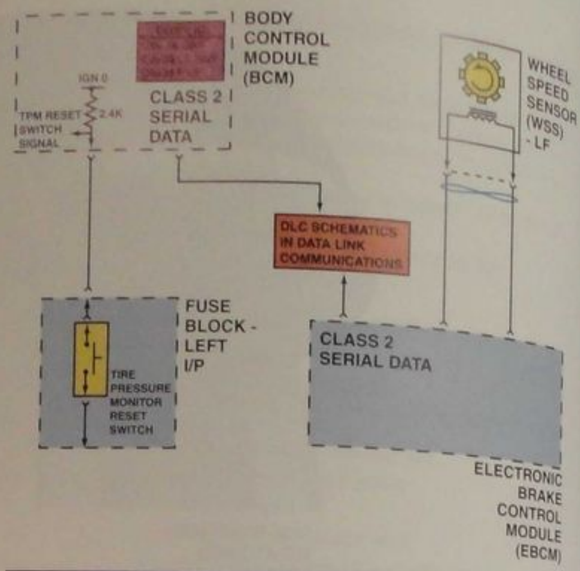


Figure 83–23 The indirect tire-pressure monitoring system has a reset switch that should be depressed after rotating or replacing tires.



Figure 83–24 A wheel-mounted tire-pressure monitoring transmitter.

As a part of routine maintenance, the reset switch should be depressed after the tire pressures have been changed or when the tires are rotated. If the reset switch is not depressed, the TPMS function may falsely detect a tire inflation fault and illuminate the "low tire" lamp.

Direct TPMS There are two types of direct tire-pressure monitoring systems.

- **Wheel-mounted transmitter type**—This type of transmitter uses a strap to hold the unit to the center of the wheel. See Figure 83–24.
- **Tire-valve-mounted transmitter type**—Systems using this type of tire-pressure monitoring usually have a receiver located near the wheel well of each wheel. The sensor inside the wheel then broadcasts.

There is a wireless RF sensor/transmitter unit built into the valve stem of each wheel. It is inserted from the inside of the wheel and retained by a nut torqued to 35 lb-in. and sealed with a grommet. The pressure sensors each weigh about 1 ounce (28 grams) and will most likely be noticed during wheel balancing. A 3-volt lithium battery with 10-year design life powers the sensors, but the sensors do not operate continuously. The sensors do not operate when the vehicle travels below 20 mph (32 km/h) and they transmit a pressure signal only once each hour when the vehicle is parked, which helps retain battery power. The signal from the sensors is received by either a receiver near each wheel or by the keyless entry system radio receiver. The receiver then sends tire-pressure information to the body control module (BCM) for display on the driver information center (DIC). A warning is sounded automatically if the pressure falls below 24 PSI (165 kPa) or rises above 39 PSI (269 kPa).



Figure 83–25 A typical tire-pressure monitoring system tester. The unit should be held near the tire and opposite the valve stem if equipped with a wheel-mounted sensor, and near the valve stem if equipped with a valve-stem-type sensor.

TPMS SENSORS

Depending on the type and manufacturer, tire-pressure monitoring sensors can be any of several different designs, including:

- **Continuous-wave-type sensor**—designed to signal a tester when exposed to 5 to 7 seconds of continuous 125 KHz wave signal.
- **Magnetically-triggered-type sensor**—designed to trigger a tester if exposed to a powerful magnetic force.
- **Pulse-width-modulated-type sensor**—designed to be triggered when exposed to modulated wave 125 KHz signal.

The sensor also can vary according to the frequency at which it transmits tire-pressure information to the receiver in the vehicle. The two most commonly used frequencies are:

- 315 MHz
- 433.92 MHz (commonly listed as 434 MHz)

FREQUENTLY ASKED QUESTION ???

Doesn't the Tread Act Specify the Type of Sensor?

No. The TREAD Act establishes only the tire-pressure standards and does not specify how the vehicle manufacturer must achieve this standard. As a result, different manufacturers have developed various methods to meet the standard. For additional information on TPMS testers, see *www.tipstool.com* or *www.otctools.com*.

TECH TIP ✓ **Check the TPMS Sensors Before and After Service**

It is wise to check that all of the tire-pressure monitoring system sensors are working before beginning service work. For example, if the tires need to be rotated, the sensors will have to be reprogrammed for their new location. If a tire-pressure monitoring sensor is defective, the procedure cannot be performed. Use an aftermarket or original equipment tire-pressure monitoring sensor tester, as shown in Figure 83–25.

Then the tire-pressure sensors should be checked again after the service to make sure that they are working correctly before returning the vehicle to the customer.



Figure 83–26 A magnet is placed around the valve stem to reprogram stem-mounted tire-pressure sensors.

Programming the TPM Receiver Whenever the tires are rotated or a new sensor has been installed, the TPM receiver must be reprogrammed to recognize the new sensor locations. Failure to do so will result in the pressure readings being incorrectly displayed on the driver information center. A scan tool will handle this reprogramming task, but if no new sensors were installed, there is also a way to reprogram the receiver without the scan tool. The wireless TPM receiver is housed in the keyless entry system's RF receiver. Using the key fob to place the receiver in "program" mode, the sensor locations can be programmed with a special magnet. See Figure 83–26.

The magnet fits over the valve stem in a way that will force the sensor to turn itself on while stationary, allowing the receiver to "see" it and learn its location while in programming mode. The special magnet tool and a scan tool are both needed when a new sensor has been installed, but the following procedure will allow the service dealer to reprogram the TPM after tire rotation on a General Motors vehicle without using a scan tool.

1. With KOEO (key on, engine off), the "lock" and "unlock" buttons on the key fob should be simultaneously pressed and held. The horn will chirp within 10 seconds, indicating the receiver is

in programming mode. The programming procedure must now be completed within five minutes, with no more than one minute between programming.

NOTE: If the horn does not chirp at the start of this procedure, the TPM option has not been enabled. A scan tool is needed to enable the system.

2. At the left front wheel, the special magnet tool must be held over the valve stem to force the sensor to transmit its code. The horn will chirp once, indicating the TPM system has recognized the sensor. The next sensor must be programmed within one minute.
3. The remaining sensors should be programmed in the following order: RF, RR, LR. The horn will chirp once when each sensor has been detected. It will chirp twice to indicate completion of the programming process.

NOTE: The technician should not replace either the OEM cap or the valve stem with standard parts. Conventional valve stem parts will inhibit the sensor's ability to transmit its signal.

FREQUENTLY ASKED QUESTION ???

How Can You Tell If the Vehicle Has a TPMS Sensor?

If the tire/wheel assembly has a tire-pressure monitoring system (TPMS) valve-type sensor, it can usually be identified by the threaded portion of the valve stem. See Figure 83–27.

If the valve stem is black rubber, then it does not have a stem-mounted tire-pressure sensor. However, the wheel may be equipped with a wheel-mounted sensor, so care should still be taken to avoid damaging the sensor during service.



Figure 83–27 A clear plastic valve-stem tire-pressure monitoring sensor, showing the round battery on the right and the electronic sensor and transistor circuits on the left.

TIRE SELECTION CONSIDERATIONS

Selecting the proper tire is very important for the proper handling and safety of any vehicle. Do not select a tire by styling or looks alone. For best value and highest satisfaction, follow these guidelines:

Purchasing Suggestions	Reason Why
1. Purchase the same type of tire that came on your vehicle when new.	1. Chassis and tire engineers spend hundreds of hours testing and evaluating the best tire to use for each vehicle.
2. Purchase the same size as the original tire. The width of the tire should be within 10 mm of the width of the original tire. For example, a stock 195/75 × 14 tire's acceptable replacement *could be* 185/75 × 14 or 205/75 × 14.	2. The size of the tire is critical to the handling of any vehicle. Tire width, size, and aspect ratio affect the following: a. Braking effectiveness b. Headlight aiming c. Vehicle height d. Acceleration potential e. Speedometer calibration
3. Purchase tires with the same speed rating as the original.	3. When any vehicle is manufactured, it is optimized for its designed use. High-performance tires are generally stiffer and have a speed rating as well. If you purchase non-high-performance tires, the carcass is not as stiff and the suspension is not designed to work with softer tires. Therefore, the cornering and handling, especially fast evasive maneuvers, could be dangerous. The vehicle may be capable of far more speed than the tires are designed to handle.
4. Purchase four of the same type of tire. Most vehicle manufacturers recommend against installing snow tires or all-season tires on just the drive wheels.	4. Every vehicle is designed to function best with four tires of the same size, construction, and tread design, unless the vehicle is specifically designed for different sizes of tires at the front and rear. Different tire styles and tread compounds have different slip angles. It is these different slip angles that can cause a vehicle to handle "funny" or cause the vehicle to get out of control in the event of a sudden maneuver.
5. Purchase the same *brand* of tire for both front and/or both rear wheels.	5. The sizes of tires are nominal and vary according to exact size (and shape) of the mold as well as tire design and construction. The same size of tire from two different manufacturers can often differ in diameter and width. While the differences should be slight, many vehicles are extremely sensitive to these small differences, and poor vehicle handling, torque steer, and pulling could result if different brands of tires are used.
6. Purchase fresh tires. Tires that are older may have been stored in a hot warehouse, where oxygen can attack rubber and cause deterioration.	6. Look at the tire build date code (the last three numbers of the DOT code). Try to purchase four tires with the same or similar date codes.

CAUTION: If changing tire sizes or styles beyond the recommendations as stated here, consult a knowledgeable tire store representative for help in matching wheel and tire combinations to your vehicle.

NOTE: Some tires may be five or more years old when purchased. Always check the date code!

WHEELS

The concept of a wheel has not changed in the last 5,000 years, but the style and materials used have changed a lot. Early automotive wheels were constructed from wood with a steel band as the tire.

Today's wheels are constructed of steel or aluminum alloy. The center section of the wheel that attaches to the hub is called the **center section** or **spider** because early wheels used wooden spokes that resembled a spider's web. The rubber tire attaches to the rim of the wheel. The rim has two *bead flanges* where the bead of the tire is held against the wheel when the tire is inflated. The shape of this flange is very important and is designated by Tire and Rim Association letters. For example, a wheel designated 14 × 6JJ means that the diameter of the wheel is 14 in. and the wheel is 6 in. wide measured from inside to inside of the flanges. The letters JJ indicate the *exact* shape of the flange area. See Figure 83–28. This flange area shape and the angle that the rim drops down from the flange are important because of the following:

- They permit a good seal between the rim and the tire.
- They help retain the tire on the rim in the event of loss of air. This is the reason why modern wheels are called "safety rim wheels." See Figure 83–29.
- Run-flat tires (tires that are designed to operate without air for a limited distance without damage) often require a specific wheel rim shape.



Figure 83–28 The size of the wheel is usually cast or stamped into the wheel. This wheel is 5 1/2 in. wide. The letters JJ refer to the contours of the seat area of the wheel.

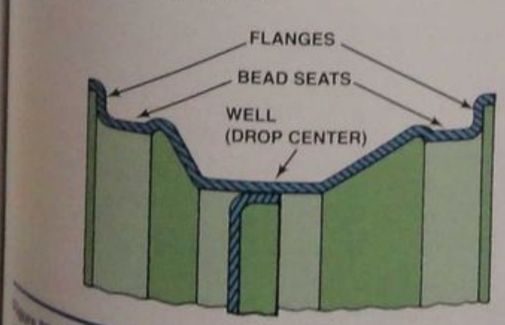


Figure 83–29 The wheel rim well provides a space for the tire to fit during mounting; the bead seat provides a tire-to-wheel sealing surface; the flange holds the beads in place.

Wheel Offset **Offset** is a very important variable in wheel design. If the center section (spider) is centered on the outer rim, the offset is zero. Wheel offset is often referred to as ET, which stands for *Einpress Tiefe* in German. See Figure 83–30.

Positive Offset The wheel has a positive offset if the center section is outward from the wheel centerline. Front-wheel-drive vehicles commonly use positive-offset wheels to improve the loading on the front wheels and to help provide for a favorable scrub radius.

Negative Offset The wheel has a negative offset if the center section is inboard (or "dished") from the wheel centerline. See Figure 83–31. Avoid using replacement wheels that differ from the original offset.

Back Spacing **Back spacing,** also called *rear spacing* or *backside setting,* is the distance between the back rim edge and the wheel center section mounting pad. **This is not the same as offset.** Back spacing can be measured directly with a ruler, as shown in Figure 83–32.

Determining Bolt Circle On four-lug axles and wheels, the **bolt circle** measurement is simply taken from center to center on opposite studs or holes, as shown in Figure 83–33.

On five-lug axles and wheels, it is a little harder to determine bolt circle. One method is to measure from the far edge of one bolt hole to the center of the hole two over from the first, as shown in

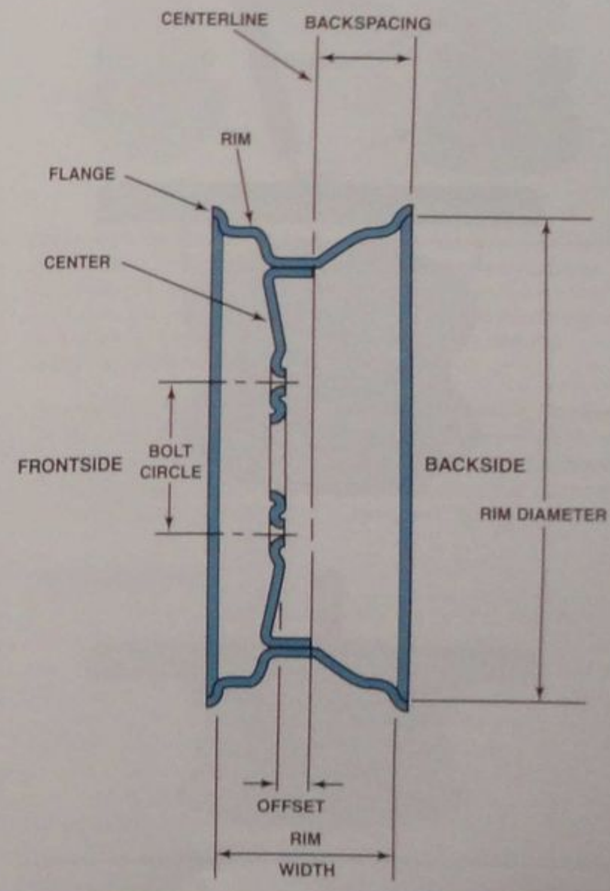


Figure 83–30 A cross section of a wheel showing part designations.

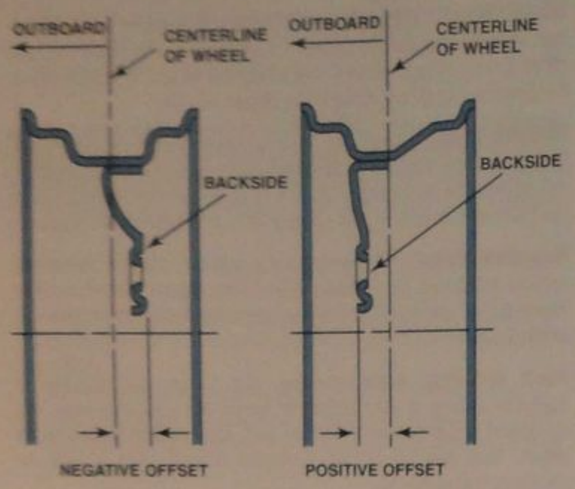


Figure 83–31 Offset is the distance between the centerline of the wheel and the wheel mounting surface.

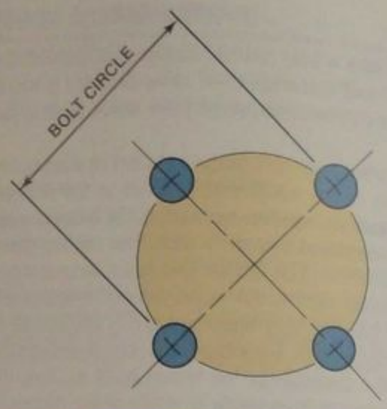


Figure 83–33 Bolt circle is the diameter of a circle that can be drawn through the center of each lug hole or stud. The bolt circle is sometimes referred to as PCD for pitch circle diameter.

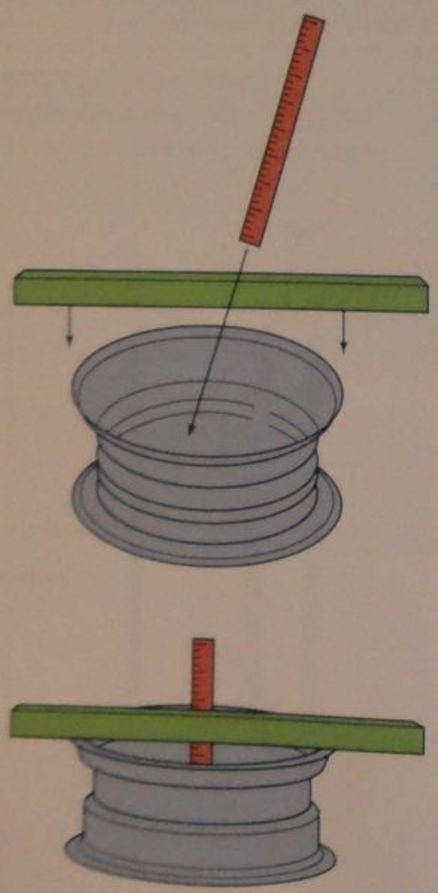


Figure 83–32 Back spacing (rear spacing) is the distance from the mounting pad to the edge of the rim. Most custom wheels use this measurement method to indicate the location of the mounting pad in relation to the rim.

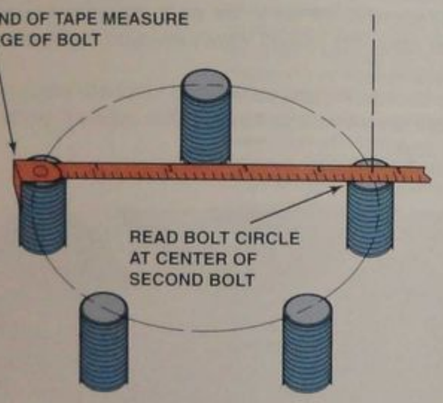


Figure 83–34 The easiest method to determine the approximate bolt circle of a five-lug wheel.

Figure 83–34. Another method for a five-lug wheel is to measure from center to center between two adjacent studs and convert this measurement into bolt circle diameter, as in the following chart. See Figure 83–35.

Center-to-Center Distance	Bolt Circle Diameter
2.645 in.	4 1/2 -in. bolt circle
2.792 in.	4 3/4 -in. bolt circle
2.939 in.	5-in. bolt circle
3.233 in.	5 1/2 -in. bolt circle

Steel Wheels Steel is the traditional wheel material. A steel wheel is very strong due to its designed shape and the fact that it is *work hardened* during manufacturing. In fact, most of the strength of a steel wheel is due to its work hardening. Painting and baking cycles also increase the strength of a steel wheel. Steel wheels are formed from welded hoops that are flared and joined to stamped spiders.

Aluminum Wheels Forged and cast aluminum wheels are commonly used on cars and trucks. *Forged* means that the aluminum is hammered or forged under pressure into shape. A forged aluminum wheel is much stronger than a *cast* aluminum wheel.

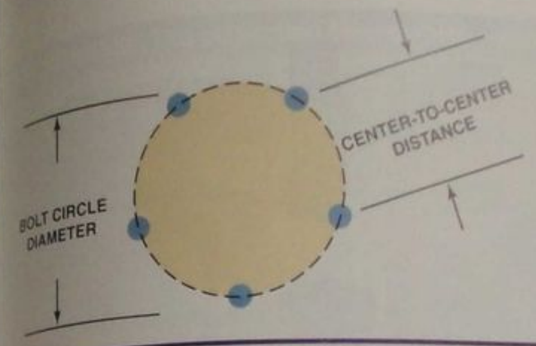


Figure 83–35 Measure center-to-center distance and compare the distance to the figures in the chart in the text to determine the diameter for a five-lug bolt circle.

A cast aluminum wheel is constructed by pouring liquid (molten) aluminum into a mold. After the aluminum has cooled, the cast aluminum wheel is removed from the mold and machined. Aluminum wheels are usually thicker than steel wheels and require special wheel weights when balancing. Coated or covered wheel weights should be used when balancing aluminum wheels to prevent galvanic corrosion damage to the wheel. Most aluminum wheels use an alloy of aluminum. Aluminum can be combined (alloyed) with copper, manganese, silicon, or other elements to achieve the physical strength and characteristics for the exact product.

Some racing wheels are made from a lighter-weight metal called magnesium. These wheels are called *mag* wheels (an abbreviation for *magnesium*). True magnesium wheels are not practical for production wheels because their cost and corrosion are excessive compared with steel or aluminum alloy wheels. The term *mag wheel*, however, is still heard when referring to alloy (aluminum) wheels.

NOTE: If purchasing replacement aftermarket wheels, check that they are certified by the SFI. SFI is the Specialty Equipment Manufacturers Association (SEMA) Foundation, Incorporated. SEMA and SFI are nongovernment agencies that were formed by the manufacturers themselves to establish standards for safety.

FREQUENTLY ASKED QUESTION ???

What Does This Mark in a Wheel Mean?

The symbol JWL, for the Japan Wheel Light Metal Standard Mark, means that the wheel meets the technical standards for passenger-car light-alloy disk wheels. See the mark in Figure 83–36.

The manufacturer is responsible for conducting the inspections set forth in the technical standard, and the JWL mark is displayed on those products that pass the inspection.

TIRE VALVES

All tires use a tire valve, called a **Schrader valve,** to hold air in the tire. The Schrader valve was invented in New York in 1844 by August Schrader for the Goodyear Brothers: Charles, Henry, and Nelson. Today, Schrader valves are used not only as valves in tires but in fuel-injection systems, air-conditioning systems, and air shock (ride control) systems. Most tire experts agree that the valve stem (which includes the Schrader valve) should be replaced whenever the tires are replaced—tires can last four or more years, and in that time the valve stem can become brittle and crack. A defective or leaking



Figure 83–36 A typical JWL symbol for the Japan Wheel Light Metal Standard Mark.

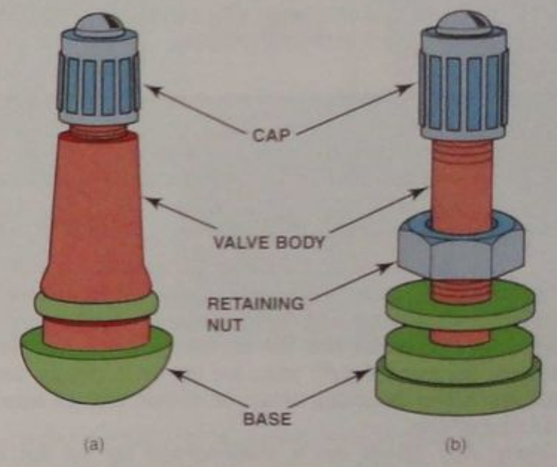


Figure 83–37 (a) A rubber snap-in style tire valve assembly. (b) A metal clamp-type tire valve assembly used on most high-pressure (over 60 PSI) tire applications such as is found on many trucks, RVs, and trailers. The internal Schrader valve threads into the valve itself and can be replaced individually, but most experts recommend replacing the entire valve assembly every time the tires are replaced to help prevent air loss.

valve stem is a major cause of air loss. Low tire pressure can cause the tire to become overheated. Replacement valve stems are therefore a wise investment whenever purchasing new tires. Aluminum (alloy) wheels often require special metal valve stems that use a rubber washer and are actually bolted to the wheel. See Figure 83–37.

UNSPRUNG WEIGHT

The lighter the wheel and tire assembly, the faster it can react to bumps and dips in the road surface and thus the better the ride. The chassis and the body of any vehicle are supported by some sort of spring suspension system. It is the purpose of the suspension system to isolate the body of the vehicle from the road surface. Also, for best handling, all four tires must remain in contact with the road. After all, a tire cannot grip the road if it leaves the ground after hitting a bump. The wheel and tire are **unsprung weight** because they are not supported by the vehicle's springs. If heavy wheels or tires are used, every time the vehicle hits a bump, the wheel is forced upward. The heavy mass of the wheel and tire would transmit this force through the spring of the vehicle and eventually to the driver and passengers. Obviously, a much lighter wheel and tire assembly

reacts faster to bumps and dips in the road surface. The end result is a smoother-riding vehicle with greater control.

An aluminum wheel is generally lighter than the same-size stamped steel wheel. This is not always the case, however, so before purchasing aluminum wheels, check their weight!

NOTE: Putting oversized tires on an off-road-type vehicle is extremely dangerous. The increased unsprung weight can cause the entire vehicle to leave the ground after hitting a bump in the road. The increased body height necessary to clear the larger tires seriously affects drive shaft angles and wheel alignment angles, making the vehicle very difficult to control.

LUG NUTS

Lug nuts are used to hold a wheel to the brake disc, brake drum, or wheel bearing assembly. Most manufacturers use a stud in the brake or bearing assembly with a lug nut to hold the wheel. Some models of VW, Audi, and Mazda use a lug *bolt* that is threaded into a hole in the brake drum or bearing assembly.

NOTE: Some aftermarket manufacturers offer a stud conversion kit to replace the lug bolt with a conventional stud and lug nut.

Typical lug nuts are tapered so that the wheel stud will center the wheel onto the vehicle. Another advantage of the taper of the lug nut and wheel is to provide a suitable surface to prevent the nuts from loosening. The taper, usually 60 degrees, forms a wedge that helps ensure that the lug nut will not loosen. Steel wheels are deformed slightly when the lug nut is torqued down against the wheel mounting flange; be certain that the taper is *toward* the vehicle.

Many alloy wheels use a *shank-nut*-type lug nut that has straight sides without a taper. This style of nut must be used with

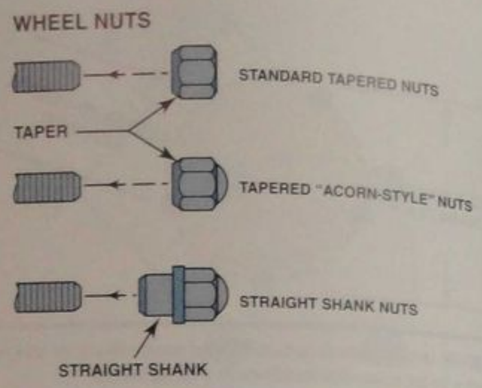


Figure 83–38 Various styles of lug nuts.

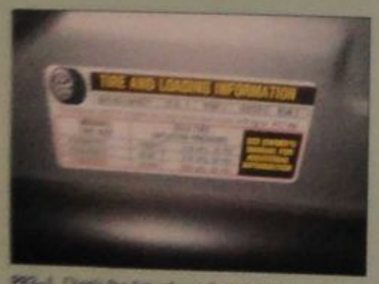
wheels designed for this nut type. If replacement wheels are used on any vehicle, check with the wheel manufacturer as to the proper type and style of lug nut. Figure 83–38 shows several of the many styles of lug nuts that are available.

Size Lug nuts are sized to the thread size of the stud onto which they screw. The diameter and the number of threads per inch are commonly stated. Since some vehicles use left-hand threads, RH and LH are commonly stated, indicating "right-hand" and "left-hand" threads. A typical size is 7/16-20RH, where the 7/16 indicates the diameter of the wheel stud and 20 indicates that there are 20 threads per inch. Another common fractional size is 1/2 × 20. Metric sizes such as M12 × 1.5 use a different sizing method.

M	metric
12	12-mm diameter of stud
1.5	1.5-mm distance from one thread peak to another

Other commonly used metric lug sizes include M12 × 1.25 and M14 × 1.5. Obviously, metric wheel studs require metric lug nuts.

PHOTO SEQUENCE Tire Inspection Step-by-Step



P83–1 Check the tire information placard, usually located on the driver's door or door jamb, for the specified tire size and tire pressures.



P83–2 Visually check the tires for abnormal wear or damage.



P83–3 Remove the tire valve cap and visually check the condition of the valve stem.

PHOTO SEQUENCE Tire Inspection Step-by-Step—continued



P83–4 Check tire pressure by pushing the tire pressure gauge straight onto the end of the tire valve.



P83–5 Read the pressure and compare to specifications. Correct as necessary.



P83–6 A typical tire tread depth gauge.



P83–7 The blade of the tire tread depth gauge is pushed down into the groove of the tire at the lowest part.



P83–8 Remove the gauge from the tire and read the tread depth at the metal housing. Tread depth is usually measured in 1/32's of an inch.



P83–9 If the top of Lincoln's head is visible, then the tread depth is lower than 2/32 in., the legal limit in many states.

SUMMARY

1. New tires have between 9/32 in. and 15/32 in. tread depth. Wear bars (indicators) show up as a bald strip across the tread of the tire when the tread depth gets down to 2/32 in.
2. All tires are assembled by hand from many different materials and chemical compounds. After a green tire is assembled, it is placed into a mold under heat and pressure for about 30 minutes. Tread design and the tire shape are determined by the mold design.
3. A 205/75R × 14 92S tire is 205 mm wide at its widest section and is 75% as high as it is wide. The R stands for radial-type construction. The tire is designed for a 14-in.-diameter rim. The number 92 is the load index of the tire (the higher the number, the more weight the tire can safely support). The S is the speed rating of the tire (S × 112 mph maximum sustained).
4. The Uniform Tire Quality Grading System is a rating for tread wear (100, 150, etc.), traction (A, B, C), and temperature resistance (A, B, C).
5. For best overall handling and satisfaction, always select the same size and type of tire that came on the vehicle when new.
6. Replacement wheels should have the same offset as the factory wheels to prevent abnormal tire wear and/or handling problems.
7. All wheels must be secured with the proper size and style of lug nuts. If a wheel stud is broken, it should be replaced immediately to avoid possible wheel damage or loss of vehicle control.

REVIEW QUESTIONS

1. List the various parts of a tire and explain how a tire is constructed.
2. Explain the effect that aspect ratio has on ride and handling.
3. List the factors that should be considered when purchasing tires.
4. Explain the three major areas of the Uniform Tire Quality Grading System.
5. Explain how to determine proper tire pressure.

CHAPTER QUIZ

1. The part of the tire that is under just the tread of a radial tire is called the _____.
   a. Bead
   b. Body (carcass) ply
   c. Belt
   d. Inner liner
2. The aspect ratio of a tire means _____.
   a. Its width to diameter of a wheel ratio
   b. The ratio of height to width
   c. The ratio of width to height
   d. The ratio of rolling resistance
3. A tire is labeled 215/60R × 15 92T; the T indicates _____.
   a. Its speed rating
   b. Its tread wear rating
   c. Its load rating
   d. Its temperature resistance rating
4. The 92 in the tire designation in question 3 refers to the tire's _____.
   a. Speed rating
   b. Tread wear rating
   c. Load rating
   d. Temperature resistance rating

5. Radial tires can cause a vehicle to pull to one side while driving. This is called "radial tire pull" and is often due to _____.
   a. The angle of the body (carcass) plies
   b. Tire conicity
   c. Tread design
   d. Bead design

6. Tire inflation is very important to the safe and economical operation of any vehicle. Technician A says that the pressure should never exceed the maximum pressure imprinted on the sidewall of the tire. Technician B says to inflate the tires to the pressures recommended on the tire information decal or placard on the driver's door. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. When purchasing replacement tires, do not change tire width from the stock size by more than _____.
   a. 10 mm
   b. 15 mm
   c. 20 mm
   d. 25 mm

8. What do the letters JJ mean in a wheel designation size labeled 14 × 7JJ?
   a. The offset of the rim
   b. The bolt circle code
   c. The back spacing of the rim
   d. The shape of the flange area

9. Technician A says that a PAX run-flat tire uses a special wheel. Technician B says that a standard tire can be used to replace a PAX run-flat tire. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Technician A says that a tire-pressure monitor system that uses a valve-stem-type transmitter is the direct-reading type of TPMS. Technician B says that a tire-pressure monitoring system that uses a sensor inside and strapped to the wheel is an indirect-reading type of TPMS. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 84

Tire and Wheel Service

OBJECTIVES: **After studying Chapter 84, the reader will be able to:** Prepare for ASE Suspension and Steering (A4) certification test content area "E" (Wheel and Tire Diagnosis and Repair). • Discuss proper tire mounting procedures. • Describe recommended tire rotation methods. • Discuss how to properly balance a tire. • Describe tire repair procedures. • Explain wheel and tire safety precautions.

KEY TERMS: dynamic balance • lateral runout • match mounting • modified X • radial force variation • radial runout • shimmy • static balance • tire rotation • tramp • wheel mounting torque

Proper tire service is extremely important for the safe operation of any vehicle. Premature wear can often be avoided by checking and performing routine service, such as frequent rotation and monthly inflation checks. See Figure 84–1.



Figure 84–1 Using soapy water from a spray bottle is an easy method to find the location of an air leak from a tire.

TIRE INFLATION

Tires should always be inflated to the pressure indicated on the driver's door or pillar sticker. Tires should be checked when cold, before the vehicle has been driven, because driving on tires increases the temperature and therefore the pressure of the tires. Proper tire inflation is important for the following reasons:

- **Inflation pressure carries the load of the vehicle.** If the pressure is low, the load capacity of the tire is decreased. See Figure 84–2
- **Inflation pressure varies with temperature.** Tires lose 1 PSI for every 10-degree drop in temperature. This means that as the seasons change and the temperature changes, so does the inflation pressure inside the tires. For example, if tires were inflated to 35 PSI on the first day of summer (June 21) when the temperature

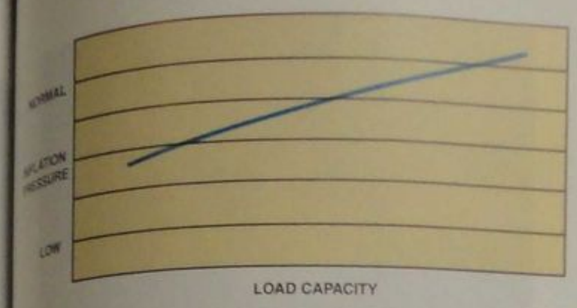


Figure 84–2 This chart shows the relationship between tire inflation pressure and load capacity of the tire.

was 90°F (32°C), then the following pressures would occur, assuming no air loss at all:

Summer (June 21) 90°F—35 PSI
Fall (September 21) 80°F—34 PSI
Winter (December 21) 30°F—29 PSI

Therefore, it is very important to check and correct inflation pressures regularly.

- **Tire inflation affects fuel economy.** A drop in inflation pressure from 30 PSI to 23 PSI can result in a drop of fuel economy from 20 miles per gallon to 18 miles per gallon. See Figure 84–3.
- **Tire inflation affects tire life.** Even a slight drop in air pressure can have a major effect on the life of a tire. If, for example, the inflation pressure dropped 10 PSI, the life of the tire would be reduced by 40%. See Figure 84–4.
- **The TREAD Act specifies that the driver be notified if the inflation of a tire drops by 25%.** However, 25% represents a loss of air pressure of about 8 PSI. A drop of 8 PSI means an approximate 2-mpg decrease in fuel economy as well as about a 25% reduction in tread wear.

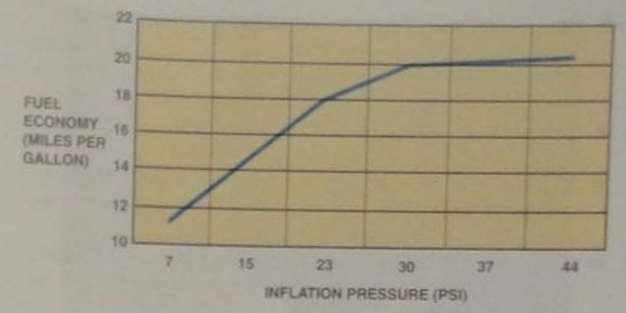


Figure 84–3 This chart shows that a drop in inflation pressure has a major effect on fuel economy.

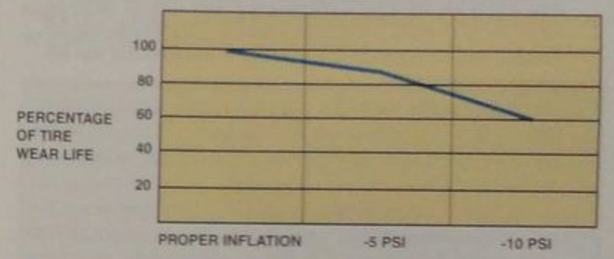


Figure 84–4 Notice that if a tire is underinflated by 10 PSI, the life expectancy is reduced by 40%.

FREQUENTLY ASKED QUESTION ???

What Is a "Temporary Mobility Kit"?

A temporary mobility kit is a system to inflate a flat tire supplied by the vehicle manufacturer instead of a spare tire. A temporary mobility kit can include:

- A compressor powered by the cigarette lighter with stop leak. See Figure 84–5.
- An aerosol spray can that provides inflation and sealer. See Figure 84–6.

Either type can be found in many vehicles because such devices save weight, increase trunk space, and cost less than a conventional spare tire and rim. However, these kits are designed to be a temporary repair only because the cause of the low tire was never determined. If the tire appears to be fixed, many vehicle owners may think that the tire has been repaired. However, the tire should be carefully inspected inside and out for damage and properly repaired.

NITROGEN INFLATION

Some shops recommend and inflate tires using nitrogen instead of using compressed air. Compressed air contains about 78% nitrogen, 21% oxygen, and 1% other gases. If air already contains mostly nitrogen, why use pure nitrogen? There are several reasons, including:

- The nitrogen molecule is slightly larger than the oxygen molecule so the tire will lose pressure faster if air is used instead of nitrogen.

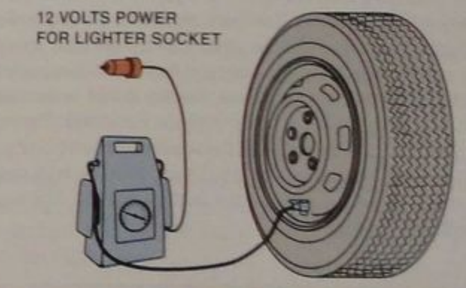


Figure 84–5 A temporary inflation pump that uses 12 volts from the cigarette lighter to inflate the tire.

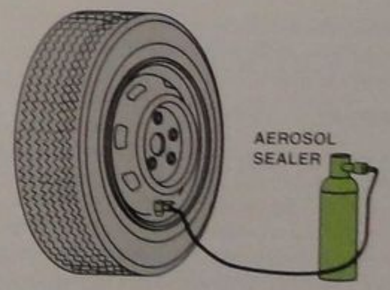


Figure 84–6 Many vehicle manufacturers include an aerosol can of sealer on vehicles that are not equipped with a conventional spare tire.

- Compressed nitrogen contains less moisture than compressed air. When the tire heats up, moisture in the tire vaporizes and expands, causing the pressure inside the tire to increase. Even small changes in tire pressure can noticeably affect the handling of the vehicle.
- Race teams use nitrogen because they already come to the track with a cylinder of nitrogen to power the air tools.
- Race teams also have more control over how much the pressure will increase when the tires heat up, because nitrogen has less tendency to change pressure with temperature change.
- Some oxygen in the tires could, over a long period of time, cause the oxidation of the inner liner of the tire and the corrosion of the wheel. See Figure 84–7.

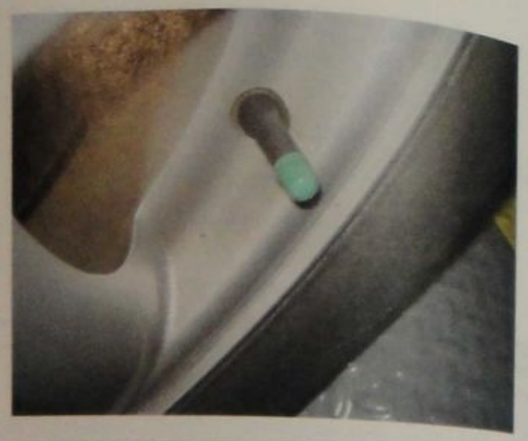


Figure 84–7 Most shops that use nitrogen inflation install a green tire value cap to let others know that nitrogen, rather than air has been used to inflate the tire.

TIRE MOUNTING RECOMMENDATIONS

1. When removing a wheel from a vehicle for service, mark the location of the wheel and lug stud to ensure that the wheel can be replaced in exactly the same location. This ensures that tire balance will be maintained if the tire/wheel assembly was balanced on the vehicle.
2. Make certain that the wheel has a good, clean metal-to-metal contact with the brake drum or rotor. Grease, oil, or dirt between these two surfaces could cause the wheel lug nuts to loosen while driving.
3. Always check the rim size. For example, simply by looking it is hard to distinguish a 16-in. wheel from a 16.5-in. wheel used on some trucks. See Figure 84–8. The rim size is marked on the sidewall of the tire, and the rim's diameter and width are stamped somewhere on the wheel.
4. Install the tire-pressure monitoring system (as shown in Figure 84–9).
5. Many tires have been marked with a paint dot or sticker, as shown in Figure 84–10. This mark represents the largest diameter (high point) and/or stiffest portion of the tire. This variation is due to the overlapping of carcass and belt fabric layers, as well as tread and sidewall rubber splices. The tire should be mounted to the rim with this mark lined up with the valve stem. The valve stem hole is typically drilled at the smallest diameter (low point) of the wheel. Mount the tires on the rim with the valve stem matched to (lined up next to) the mark on the tire. This is called **match mounting.**

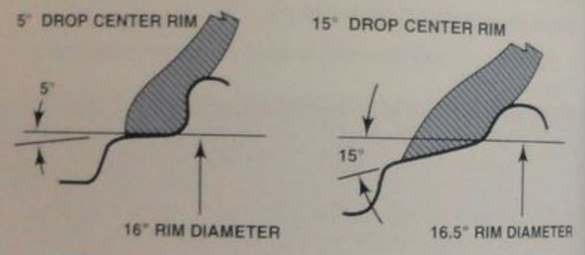


Figure 84–8 Note the difference in the shape of the rim contour of the 16-in. and 16 1/2-in. diameter wheels. While it is possible to mount a 16-in. tire on a 16 1/2-in. rim, it cannot be inflated enough to seat against the rim flange. If an attempt is made to seat the tire bead by overinflating (over 40 PSI), the tire bead can break, resulting in an explosive force that could cause serious injury or death.

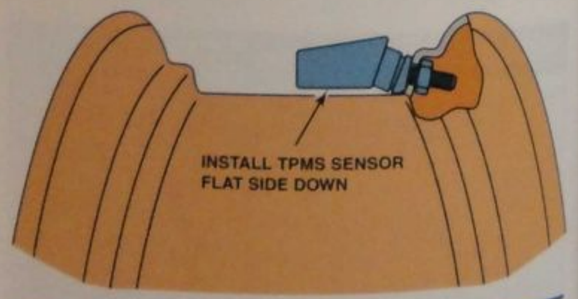


Figure 84–9 When installing a tire-pressure monitoring system sensor, be sure that the flat part of the sensor is parallel to the center section of the rim.

TECH TIP ✔ **Spin the Tires**

When performing a vehicle inspection and the vehicle has been hoisted on a frame-type lift, check the tires by rotating them by hand. The tires on the non-drive wheels should spin freely.

- On front-wheel-drive vehicles, rear wheels should rotate easily.
- On rear-wheel-drive vehicles, front wheels should rotate easily.
- On all-wheel-drive vehicles, all four wheels may require effort to rotate.

What to Look For:

- When rotating the wheels, look at the tires from the front or rear and check that the tread of the tires does not change or look as if the tread is moving inward or outward. If the tread is moving, this indicates an internal fault with the tire and it should be replaced. This type of fault can cause a vibration even though the tire/wheel assembly has been correctly balanced.
- Look from the side of the vehicle as the wheel/tire assembly is being rotated. Look carefully at the tread of the tire and see if the tire is round. If the tire is out-of-round, the tread will appear to move up and down as the tire is being rotated.

6. Never use more than 40 PSI (275 kPa) to seat a tire bead.
7. Rim flanges must be free of rust, dirt, scale, or loose or flaked rubber build-up prior to mounting the tire. See Figure 84–11.
8. When mounting new tires, do *not* use silicone lubricant on the tire bead. Use special lubricant such as rendered (odorless) animal fat or rubber lubricant to help prevent tire rotation on the rim. This rubber lube is a water-based soap product that is slippery when wet (coefficient of friction when less than 0.3) and acts almost as an adhesive when dry (coefficient of friction when dry of over 0.5 for natural products and over 1.0 for synthetic products). See Figure 84–12. If the wrong lubricant is used, the rubber in the bead area of the tire can be softened or weakened. Also, most other lubricants do not increase in friction when they dry like rubber lubricant does. The result can be the rotation of the tire on the rim (wheel), especially during rapid acceleration or braking.

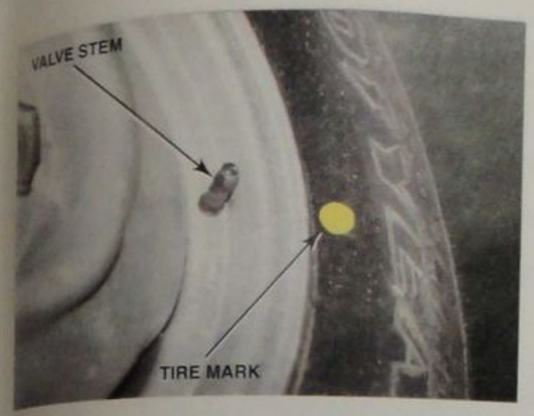


Figure 84–10 This tire on a new vehicle has been match mounted at the factory. The yellow sticker is placed at the largest diameter of the tire. The valve core hole in the wheel is usually drilled at the smallest diameter of the wheel. The best way to make sure the assembly is as round as possible and to reduce the number of wheel weights needed to balance the tire is to align the sticker with the valve core.



(a)



(b)

Figure 84–11 (a) Cleaning the bead area of an aluminum (alloy) wheel using a handheld wire brush. The technician is using the tire changer itself to rotate the wheel as the brush is used to remove any remnants of the old tire. (b) Using an electric or air-powered wire brush speeds the process, but care should be exercised not to remove any of the aluminum itself. (Remember, steel is harder than aluminum and a steel wire brush could cause recesses to be worn into the aluminum wheel, which would prevent the tire from proper seating in the bead area.)



Figure 84–12 Rendered (odorless) animal fat is recommended by some manufacturers of tire changing equipment for use as a rubber lubricant.

NOTE: Many experts recommend that when a new tire is installed the vehicle should be driven at less than 50 mph (80 km/h) for the first 50 miles (80 km) to allow the tires to adhere to the rim. During this break-in period, the rubber lube used to mount the tire is drying and the tire is becoming fully seated on the rim. By avoiding high speeds, rapid acceleration, and fast braking, the driver is helping to prevent the tire from rotating on the rim.

WHEEL MOUNTING TORQUE

For **wheel mounting torque,** make certain that the wheel studs are clean and dry, and torqued to the manufacturer's specifications.

CAUTION: Most manufacturers warn that the wheel studs should not be oiled or lubricated with grease; this can cause the wheel lug nuts to loosen while driving. Always follow the vehicle manufacturers' recommended service procedures.

Always tighten lug nuts gradually in the proper sequence—star pattern (tighten one nut, skip one, and tighten the next nut). This helps prevent warping the brake drums or rotors, or bending a wheel. See Figure 84–13.

TECH TIP ✔ **Fine-Tune Handling with Tire-Pressure Changes**

The handling of a vehicle can be changed by changing tire pressures between the front and rear tires.

Understeer—A term used to describe how a vehicle handles when cornering where additional steering input is needed to maintain the corner, or resisting turning into a corner. This is normal handling for most vehicles.

Oversteer—A term used to describe handling where correction while cornering is often necessary because the rear tires lose traction before the front tires.

Tire Pressure	To Decrease Understeer	To Decrease Oversteer
Front tire inflation pressure	Increase	Decrease
Rear tire inflation pressure	Decrease	Increase

CAUTION: Do not exceed the maximum inflation pressure as imprinted on the tire sidewall.



TORQUE SEQUENCE

Figure 84–13 Always tighten wheel lug nuts (or studs) in a star pattern to ensure even pressure on the axle flange, brake rotors or drums, and the wheel itself.

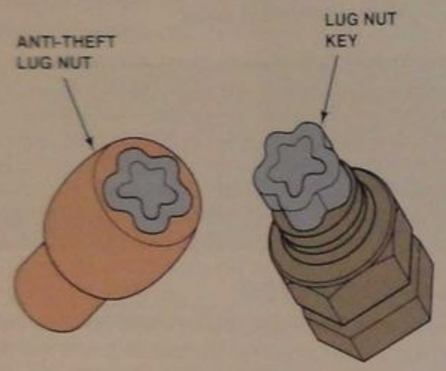


Figure 84–14 Most manufacturers recommend using hand tools rather than an air impact wrench to remove and install lock-type lug nuts to prevent damage. If either the key or the nut is damaged, the nut may be very difficult to remove!

If the exact torque value is not available, use the following chart as a guide for the usual value based on the size (diameter) of the lug studs.

Stud Diameter	Torque (lb-ft)
3/8 in.	35–45
7/16 in.	55–65
1/2 in.	75–85
9/16 in.	95–115
5/8 in. (usually only trucks)	125–150
12 mm	70–80
14 mm	85–95

Many factory-installed and aftermarket wheels use antitheft wheel lug nuts, as shown in Figure 84–14, usually on only one wheel stud. When removing or installing a locked lug nut, be sure the key is held square to the lug nut to prevent damaging either the nut or the key.

Whenever you install a brand new set of aluminum wheels, re-torque the wheels after the first 25 miles. The soft aluminum often compresses slightly, loosening the torque on the wheels.

NOTE: The use of torque-absorbing adapters (torque-limiting shank sockets) on lug nuts with an air impact wrench properly set has proved to give satisfactory results. See Figure 84–15 for a photo of a torque-absorbing adapter.



Figure 84–15 A torque-limiting adapter for use with an air impact wrench still requires care to prevent overtightening. The air pressure to the air impact should be limited to 125 PSI (860 kPa) in most cases, and the proper adapter must be selected for the vehicle being serviced. The torque adapter absorbs any torque beyond its designed rating. Most adapters are color coded for easy identification as to the size of lug nut and torque value.

TIRE ROTATION

To ensure long life and even tire wear, **tire rotation** is essential. It is important to rotate each tire to another location. Some

REAL WORLD FIX — **I Thought the Lug Nuts Were Tight!**

Proper wheel nut torque is critical, as one technician discovered when a customer returned complaining of a lot of noise from the right rear wheel. See Figure 84–16 for a photo of what the technician discovered. The lug (wheel) nuts had loosened and ruined the wheel.

CAUTION: Most vehicle manufacturers also specify that the wheel studs/nuts should not be lubricated with oil or grease. The use of a lubricant on the threads could cause the lug nuts to loosen.



Figure 84–16 This wheel was damaged because the lug nuts were not properly torqued.

wheel-drive vehicles, for example, may show premature tire wear on the front tires. The wear usually starts on the outer tread rib. This wear usually appears as a front-to-back (high and low) wear pattern on individual tread blocks. These *blocks of tread* rubber are deformed during cornering, stopping, and turning. This type of tread block wear can cause tire noise and/or tire roughness. While some shoulder wear on front tires is normal, it can be reduced by proper inflation, alignment, and tire rotation. For best results, tires should be rotated every 6,000 miles or every six months. See Figure 84–17 for suggested methods of rotation, such as the **modified X.**

NOTE: Radial tires can cause a radial pull due to their construction. If wheel alignment is correct, attempt to correct a pull by rotating the tires front to rear or, if necessary, side to side.

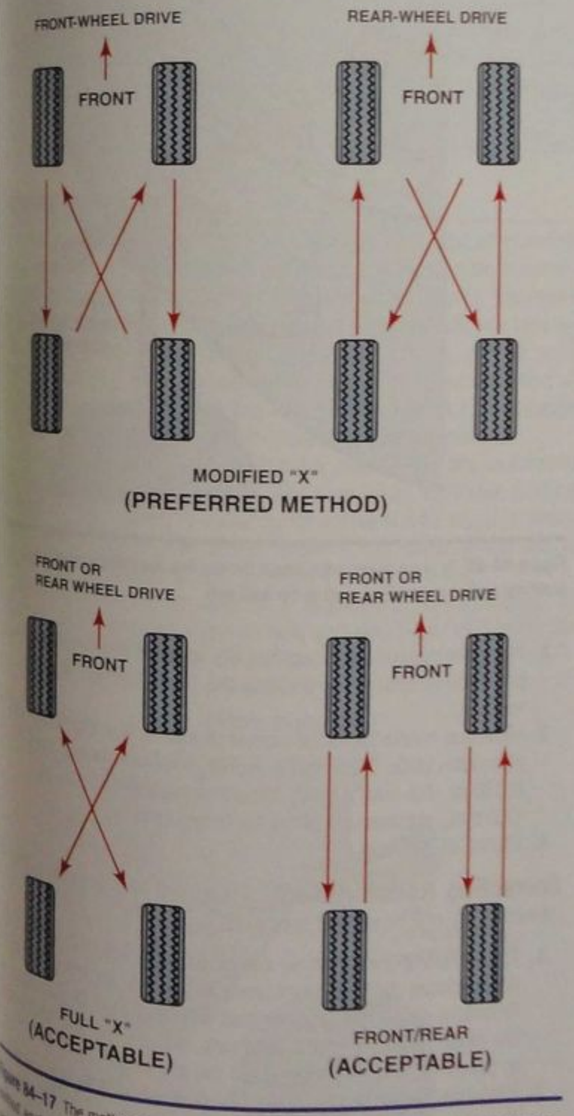


Figure 84–17 The method most often recommended is the modified X method. Using this method, each tire eventually is used at each of the four wheel locations. An easy way to remember the sequence, whether front wheel drive or rear wheel drive, is to say to yourself, "front wheels straight, cross the nondrive wheels."

TECH TIP — **Tire Rotation**

Tire rotation should be done at every other oil change. Most manufacturers recommend changing the engine oil every 3,000 miles (4,800 km) or every three months; tire rotation is recommended every 6,000 miles (9,600 km), or every six months.

Some tire manufacturers do not recommend rotating the tires on front-wheel-drive vehicles because the front tires often wear three times as fast as the rear. They recommend replacing just front tires, because the rear tires often last over 90,000 miles (145,000 km).

General Motors also warns that the wheels on many vehicles such as the Pontiac Trans Am and the newer Grand Prix cannot be rotated front to rear because the wheels and tires are different sizes. Always check service information as to the specified tire rotation procedure to follow on the vehicle being serviced.

TIRE INSPECTION

All tires should be carefully inspected for faults in the tire itself or for signs that something may be wrong with the steering or suspension systems of the vehicle. See Figures 84–18 through 84–20 for examples of common problems.

TECH TIP — **All-Wheel-Drive Tire Concerns**

It is very important that all-wheel-drive vehicles be equipped with tires that are all the same outside diameter. If, for example, the vehicle has 20,000 miles and the tires are half worn, all of the tires should be replaced in the event of a problem requiring replacement of only one tire.

Most vehicle manufacturers specify that all tires must be within 2/32 in. of tread depth without causing a constant strain on the drive train.

RADIAL RUNOUT

Even though a tire has no visible faults, it can be the cause of vibration. If vibration is felt above 45 mph, regardless of the engine load, the cause is usually an out-of-balance or a defective out-of-round tire. Both of these problems cause a **tramp** or *up-and-down*-type vibration. If the vibration is seen in the hood of the vehicle or felt in



Figure 84–18 Tire showing excessive shoulder wear resulting from underinflation and/or high-speed cornering.



Figure 84–19 Tire showing excessive wear in the center, indicating overinflation or heavy acceleration on a drive wheel.



Figure 84–20 Wear on the outside shoulder only is an indication of an alignment problem.

FREQUENTLY ASKED QUESTION ???

I Thought Radial Tires Couldn't Be Rotated!

When radial tires were first introduced by American tire manufacturers in the 1970s, rotating tires side-to-side was *not* recommended because of concerns about belt or tread separation. Since the late 1980s, most tire manufacturers throughout the world, including the United States, have used tire-building equipment specifically designed for radial-ply tires. These newer radial tires are constructed so that the tires can now be rotated from one side of the vehicle to the other without fear of causing a separation by the resulting reversal of the direction of rotation.

the steering wheel, then the problem is usually the *front* tires. If the vibration is felt throughout the entire vehicle or in the seat of your pants, then the rear tires (or drive shaft, in rear-wheel-drive vehicles) are the problem. This can be checked by using a runout gauge and checking for **radial runout.** See Figures 84–21 and 84–22. To check radial runout (checking for out-of-round) and lateral runout (checking for side-to-side movement), follow these steps:

1. Raise the vehicle so that the tires are off the ground approximately 2 in. (5 cm).



Figure 84–21 A tire runout gauge being used to measure the radial runout of a tire.

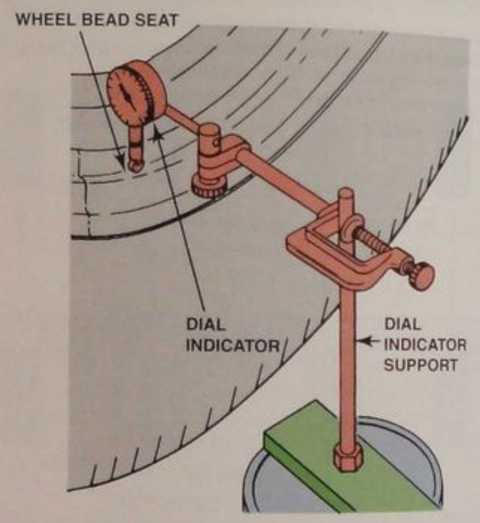


Figure 84–22 To check wheel radial runout, the dial indicator plunger tip rides on a horizontal surface of the wheel, such as the bead seat.

2. Place the runout gauge against the tread of the tire in the center of the tread and, while rotating the tire, observe the gauge reading.
3. Note that maximum radial runout should be less than 0.060 in. (1.5 mm). Little, if any, tramp will be noticed with less than 0.030 in. (0.8 mm) runout. If the reading is over 0.125 in. (3.2 mm), replacement of the tire is required.
4. Check all four tires.

Correcting Radial Runout Excessive radial runout may be corrected by one of several methods:

1. Try relocating the wheel on the mounting studs. Mark one stud and remount the wheel two studs away from its original position. Excessive wheel hole and/or stud tolerance may be the cause. If the radial runout is now satisfactory, re-mark the stud and wheel to prevent a future occurrence of the problem.
2. Remount the tire on the wheel 180 degrees from its original location. This can solve a runout problem, especially if the tire was not match mounted to the wheel originally.
3. If runout is still excessive, remove the tire from the wheel and check the runout of the *wheel.* If the wheel is within 0.035 in.

(0.9 mm), yet the runout of the tire/wheel assembly is excessive, the problem has to be a defective tire and it should be replaced.

Sometimes a problem within the tire itself can cause a vibration, and yet not show up as being out-of-round when tested for radial runout. A condition called **radial force variation** can cause a vibration even if correctly balanced.

NOTE: Some tire balancers are equipped with a roller that is pressed against the tread of the tire to measure radial force variations. Follow the instructions as shown on the balancer display to correct for excessive radial force variations.

FREQUENTLY ASKED QUESTION ???

Is the Age of a Tire Important?

Yes. The National Highway Traffic Safety Administration (NHTSA) recommends that any tire six years old or older should be replaced regardless of tread depth. This means that tires that look almost like new but are six years old or older should be replaced because the NHTSA determined that age, not tread depth, was a major factor in tire failures.

LATERAL RUNOUT

Another possible problem that tires can cause is a type of vibration called **shimmy.** This *rapid back-and-forth motion* can be transmitted through the steering linkage to the steering wheel. Excessive runout is usually noticeable by the driver of the vehicle as a side-to-side vibration, especially at low speeds between 5 and 45 mph (8 and 72 km/h). Shimmy can be caused by an internal defect of the tire or a bent wheel. This can be checked using a runout gauge on the side of the tire or wheel to check for **lateral runout.**

Place the runout gauge against the side of the tire and rotate the wheel. Observe the readings. The maximum allowable reading is 0.045 in. (1.1 mm). If close to or above 0.045 in. (1.1 mm), check on the edge of the wheel to see if the cause of the lateral runout is due to a bent wheel, as shown in Figure 84–23.

Most manufacturers specify a maximum lateral runout of 0.035 in. (0.9 mm) for alloy wheels and 0.045 in. (1.1 mm) for steel wheels. See Figure 84–24.

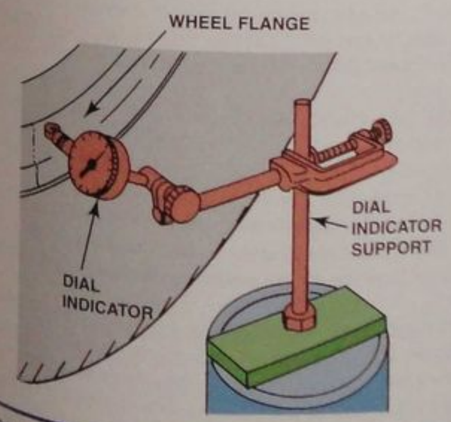


Figure 84–23 To check lateral runout, the dial indicator plunger tip rides on a vertical surface of the wheel, such as the wheel flange.

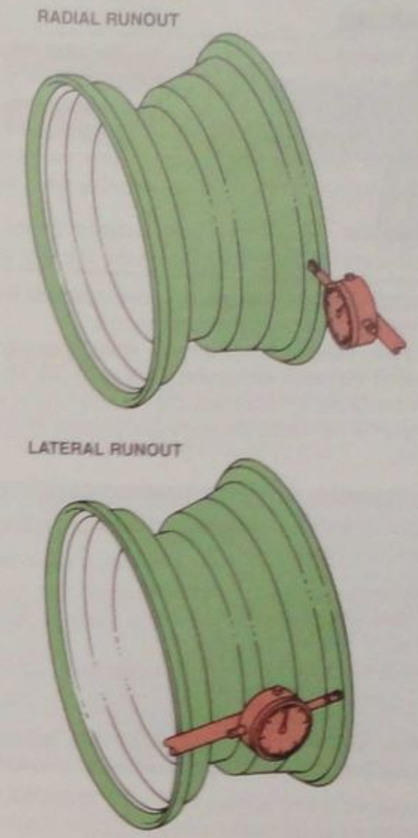


Figure 84–24 The most accurate method of measuring wheel runout is to dismantle the tire and take dial indicator readings on the inside of the wheel rim.

Correcting Lateral Runout Excessive lateral runout may be corrected by one of several methods:

1. Re-torque the wheel in the proper star pattern to the specified torque. Unequal or uneven wheel torque can cause excessive lateral runout.
2. Remove the wheel and inspect the wheel mounting flange for corrosion or any other reason that could prevent the wheel from seating flat against the brake rotor or drum surface.
3. Check the condition of the wheel or axle bearings. Looseness in the bearings can cause the wheel to wobble.

REAL WORLD FIX — **The Greased Wheel Causes a Vibration**

Shortly after an oil change and a chassis lubrication, a customer complained of a vibration at highway speed. The tires were checked for excessive radial runout to be certain the cause of the vibration was not due to a defective out-of-round tire. After removing the wheel assembly from the vehicle, excessive grease was found on the inside of the rim. Obviously, the technician who greased the lower ball joints had dropped grease on the rim. After cleaning the wheel, it was checked for proper balance on a dynamic computer balancer and found to be properly balanced. A test-drive confirmed that the problem was solved.

TIRE BALANCING

Proper tire balance is important for tire life, ride comfort, and safety. Tire balancing is needed because of the lack of uniform weight and stiffness (due to splices) and a combination of wheel runout and tire runout. Balancing a tire can compensate for most of these conditions. However, if a tire or wheel is excessively out of round or bent, then replacement of the wheel or tire is required.

Static Balance The term **static balance** means that the weight mass is evenly distributed around the axis of rotation.

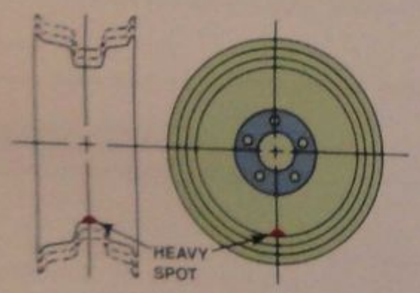
1. For example, if a wheel is spun and stops at different places with each spin, then the tire is statically balanced.
2. **If the static balance is not correct, wheel tramp-type (vertical shake) vibration and uneven tire wear can result.**
3. Static balance can be tested with the tire stationary or while being spun to determine the heavy spot (sometimes called *kinetic balance*).

Dynamic Balance The term **dynamic balance** means that the centerline of weight mass is in the same plane as the centerline of the wheel. See Figure 84–25.

1. Dynamic balance must be checked while the tire and the wheel are rotated, to determine side-to-side as well as up-and-down out of balance.
2. **Incorrect dynamic balance causes shimmy.** Shimmy-type vibration causes the steering wheel to shake from side to side.

Prebalance Checks Before attempting to balance any tire, the following should be checked and corrected to ensure good tire balance:

STATIC IMBALANCE



DYNAMIC IMBALANCE

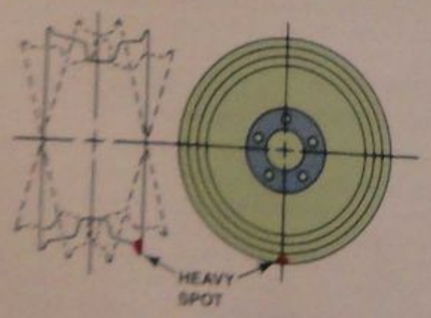


Figure 84–25 A wheel balancer detects heavy spots on the wheel and tire, and indicate where to place weight to offset both static and dynamic imbalance.



Figure 84–26 An assortment of wheel weights designed to fit different shaped rims.

1. Check the wheel bearing adjustment for looseness or wear.
2. Check the radial runout.
3. Check the lateral runout.
4. Remove stones from the tread.
5. Remove grease or dirt build-up on the inside of the wheel.
6. Check for dragging or misadjusted brakes.
7. Check for loose or backward lug nuts.
8. Check for proper tire pressures.
9. Remove all of the old weights.
10. Check for bent or damaged wheel covers.

Wheel Weights Wheel weights are available in a variety of styles and types, including the following:

1. Clip-on lead weights for standard steel rims.
2. Clip-on weights for alloy (aluminum) wheels. See Figure 84–26.
   a. Uncoated—generally *not* recommended by wheel or vehicle manufacturers because corrosion often occurs where the lead weight contacts the alloy wheel surface.

REAL WORLD FIX **The Vibrating Ford Van**

A technician was asked to solve a vibration problem on a rear-wheel-drive Ford van. During a test-drive, the vibration was felt everywhere—the dash, the steering wheel, the front seat, the shoulder belts; everything was vibrating! The technician balanced all four tires on a computer balancer. Even though wheel weights were put on all four wheels and tires, the vibration was even worse than before. The technician rebalanced all four wheels time after time, but the vibration was still present. The shop supervisor then took over the job of solving the mystery of the vibrating van. The supervisor balanced one wheel/tire assembly and then tested it again after installing the weights. The balance was way off! The supervisor broke the tire down and found about 1 quart (1 liter) of liquid in the tire! Liquid was found in all four tires. No wonder the tires couldn't be balanced! Every time the tire stopped, the liquid would settle in another location.

The customer later admitted to using a tire stop-leak liquid in all four tires. Besides stop leak, another common source of liquid in tires is water that accumulates in the storage tank of air compressors, which often gets pumped into tires when air is being added. All air compressor storage tanks should be drained of water regularly to prevent this from happening. See Figure 84–27.



Figure 84–27 Liquid tire stop leak was found in all four tires. This liquid caused the tires to be out of balance.

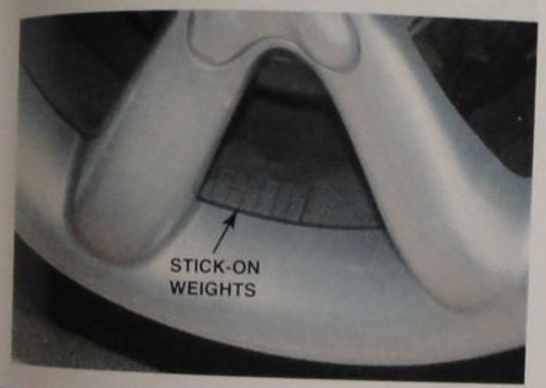


Figure 84–28 Stick-on weights are used from the factory to balance the alloy wheels of this Prowler.

   b. Coated—lead weights that are painted or coated in a plastic material are usually the *recommended* type of weight to use on alloy wheels.

   Weights are usually coated with a nylon or polyester-type material that often matches the color of the aluminum wheels.

3. Stick-on weights come with an adhesive backing that is most often used on alloy wheels. See Figure 84–28.

TECH TIP **Stop Leak Can Damage TPMS Sensors**

Stop leak should never be used in a tire that is equipped with the TPMS sensor because the sensor can be damaged.

Most wheel weights come in 1/21-ounce (0.25-oz) increment (1/4 oz = 7 gm × 28 = grams).

1/4 oz = 7 gm	1.75 oz = 49 gm
1/2 oz = 14 gm	2.00 oz = 56 gm
3/4 oz = 21 gm	2.25 oz = 63 gm
1 oz = 28 gm	2.50 oz = 70 gm
1 1/4 oz = 35 gm	2.75 oz = 77 gm
1 1/2 oz = 42 gm	3.00 oz = 84 gm

Use a wheel weight pliers to help ensure proper installation and removal of wheel weights. See Figure 84–29.



Figure 84–29 Wheel weight pliers are specially designed to remove and install wheel weights.

Bubble Balancer This type of static balancer is commonly used and is accurate, if calibrated and used correctly. A bubble balancer is portable and can be easily stored away when not in use. It is also easy to use and is relatively inexpensive.

FREQUENTLY ASKED QUESTION ???

How Much Is Too Much Weight?

Whenever balancing a tire, it is wise to use as little amount of weight as possible. For most standard-size passenger vehicle tires, most experts recommend that no more than 5.5 oz of weight be added to correct an imbalance condition. If more than 5.5 oz is needed, remove the tire from the wheel (rim) and carefully inspect for damage to the tire or the wheel. If the tire still requires more than 5.5 oz and the wheel is not bent or damaged, replace the tire.

Computer Balancer The most popular type of tire balancer is the computer dynamic balancer. Most computer balancers are designed to balance wheels and tires off the vehicle. Computer dynamic balancers spin the tire at a relatively slow speed (approximately 20 mph). Sensors attached to the spindle of the balancer determine the amount and location of weights necessary to balance the tire dynamically. All computer balancers must be programmed with the actual rim size and tire location for the electronic circuits to calibrate the required weight locations. Some computer balancers can perform loaded radial force and lateral force variation testing on the tire/wheel assembly and display corrective actions. See Figure 84–30.



Figure 84–30 A tire balancer that can also detect radial and lateral force variation and instruct the operator where to rotate the tire to achieve the best ride, or indicate a bent wheel.

Most computer balancers will be accurate to within 1/4 oz (0.25 oz), while some are accurate to within 1/8 oz (0.125 oz). (Most drivers can feel an out-of-balance of 1 oz or more, but few can feel a vibration caused by just 1/4 oz.) For sensitive drivers or vehicles used for high speeds, such as racing, most computer balancers can be programmed to balance within 1/8 oz (0.125 oz). Refer to the manufacturer's instructions for the exact capabilities and procedures for your computer balancer.

Most vehicle manufacturers specify that no more than 5.5 oz (150 gm) be used to balance any tire, with no more than 3.5 oz (100 gm) used per side of each wheel.

FREQUENTLY ASKED QUESTION ???

Are the Brake Drums and Rotors Balanced?

Whenever an off-the-vehicle computer balancer is used, a question often asked by beginning technicians is, "What about the balance of the brake drums and rotors?" Brake drums and rotors are balanced at the factory, usually to within 0.5 oz-in. Imbalance measured in oz-in. means that any imbalance force is measured in ounces, then multiplied by the distance from the center measured in inches. This means that at a distance of 1 in. from the center of the drum or rotor, it is within 0.5 ounce of being perfectly balanced. Being within 0.5 ounce-inch also means that at 5 inches from the center, the imbalance is only 0.1 ounce.

What this means to the technician is that most drums and rotors are balanced well enough not to be a problem when using off-the-vehicle balancers. However, the smart technician should look for evidence that weights have been removed from brake drums to permit aluminum wheels to fit, or other cases where the factory balance of the drums and rotors has been changed.

REPLACEMENT WHEELS

Whenever a replacement wheel is required, the same offset should be maintained. If wider or larger-diameter wheels are to be used, consult a knowledgeable wheel or tire salesperson to determine the correct wheel for your application.

CAUTION: Never remove the weights that are welded to the surface of the brake drum facing the wheel. See Figure 84–31. If replacement wheels do not fit without removing these weights, either replace the brake drum (one without a weight) or select another brand or style of wheel. Removing the weights from a brake drum can cause severe vibration at highway speeds.

REAL WORLD FIX **It Happened to Me—It Could Happen to You**

During routine service, I rotated the tires on a Pontiac Trans Am. Everything went well and I even used a torque wrench to properly torque all of the lug nuts. Then, when I went to drive the car out of the service stall, I heard a horrible grinding sound. When I hoisted the car to investigate, I discovered that the front wheels were hitting the outer tie rod ends. See Figure 84–32. The 16-in. wheels had a different back spacing front and rear, and therefore these wheels could not be rotated. Always check replacement or aftermarket wheels for proper fit before driving the vehicle.

TIRE REPAIR

Tread punctures, nail holes, or cuts up to 1/4 in. (2.6 mm) can be repaired. Repairs should be done from the inside of the tire using

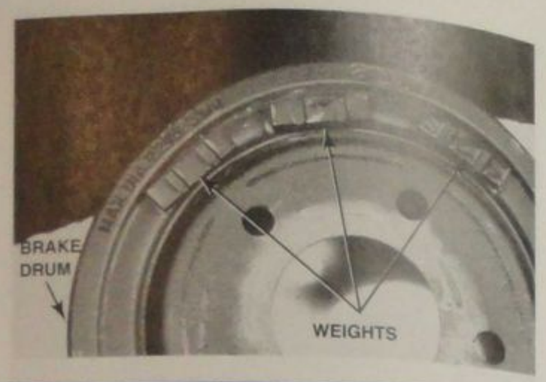


Figure 84–31 Most brake drums do not have this much attached weight.

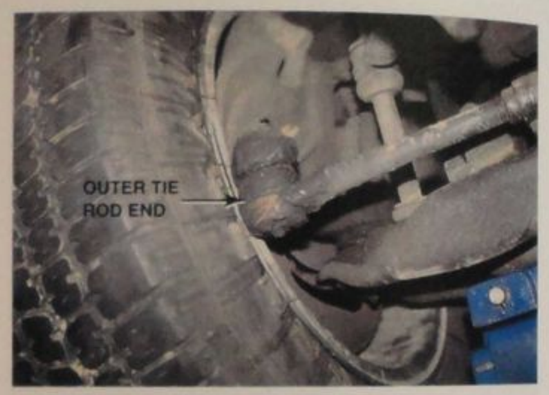


Figure 84–32 Notice that the rim touches the tie rod end.

plugs or patches. The tire should be removed from the rim to make the repair. With the tire off the wheel, inspect the wheel and the tire for hidden damage. The proper steps to follow for a tire repair are as follows:

1. Mark the location of the tire on the wheel.

FREQUENTLY ASKED QUESTION ???

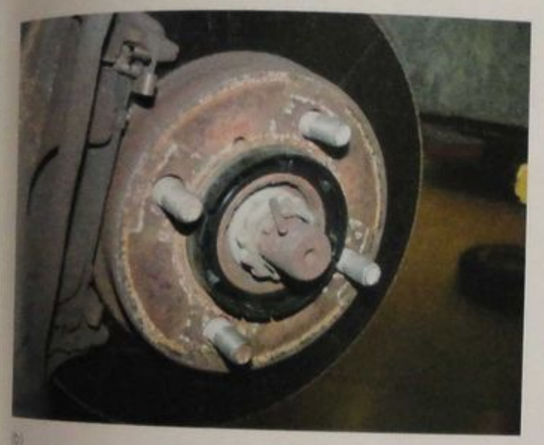
What Are Hubcentric Wheels?

Most wheels are designed to fit over and be supported by the axle hub. Some wheels use an enlarged center hub section and rely on the wheel studs for support and to keep the wheel centered on the axle. Some aftermarket wheels may be designed to fit several different vehicles. As a result, the wheel manufacturers use plastic hubcentric adapter rings. See Figure 84–33.

2. Dismount the tire; inspect and clean the punctured area with a prebuff cleaner. DO NOT USE GASOLINE!
3. Buff the cleaned area with sandpaper or a tire-buffing tool until the rubber surface has a smooth, velvet finish. See Figure 84–34.
4. Ream the puncture with a fine reamer from the inside. Cut and remove any loose wire material from the steel belts.
5. Fill the puncture with contour filling material, and cut or buff the material flush with the inner liner of the tire.
6. Apply chemical vulcanizing cement and allow to dry.



(a)



(b)

Figure 84–33 (a) A hubcentric plastic ring partially removed from an aftermarket wheel. (b) A hubcentric plastic ring left on the hub when removing a wheel.

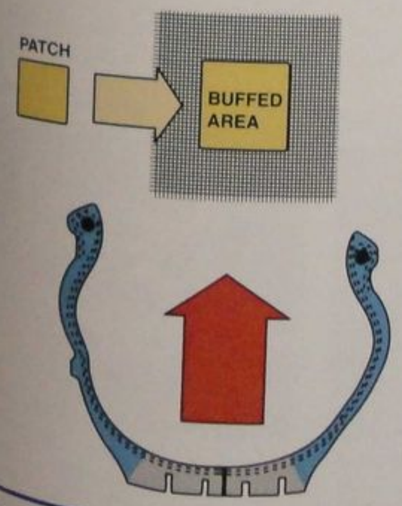


Figure 84–34 The area of the repair should be buffed slightly larger than the patch to be

NOTE: Most vulcanizing (rubber) cement is highly flammable. Use out of the area of an open flame. Do not smoke when making a tire repair.

TECH TIP ✓ **Dispose of Old Tires Properly**

Old tires cannot be thrown out in the trash. They must be disposed of properly. Tires cannot be buried because they tend to come to the surface. They also trap and hold water, which can be a breeding ground for mosquitoes. Used tires should be sent to a local or regional recycling center where the tires will be ground up and used in asphalt paving or other industrial uses. Because there is often a charge to dispose of old tires, it is best to warn the customer of the disposal fee.

7. Apply the patch and use a stitching tool from the center toward the outside of the patch to work any air out from between the patch and the tire. See Figure 84–35. Another excellent tire repair procedure uses a rubber plug. Pull the stem through the hole in the tire, as shown in Figure 84–36.
8. Remount the tire on the rim, aligning the marks made in step 1. Inflate to the recommended pressure and check for air leaks.

There are many tire repair products on the market. Always follow the installation and repair procedures exactly per the manufacturer's instructions.

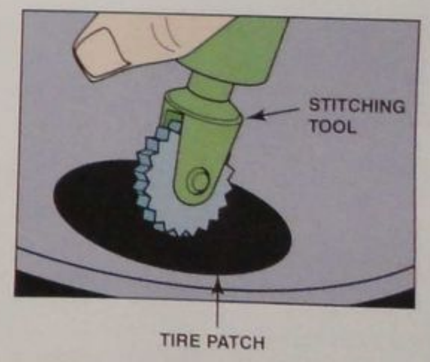


Figure 84–35 A stitching tool being used to force any trapped air out from under the patch.

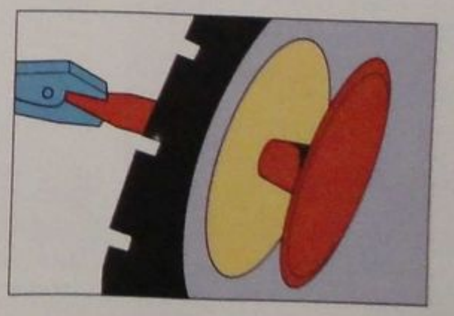


Figure 84–36 A rubber plug being pulled through a hole in the tire. The stem is then cut off flush with the surface of the tire tread.

CAUTION: Most experts agree that tire repairs should be done from the inside. Many technicians have been injured and a few killed when the tire they were repairing exploded as a steel reamer tool was inserted into the tire. The reamer can easily create a spark as it is pushed through the steel wires of a steel-belted tire. This spark can ignite a combustible mixture of gases inside the tire caused by using stop leak or inflator cans. Since there is no way a technician can know if a tire has been inflated with a product that uses a combustible gas, always treat a tire as if it could explode.

TECH TIP ✓ **Open-End Wrenches Make It Easier**

Tire repair is made easier if two open-end wrenches are used to hold the beads of the tire apart. See step 4 in the tire repair photo sequence.

PHOTO SEQUENCE Tire Mounting Step-by-Step



P84–1 A typical tire-changing machine showing the revolving table and movable arm used to remove a tire from the wheel.



P84–2 The foot-pedal controls allow the service technician to break the tire bead, damp the wheel (rim) to the machine, rotate the tire/wheel assembly, and still have both hands free.



P84–3 Using a tire valve removal tool, unscrew the valve core using extreme caution because the valve is under pressure and can be forced outward and cause personal injury.



P84–4 The valve core removed from the tire valve. Allow all of the air in the tire to escape.



P84–5 A bead breaker is being used to separate the tire from the bead seat of the wheel. Repeat as needed to break the bead on both sides of the wheel.



P84–6 After breaking the beads from both sides of the tire, install the wheel/tire assembly flat onto the machine and, using the foot-pedal control, lock the wheel to the changer.



P84–7 To remove the tire from the wheel, position the arm of the changer against the rim of the wheel and lock in position.



P84–8 The tire tool (flat bar) is placed between the bead of the tire and the wheel.



P84–9 The foot pedal that causes the table to rotate is depressed and the tire is removed from the wheel.

PHOTO SEQUENCE Tire Mounting Step-by-Step—continued



P84–10 Reposition the tire tool to remove the lower bead of the tire from the wheel.



P84–11 As the table of the tire changer is rotated, the tire is released from the wheel and can be lifted off the wheel.



P84–12 Before installing a tire, inspect and clean the bead seat.



P84–13 Before installing a new tire, most experts recommend replacing the tire valve, being installed here, using a tool that pulls the valve through the hole in the wheel.



P84–14 Apply tire soap or rubber lubricant to both beads of the tire.



P84–15 Rotate the tire on the wheel and position the arm so that the tire will be guided onto the rim as the wheel is rotated.



P84–16 Repeat for the upper bead.



P84–17 Inflate the tire, being careful to not exceed 40 PSI.



P84–18 Install the tire valve core and inflate the tire to specifications.

Tire Repair Step-by-Step



P84–1 The source of the leak was detected by spraying soapy water on the inflated tire. Needle-nose pliers are being used to remove the object that caused the flat tire.



P84–2 A part of a razor blade was found to be the cause of the flat tire.



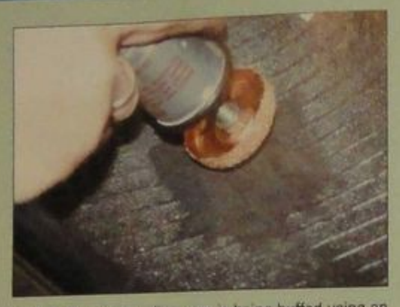
P84–3 A reamer is being used to clean the puncture hole.

(continued)

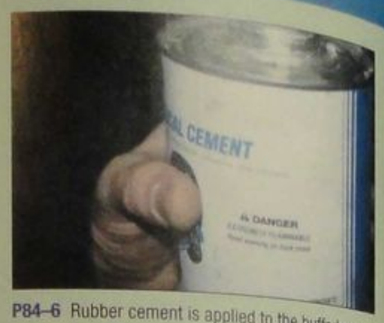
PHOTO SEQUENCE Tire Repair Step-by-Step—continued



P84–4 A method used by some technicians is to hold the beads apart with two open-end wrenches, and this provided more than enough room to gain access to the inside of the tire.



P84–5 The surrounding area is being buffed using an air-powered die grinder equipped with a special buffing tool specifically designed for this process.



P84–6 Rubber cement is applied to the buffed area.



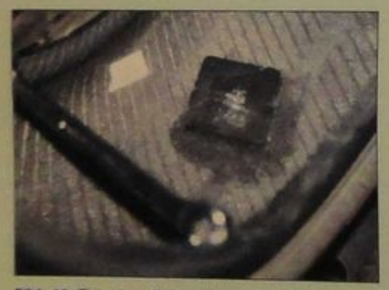
P84–7 The brush included with the rubber cement makes the job easy. Be sure to cover the entire area around the puncture.



P84–8 Peel off the paper from the adhesive on the patch. Insert the tip of the patch through the puncture from the inside of the tire.



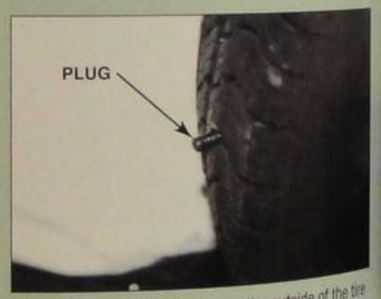
P84–9 Use a pair of pliers to pull the plug of the patch through the puncture.



P84–10 This view of the patch is from the inside of the tire.



P84–11 To be assured of an airtight patch, the adhesive of the patch should be "stitched" to the inside of the tire using a serrated roller called a stitching tool.



P84–12 A view of the plug from the outside of the tire after metal covering used to pierce the puncture is removed from the patch plug. The plug can be trimmed to the level of the tread using side cutters or a knife.

SUMMARY

1. For safety and proper vehicle handling, all four tires of the vehicle should be of the same size, construction, and type, except where specified by the manufacturer, such as on some high-performance sports cars.
2. Wheels should always be tightened with a torque wrench to the proper torque in a star pattern.
3. Tires should be rotated every 5,000 to 7,000 miles (8,000 to 11,000 km), or at every other oil change.
4. Wheels should be cleaned around the rim area whenever tires are changed and carefully inspected for cracks or other defects such as excessive lateral or radial runout.
5. Properly balanced tires prolong tire life. Wheel tramp or an up-and-down type of vibration results if the tires are statically out of balance or if the tire is out-of-round.
6. Dynamic balance is necessary to prevent side-to-side vibration, commonly called shimmy.
7. Only coated or stick-on-type wheel weights should be used on alloy wheels to prevent corrosion damage.

REVIEW QUESTIONS

1. List the precautions and recommendations regarding tire selection and maintenance.
2. Determine the proper wheel mounting torque for your vehicle from the guidelines provided.
3. Determine the proper bolt circle, wheel diameter, and wheel width for your vehicle.
4. Describe the difference between static and dynamic balance.

CHAPTER QUIZ

1. A tire is worn excessively on both edges. The most likely cause of this type of tire wear is _____.
   a. Overinflation
   b. Underinflation
   c. Excessive radial runout
   d. Excessive lateral runout
2. When seating a bead of a tire, never exceed _____ PSI.
   a. 30
   b. 40
   c. 50
   d. 60
3. For best tire life, most vehicle and tire manufacturers recommend tire rotation every _____.
   a. 3,000 miles
   b. 6,000 miles
   c. 9,000 miles
   d. 12,000 miles
4. What lubricant should be used when mounting a tire?
   a. Silicone spray
   b. Grease
   c. Water-based soap
   d. SAE 10W-30 engine oil
5. The most common torque specification range for lug nuts is _____.
   a. 125 to 150 lb-ft
   b. 100 to 120 lb-ft
   c. 80 to 100 lb-ft
   d. 60 to 80 lb-ft
6. Which statement is *false*?
   a. Excessive radial runout can cause a tramp-type vibration.
   b. Excessive lateral runout can cause a tramp-type vibration.
   c. A tire out of balance dynamically can cause a shimmy-type vibration.
   d. A tire out of balance statically can cause a tramp-type vibration.
7. The recommended type of wheel weight to use on aluminum (alloy) wheels is _____.
   a. Lead with plated spring steel clips
   b. Coated (painted) lead weights
   c. Lead weights with longer-than-normal clips
   d. Aluminum weights
8. Most vehicle and tire manufacturers recommend that no more than _____ ounces of balance weight be added to a wheel/tire assembly.
   a. 2.5
   b. 3.5
   c. 4.5
   d. 5.5
9. A vehicle vibrates at highway speed. Technician A says that water in the tire(s) could be the cause. Technician B says that an out-of-round tire could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Proper tire inflation pressure information is found _____.
    a. On the driver's door or post
    b. In the owner's manual
    c. On the sidewall of the tire
    d. Both a and b

CHAPTER 85 Suspension System Components and Operation

OBJECTIVES: After studying Chapter 85, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "B" (Suspension System Diagnosis and Repair). • List various types of suspensions and their component parts. • Explain how coil, leaf, and torsion bar springs work. • Describe how suspension components function to allow wheel movement up and down and provide for turning. • Describe how shock absorbers control spring forces.

KEY TERMS: air spring • anti-dive • anti-squat • ball joints • bulkhead • bump stop • center bolt • coil springs • composite leaf spring • control arms • cradle • full frame • gVW • Hooke's Law • independent suspension • insulators • kingpin • ladder frame • lateral links • leaf springs • load-carrying ball joint • mono leaf • non-load-carrying ball joint • perimeter frame • platforms • rebound clips • shackles • shock absorbers • space frame • spring pocket • spring rate • springs • sprung weight • stabilizer bars • steering knuckles • stress riser • strut rod • struts • stub-type frame • torsion bar • unit-body • unsprung weight • wheel rate

Street-driven cars and trucks use a suspension system to keep the tires on the road and to provide acceptable riding comfort. A vehicle with a solid suspension, or no suspension, would bounce off the ground even the tires hit a bump. If the tires are off the ground, even for a fraction of a second, loss of control is possible. The purpose of the suspension is to provide the vehicle with the following:

1. A smooth ride
2. Accurate steering

3. Responsive handling
4. Support for the weight of the vehicle
5. Maintenance of acceptable tire wear

FRAME CONSTRUCTION

Frame construction usually consists of channel-shaped steel beams welded and/or fastened together. The frame of a vehicle supports all the "running gear" of the vehicle, including the engine, transmission, rear axle assembly (if rear-wheel drive), and all suspension components.

This frame construction, referred to as **full frame,** is so complete that most vehicles can usually be driven without the body. Most trucks and larger rear-wheel-drive cars use a full frame.

Ladder Frame A **ladder frame** is a common name for a type of perimeter frame where the transverse (lateral) connecting members are straight across. See Figures 85–1 and 85–2. When viewed with the body removed, the frame resembles a ladder. Most pickup trucks are constructed with a ladder-type frame.

Perimeter Frame A **perimeter frame** consists of welded or riveted frame members around the entire perimeter of the body.

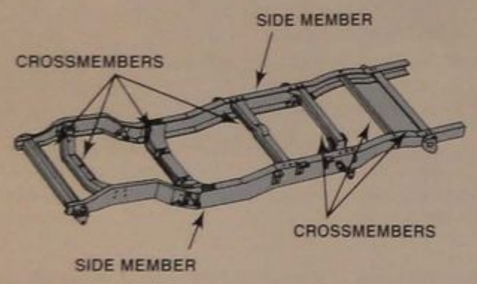


Figure 85–1 A typical truck frame is an excellent example of a ladder-type frame. The two side members are connected by a crossmember.

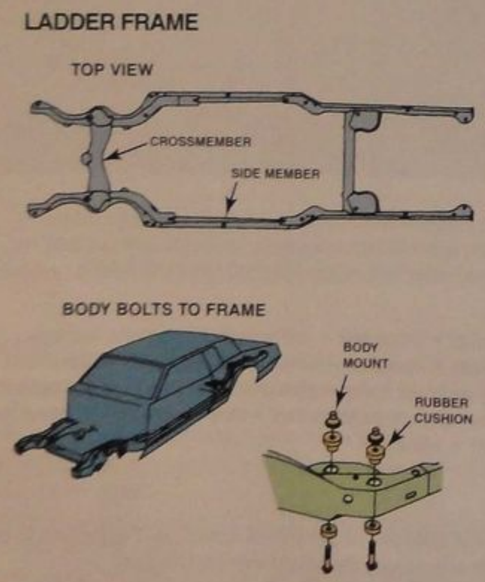


Figure 85–2 Rubber cushions used in body or frame construction isolate noise and vibration from traveling to the passenger compartment.

This means that the frame members provide support underneath the sides as well as for the suspension and suspension components.

Stub-Type Frames A **stub-type frame** is a partial frame often used on unit-body vehicles to support the power train and suspension components. It is also called a **cradle** on many front-wheel-drive vehicles. See Figure 85–3.

Unit-Body Construction **Unit-body** construction (sometimes called *unibody*) is a design that combines the body with the structure of the frame. The body supports the engine and drive line components, as well as the suspension and steering components. The body is composed of many individual stamped-steel panels welded together.

The strength of this type of construction lies in the *shape* of the assembly. The typical vehicle uses 300 separate and different stamped steel panels that are spot-welded to form a vehicle's body. See Figure 85–4.

NOTE: A typical vehicle contains about 10,000 individual parts.

Space Frame Construction **Space frame** construction consists of formed sheet steel used to construct a framework for the entire vehicle. The vehicle is drivable without the body, which uses plastic or steel panels to cover the steel framework.

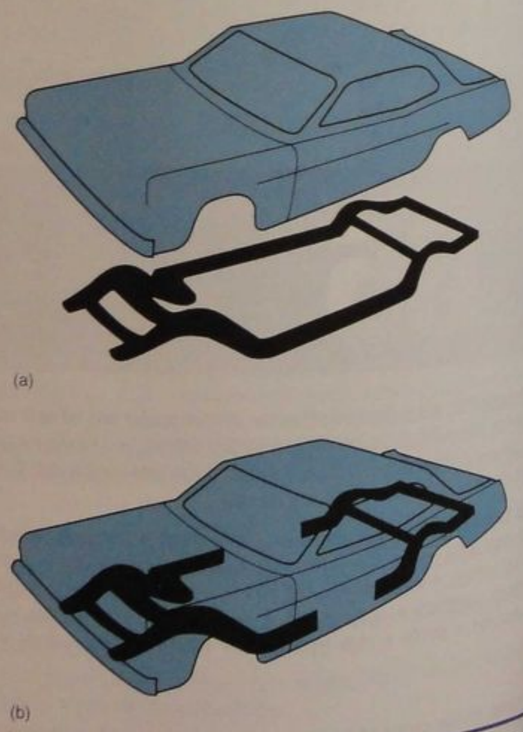


Figure 85–3 (a) Separate body and frame construction; (b) unitized construction. the small frame members are for support of the engine and suspension components. Many vehicles attach the suspension components directly to the reinforced sections of the body and do not require the rear frame section.

UNIT-BODY CONSTRUCTION

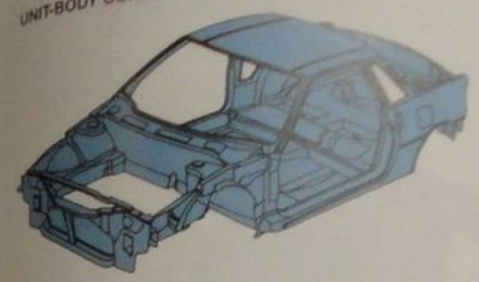


Figure 85–4 Welded metal sections create a platform that combines the body with the frame using unit-body construction.

FREQUENTLY ASKED QUESTION ???

What Does GVW Mean?

GVW, gross vehicle weight, is the weight of the vehicle plus the weight of all passengers the vehicle is designed to carry (× 150 lb [68 kg] each), plus the maximum allowable payload or luggage load. *Curb weight* is the weight of a vehicle when wet, meaning with a full tank of fuel and all fluids filled, but without passengers or cargo (luggage). *Model weight* is the weight of a vehicle wet and with passengers.

The GVW is found stamped on a plate fastened to the doorjamb of most vehicles. A high GVW rating does not mean that the vehicle itself weighs a lot more than other vehicles. For example, a light truck with a GVW of 6,000 lbs (2,700 kg) will not ride like an old 6,000-lb luxury car. In fact, a high GVW rating usually requires stiff springs to support the payload; these stiff springs result in a harsh ride. Often technicians are asked to correct a harsh-riding truck that has a high GVW rating. The technician can only check that everything in the suspension is satisfactory and then try to convince the owner that a harsher-than-normal ride is the result of a higher GVW rating.

PLATFORMS

The **platform** of any vehicle is its basic size and shape. Various vehicles of different makes can share the same platform, and therefore many of the same drive train (engine, transmission, and final drive components) and suspension and steering components.

A platform of a unit-body vehicle includes all major sheet-metal components that form the load-bearing structure of the vehicle, including the front suspension and engine-supporting sections. The area separating the engine compartment from the passenger compartment is called the **bulkhead.** The height and location of this bulkhead relative to a large degree determines the shape of the rest of the vehicle. Other components of vehicle platform design that affect handling and ride are the track and wheelbase of the vehicle. *The track of a vehicle is the distance between the wheels, as viewed from the front or rear.* A wide-track vehicle is a vehicle with a wide wheel stance; this increases the stability of the vehicle, especially when cornering. *The wheelbase of a vehicle is the distance between the center of the front wheel and the center of the rear wheel, as viewed from the side.* A vehicle with a long wheelbase tends to ride smoother than a vehicle with a short one.

TECH TIP

Hollander Interchange Manual

Most salvage businesses that deal with wrecked vehicles use a reference book called the *Hollander Interchange Manual*. In this yearly publication, every vehicle part is given a number. If a part from another vehicle has the same Hollander number, then the parts are interchangeable.

Examples of common platforms include the following:

1. Chevrolet Impala and Pontiac Grand Prix
2. Toyota Camry and Lexus ES 350
3. Buick Lucerne and DTS

UNSPRUNG WEIGHT

A suspension system has to be designed to allow the wheels to move up and down quickly over bumps and dips without affecting the entire weight of the car or truck. In fact, the lighter the total weight of the components that move up and down, the better the handling and ride. This weight is called **unsprung weight.** The idea of very light weight resulted in magnesium wheels for racing cars, which are very light yet strong. Aftermarket wheels that resemble racing car wheels are often referred to as *mag* wheels. For best handling and ride, the unsprung weight should be kept as low as possible.

Sprung weight is the term used to identify the weight of the car or truck that does *not* move up and down and is supported or *sprung* by the suspension.

TYPES OF SUSPENSIONS

Early suspension systems on old horse wagons, buggies, and older vehicles used a solid axle for front and rear wheels. See Figure 85–5. If one wheel hit a bump, the other wheel was affected, as shown in Figure 85–6.

Most vehicles today use a separate control-arm-type of suspension for each front wheel, which allows for movement of one front wheel without affecting the other front wheel. This type of front suspension is called **independent suspension.** See Figure 85–7.

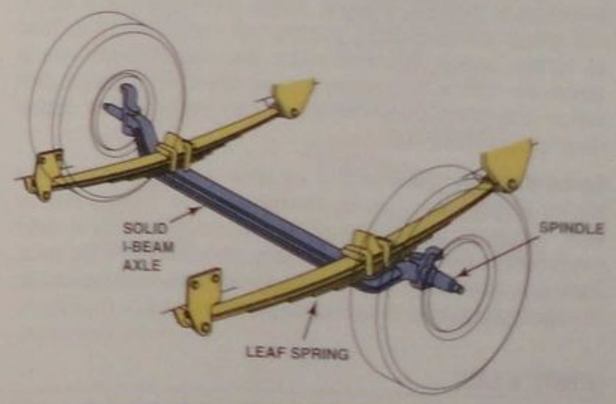


Figure 85–5 Solid I-beam axle with leaf springs.

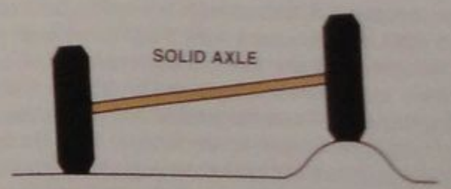


Figure 85–6 When one wheel hits a bump or drops into a hole, both left and right wheels are moved. Because both wheels are affected, the ride is often harsh and feels stiff.

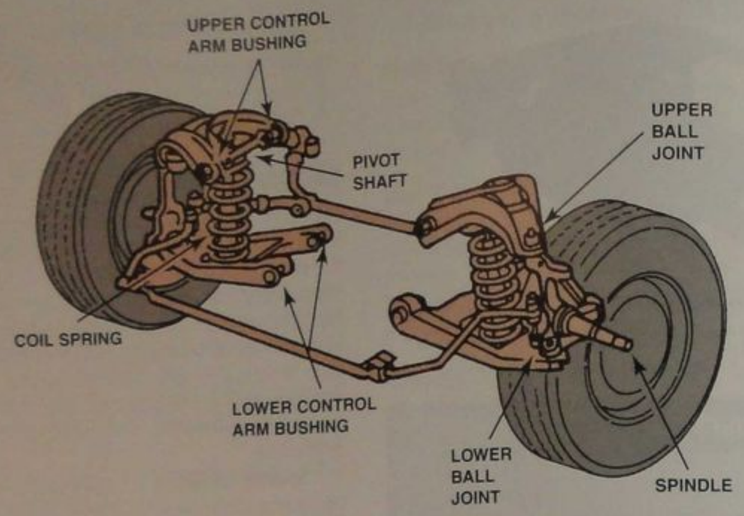


Figure 85–7 A typical independent front suspension used on a rear-wheel-drive vehicle. Each wheel can hit a bump or hole in the road independently without affecting the opposite wheel.

Many rear suspensions also use independent-type suspension systems. Regardless of the design type of suspension, all suspensions use springs in one form or another.

Springs A suspension **spring** serves two purposes. First, it acts as a buffer between the suspension and frame to absorb vertical wheel and suspension movement without passing it on to the frame. Second, each spring transfers part of the vehicle weight to the suspension component it rests on, which transfers it to the wheels.

The basic method by which springs absorb road shocks varies according to the type of spring. Simply stated, leaf springs flatten, coil springs and air springs compress, and torsion bars twist. What all springs have in common is that they somehow give way to absorb the vertical force of the moving wheel during jounce, then release that force during rebound as they return to their original shape and position.

Spring Materials Most springs are made of a tempered steel alloy known as spring steel, usually chrome silicon or chrome-vanadium alloy. Tempering is a process of heating and cooling metal under controlled conditions, which increases the resilience of the metal. Resilience is the ability of the metal to return to, or spring back to, its original shape after being twisted or compressed.

HOOKE'S LAW

Regardless of type, all suspensions use springs that share a common characteristic described by **Hooke's Law.** Robert Hooke (1635–1703), an English physicist, discovered the force characteristics of springs: *The deflection (movement or deformation) of a spring is directly proportional to the applied force.*

What this means is that when a coil spring (for example) is depressed 1 in., it pushes back with a certain force (in pounds), such as 400 pounds. If the spring is depressed another inch, the force exerted by the spring is increased by another 400 pounds. The **spring rate** or force constant for this spring is therefore "400 lb per inch," usually symbolized by the letter K. Since the force constant is the force per unit of displacement (movement), it is a measure of the stiffness of the spring. The higher the spring rate (K), the stiffer the spring. See Figure 85–8.

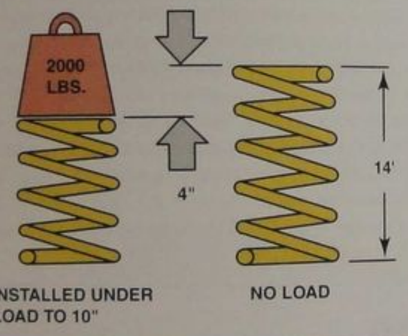


Figure 85–8 This spring was depressed 4 inches due to a weight of 2,000 lb. This means that this spring has a spring rate (K) of 500 lb per inch (2000 ÷ 4 in. = 500 lb./in.)

COIL SPRINGS

Coil springs are made of special round spring steel wrapped in a helix shape. The strength and handling characteristics of a coil spring depend on the following:

1. Coil diameter
2. Number of coils
3. Height of spring
4. Diameter of the steel coil that forms the spring. See Figure 85–9.

The spring rate (K) for coil springs is expressed by the formula:

$$K = \frac{Gd4}{8ND3}$$

where

G = 11,250,000 (constant for steel)
d = diameter of wire
N = number of coils
D = diameter of the coil

Coil springs are used in front and/or rear suspensions.

The larger the diameter of the steel, the "stiffer" the spring.

The shorter the height of the spring, the stiffer the spring.

The fewer the coils, the stiffer the spring.

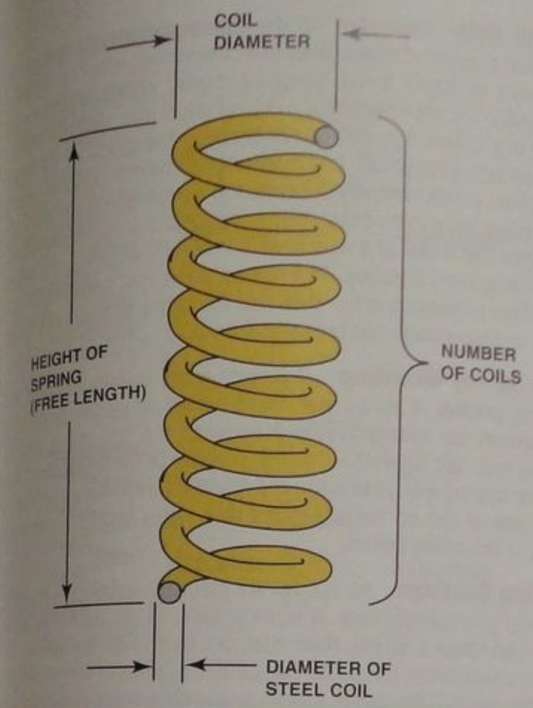


Figure 85–9 The spring rate of a coil spring is determined by the diameter of the spring and the diameter of the steel used in its construction plus the number of coils and the free length (height).

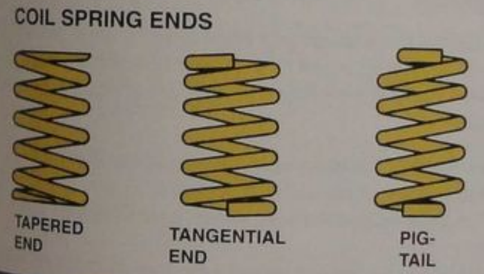


Figure 85–10 Coil spring ends are shaped to fit the needs of a variety of suspension designs.

Springs are designed to provide desired ride and handling and come in a variety of spring ends, as shown in Figure 85–10.

CAUTION: The use of spacers between the coils of a coil spring is *not* recommended because the force exerted by the spacers on the springs can cause spring breakage. When a spacer is installed between the coils, the number of coils is reduced and the spring becomes stiffer. The force exerted on the coil spring at the contact points of the spacer can cause the spring to break.

Spring Rate Spring rate, also called *deflection rate*, is a value that reflects how much weight it takes to compress a spring a certain amount. Generally, spring rate is specified in pounds per inch, which is the weight in pounds it takes to compress the spring 1 inch. In other words, if a 100-pound weight causes a spring to compress 1 inch, the spring has a spring rate of 100 pounds.

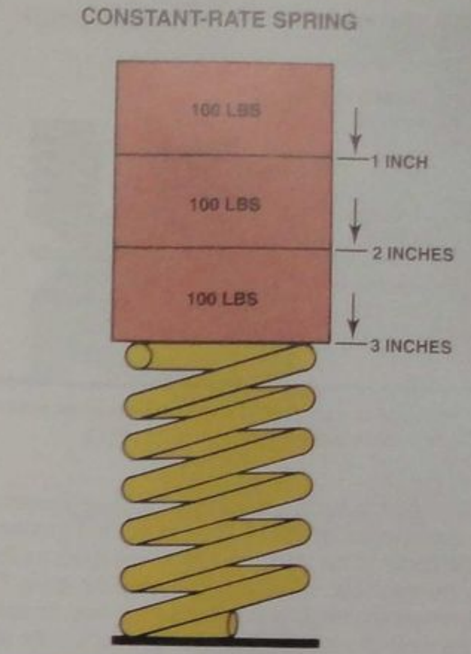


Figure 85–11 A constant-rate spring compresses at the same rate regardless of the amount of weight that is applied.

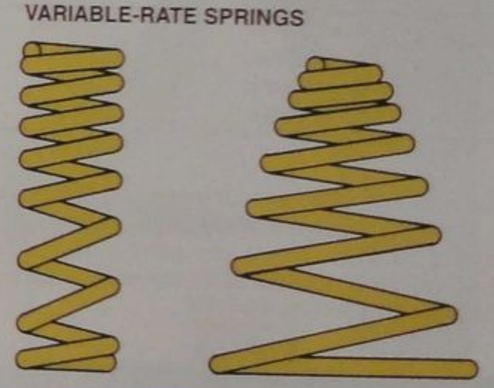


Figure 85–12 Variable-rate springs come in a variety of shapes and compress more slowly as weight is applied.

A constant-rate spring continues to compress at the same rate throughout its complete range of deflection. For example, if a constant-rate spring compresses 1 inch under a 100-pound load, it will compress 2 inches under a 200-pound load, and so on. See Figure 85–11. Many automotive suspension springs, both coil and leaf, compress at a variable rate. That is, they become stiffer and exert more force the further they compress. For example, a variable-rate spring may compress 1 inch under a 100-pound load, but only compress an additional 1/2 inch under a 200-pound load. Variable-rate springs offer a soft, comfortable ride under normal circumstances but will not bottom out as quickly when adverse road conditions compress them further. See Figure 85–12.

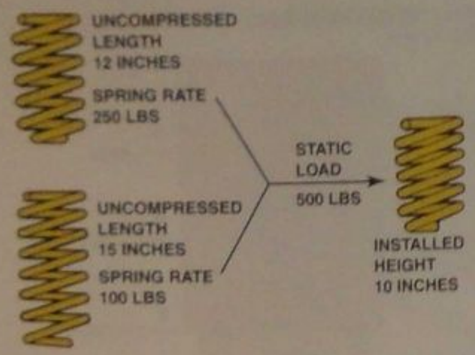


Figure 85–13 Two springs, each with a different spring rate and length, can provide the same ride height even though the higher-rate spring will give a stiffer ride.

Before a spring is installed on a vehicle or any load is placed on it, it is at its uncompressed length, or free length. Once installed, the weight of the corner of the vehicle resting on the spring is called its *static load*. The static load constantly compresses the spring. Therefore, the uncompressed length and the spring rate must be such that the spring has room to compress and keep the vehicle at the correct ride height *after* the static load is applied. See Figure 85–13.

Typical Front-Wheel-Drive Sedan Springs

	Force @ Height	Spring Rate
LF	1,343 lbs. @ 7.6 in.	256 lb/in.
RF	1,300 lbs. @ 7.6 in.	254 lb/in.
LR	638 lbs. @ 9.38 in.	200 lb/in.
RR	610 lbs. @ 9.38 in.	195 lb/in.

Notice that each of the four coil springs used on this vehicle is unique. The higher spring rate on the left is used to help support the weight of the driver. Because each spring is designed for each location on the vehicle, they should be marked if they are removed from a vehicle during service.

FREQUENTLY ASKED QUESTION ???

Does the Spring Rate Change as the Vehicle Gets Older?

No, the spring rate of a spring does not change, but the spring load can change due to fatigue. The spring rate is the amount of force it takes to compress the spring 1 inch. The spring load is the amount of weight that a spring can support at any given compressed height. When a spring fatigues, the spring's load capacity decreases and the vehicle will sag.

Spring Frequency Spring frequency is a value that reflects the speed at which a spring oscillates, or bounces, after it is released from compression or extension. Frequency is typically measured in cycles per second (CPS) or hertz (Hz). See Figure 85–14. There is a direct correlation between spring rate and spring frequency: the higher the spring rate, the higher the spring frequency. This means that stiffer springs bounce at a higher frequency, while softer springs bounce more slowly.

Wheel Rate Depending on the suspension design, springs are installed a certain distance away from the wheel, which determines the ratio of wheel travel to spring travel, or **wheel rate.** See Figure 85–15. For example, if a coil spring is mounted on the midpoint of a control arm, or halfway between the center of the wheel and the arm pivot points, it compresses approximately 1 inch when the wheel travels vertically 2 inches. On a strut-type suspension, the coil spring has a more direct ratio because it is closer to the wheel, so when the wheel of a strut travels vertically 2 inches, the spring also compresses 2 inches. This means that a coil spring used on a strut-type suspension is less than half the spring rate of a coil spring used on suspensions that use control arms.

Coil Spring Mounting Coil springs are usually installed in a **spring pocket** or spring seat. Hard rubber or plastic cushions or **insulators** are usually mounted between the coil spring and the spring seat. See Figure 85–16. The purpose of these insulators is to isolate and dampen road noise and vibration from the vehicle body. The type of end on the coil spring also varies and determines the style of the spring mount.

Spring Coatings All springs are painted or coated with epoxy to help prevent breakage. A scratch, nick, or pit caused by corrosion can cause a **stress riser** that can lead to spring failure. The service technician should be careful not to remove any of the protective coating. Whenever a service operation requires the spring to be compressed, always use a tool that will not scratch or nick the surface of the spring.

TECH TIP ✓ Don't Cut Those Coil Springs!

Chassis service technicians are often asked to lower a vehicle. One method is to remove the coil springs and cut off half or more coils from the spring. While this *will* lower the vehicle, this method is generally *not* recommended for the following reasons:

1. A coil spring could be damaged during the cutting-off procedure, especially if a torch is used to do the cutting.
2. The spring will get stiffer when shortened, often resulting in a very harsh ride.
3. The amount the vehicle is lowered is *less* than the amount cut off from the spring. This is because as the spring is shortened, it becomes stiffer. The stiffer spring will compress less than the original.

Instead of cutting springs to lower a vehicle, several preferable methods are available if the vehicle *must* be lowered:

1. There are replacement springs designed specifically to lower that model vehicle. A change in shock absorbers may be necessary because the shorter springs change the operating height of the stock (original) shock absorbers. Consult spring manufacturers for exact installation instructions and recommendations. See Figure 85–17 on page 1058.
2. There are replacement spindles designed to *raise* the location of the wheel spindle, thereby lowering the body in relation to the ground. Except for ground clearance problems, this is the method recommended by many chassis service technicians. Replacement spindles keep the same springs, shock absorbers, and ride, while lowering the vehicle without serious problems.

LEAF SPRINGS

Leaf springs are constructed of one or more strips of long, narrow spring steel. These metal strips, called leaves, are assembled with plastic or synthetic rubber insulators between the leaves,

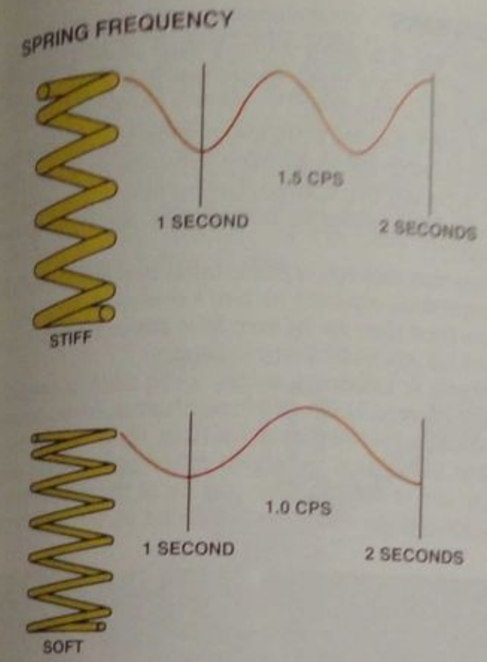


Figure 85–14 Stiffer springs bounce at a higher frequency than softer springs.

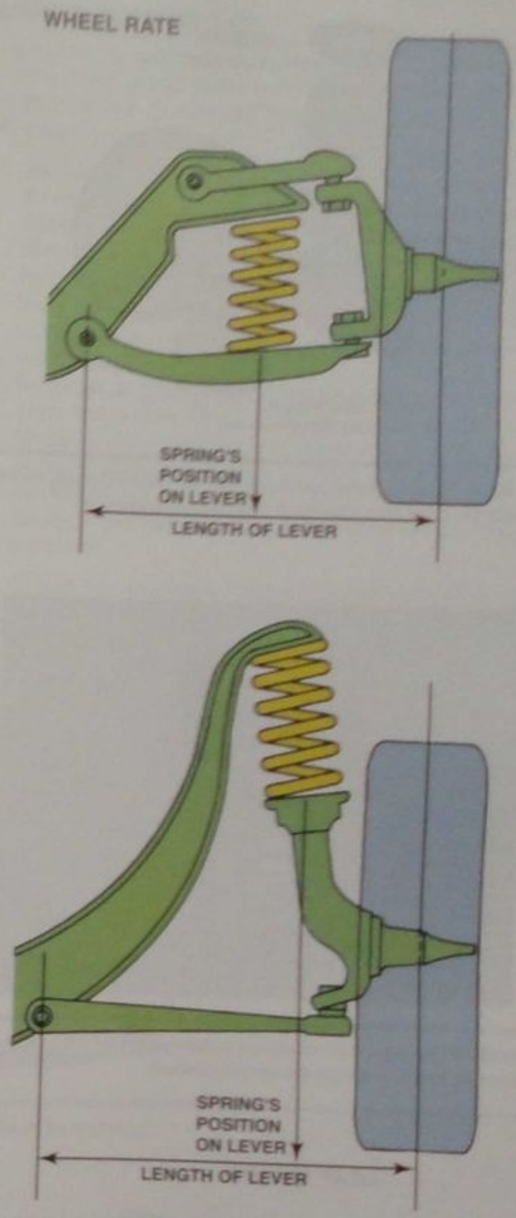


Figure 85–15 The wheel and arm acts as a lever to compress the spring. The spring used on the top picture must be stiffer than the spring used on the strut-type suspension shown on the bottom because the length of the lever arm is shorter.

owing for freedom of movement during spring operation. See ure 85–18.

The ends of the spring are rolled or looped to form eyes. Rub- bushings are installed in the eyes of the spring and act as noise d vibration insulators. See Figure 85–19.

The leaves are held together by a **center bolt,** also called a *entering pin.* See Figure 85–20 on page 1059.

One end of a leaf spring is mounted to a hanger with a bolt and ber bushings directly attached to the frame. The other end of leaf spring is attached to the frame with movable mounting ers called **shackles.** See Figure 85–21 on page 1059.

The shackles are necessary because as the spring hits a bump, slightly curved spring (semi-elliptical) becomes longer and ower, and the shackles allow for this rearward movement.

bound clips, or spring alignment clips, help prevent the leaves m separating whenever the leaf spring is rebounding from hitting ump or rise in the roadway. See Figure 85–22 on page 1059.

Single leaf steel springs, called **mono leaf,** are used on some hicles. A single or mono leaf spring is usually tapered to produce variable spring rate. Leaf springs are used for rear suspensions cars and many light trucks. A variable rate can be accomplished h a leaf spring suspension by providing contacts on the mount to effectively shorten the spring once it is compressed to a ain point. This provides a smoother ride when the load is ht and still provides a stiffer spring when the load is heavy. See re 85–23 on page 1060.

To provide additional load-carrying capacity, especially on ck and vans, auxiliary or *helper* leaves are commonly used. extra leaf becomes effective only when the vehicle is heavily ded. See Figure 85–24 on page 1060.

Leaf springs are used on the front suspension of many four- -drive trucks, especially medium and heavy trucks.

mposite Leaf Springs Since the early 1980s, fiberglass- nforced epoxy plastic **composite leaf springs** have been used on production vehicles. They save weight: An 8-pound spring can replace a conventional 40-pound steel leaf spring. The secret to making a strong plastic leaf spring is the glass fibers running continuously from one end of the spring to the other, and the use of 70% fiberglass with 30% epoxy composite. The single-leaf composite spring helps isolate road noise and vibrations. It is more efficient than a multileaf spring because it eliminates the interleaf friction of the steel leaves and requires less space. See Figure 85–25 on page 1060.

Leaf spring rate increases when the thickness increases, and decreases as the length increases.

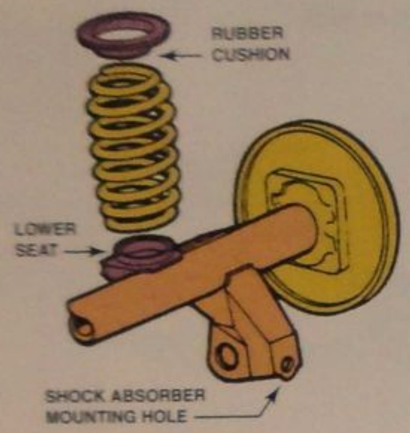


Figure 85–16 The spring cushion helps isolate noise and vibration from being transferred to the passenger compartment. *(Courtesy of Cooper Automotive Company)*



Figure 85–17 This replacement coil spring is coated to prevent rust and corrosion and colored to help identify the spring and/or spring manufacturer.

TORSION BARS

A **torsion bar** is a spring that is a long, *round*, hardened steel bar similar to a coil spring except that it is a *straight* bar. See Figure 85–26 on page 1061.

One end is attached to the lower control arm of a front suspension and the other end to the frame. When the wheels hit a bump, the bar twists and then untwists. General Motors pickup trucks use torsion-bar front suspension longitudinally. See Figure 85–27 on page 1061.

Many manufacturers of pickup trucks currently use torsion-bar-type suspensions, especially on their four-wheel-drive models. Torsion bars allow room for the front drive axle and constant velocity joint and still provide for strong suspension.

As with all automotive springs, spring action is controlled by the shock absorbers. Unlike other types of springs, torsion bars may be adjustable for correct ride height. See Figure 85–28 on page 1061.

Most torsion bars are labeled *left* or *right*, usually stamped into the end of the bars. The purpose of this designation is to make sure that the correct bar is installed on the original side of the vehicle. Torsion bars are manufactured without any built-in direction or preload. However, after being in a vehicle, the bar takes a set; reversing the side the torsion bar is used on causes the bar to be twisted in the opposite direction. Even though the bars are usually interchangeable, proper ride height can be accomplished even if the bars were installed on the side opposite from the original. But because the bar is being "worked" in the opposite direction, it can weaken and break. If a torsion bar breaks, the entire suspension collapses; this can cause severe vehicle damage, as well as a serious accident.



Figure 85–18 A typical leaf spring used on the rear of a pickup truck showing the plastic insulator between the leaves, which allows the spring to move without creating wear or noise.

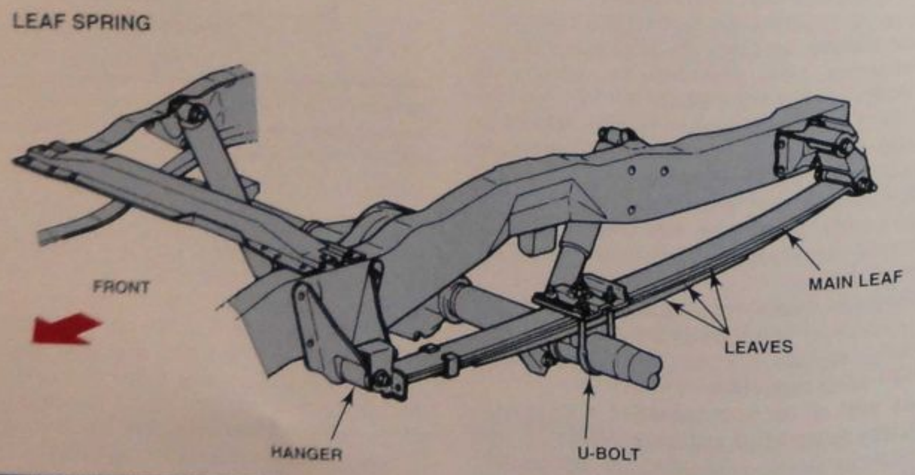


Figure 85–19 A typical leaf spring installation. The longest leaf, called the *main leaf*, attaches to the frame through a shackle and a hanger.

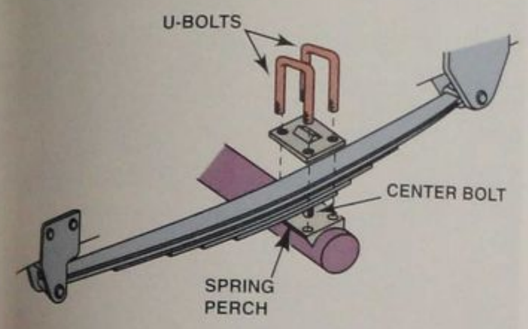


Figure 85–20 All multileaf springs use a center bolt to not only hold the leaves together but also help retain the leaf spring in the center of the spring perch.

SUSPENSION PRINCIPLES

Suspensions use various links, arms, and joints to allow the wheels to move freely up and down; front suspensions also have to allow the front wheels to turn. All suspensions must provide for the following supports:

1. **Transverse (or side-to-side) wheel support.** As the wheels of the vehicle move up and down, the suspension must accommodate this movement and still keep the wheel from moving away from the vehicle or inward toward the center of the vehicle. See Figure 85–29 on page 1061. The control arm pivots on the vehicle frame. The wheels attach to a spindle that attaches to the ball joint at the end of the control arm. Transverse links are also called **lateral links.**
2. **Longitudinal (front-to-back) wheel support.** As the wheels of the vehicle move up and down, the suspension must allow for this movement and still keep the wheels from moving backward whenever a bump is hit. Note in Figure 85–29 how the separation of the pivot points, where the control arm meets the frame, provides support to prevent front-to-back wheel movement.

At least two suspension links or arms are required in order to provide for freedom of movement up or down, and to *prevent* any in-out or forward-back movement. Some suspension designs use an additional member to control forward-back movement. See Figure 85–30 on page 1062.

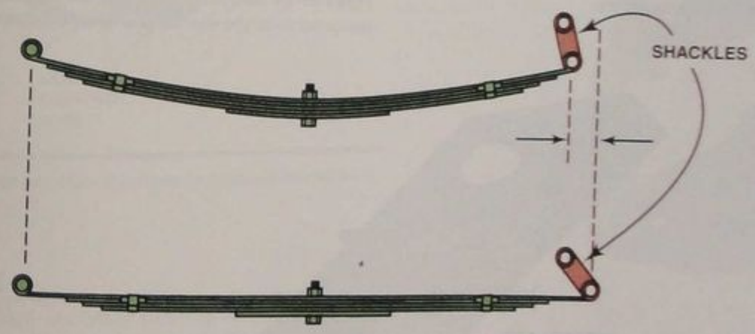


Figure 85–21 When a leaf spring is compressed, the spring flattens and becomes longer. The shackles allow for this lengthening.

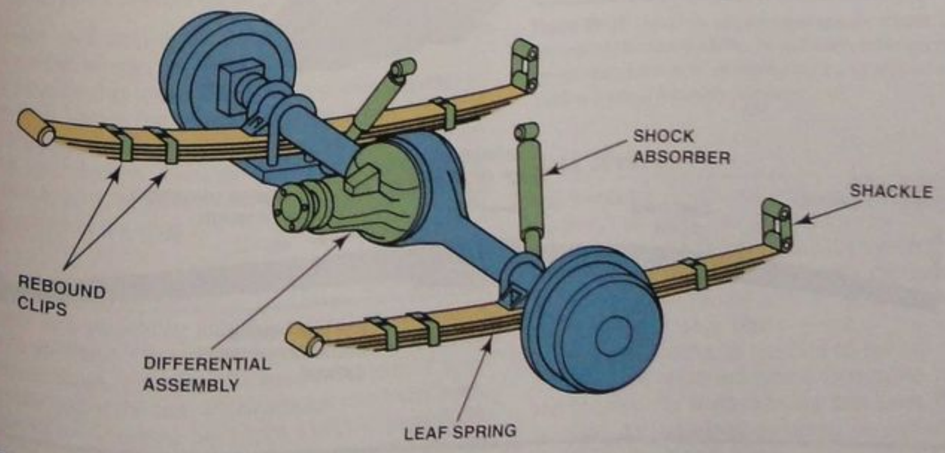


Figure 85–22 Typical rear leaf-spring suspension of a rear-wheel-drive vehicle.

The design of the suspension and the location of the suspension mounting points on the frame or body are critical to proper vehicle handling. Two very important design factors are called **anti-squat** and **anti-dive.**

1. **Anti-squat.** Anti-squat refers to the reaction of the body of a vehicle during acceleration. It is normal in most designs for the vehicle to squat down at the rear while accelerating. Most drivers feel comfortable feeling this reaction, even on front-wheel-drive vehicles. Anti-squat refers to the degree to which this normal force is neutralized. If 100% anti-squat were designed into the suspension system, the vehicle would remain level while accelerating.

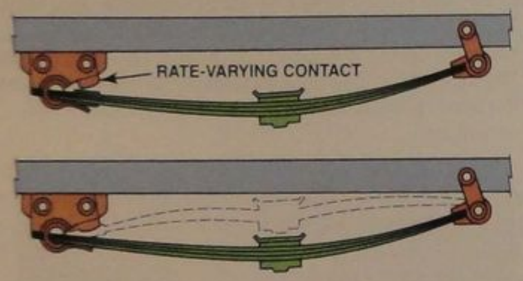


Figure 85–23 As the vehicle is loaded, the leaf spring contacts a section of the frame. This shortens the effective length of the spring, which makes it stiffer.

2. **Anti-dive.** Anti-dive refers to the force that causes the front of the vehicle to drop down while braking. Some front-nose dive feels normal to most drivers. If 100% anti-dive were designed into a vehicle, it would remain perfectly level while braking.

The service technician cannot, and should not, attempt to change anti-squat or anti-dive characteristics built into the design of the vehicle. However, if the customer notices more squat or dive than normal, then the technician should carefully inspect all suspension components, especially those mounting points to the frame or body.

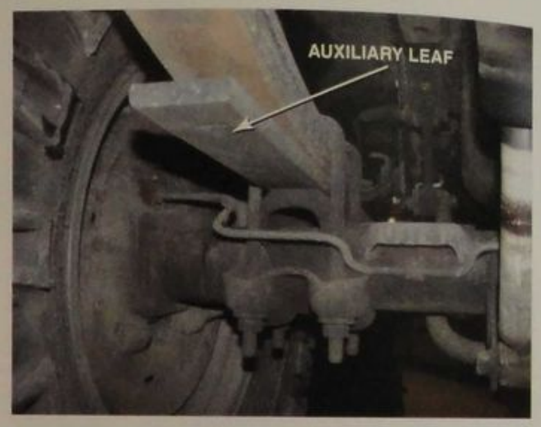


Figure 85–24 Many pickup trucks, vans, and sport utility vehicles (SUVs) use auxiliary leaf springs that contact the other leaves when the load is increased.

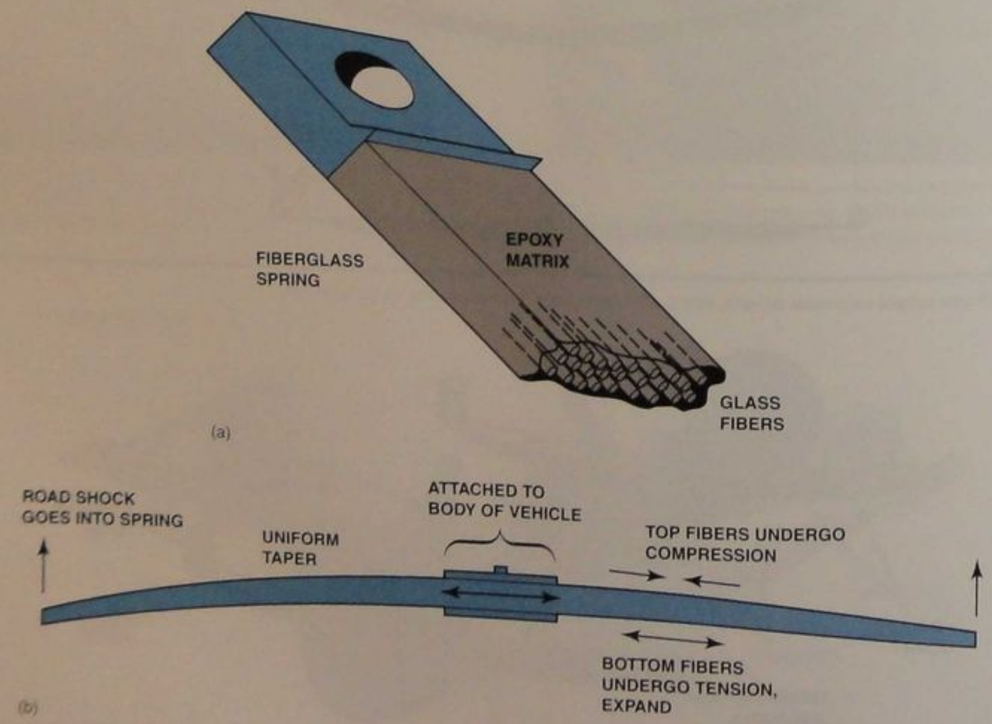


Figure 85–25 (a) A fiberglass spring is composed of long fibers locked together in an epoxy (resin) matrix. (b) When the spring compresses, the bottom of the spring expands and the top compresses.

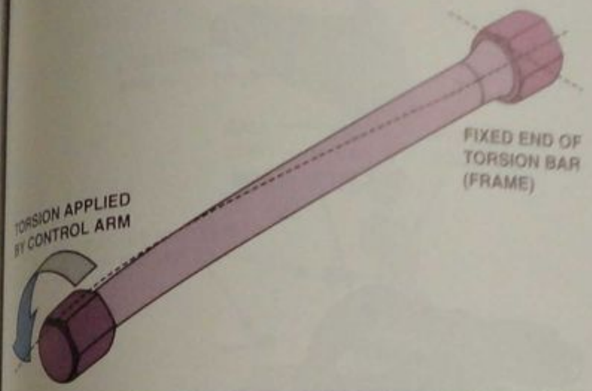


Figure 85–26 A torsion bar resists twisting and is used as a spring on some cars and many four-wheel-drive pickup trucks and sport utility vehicles. The larger the diameter, or the shorter the torsion bar, the stiffer the bar.

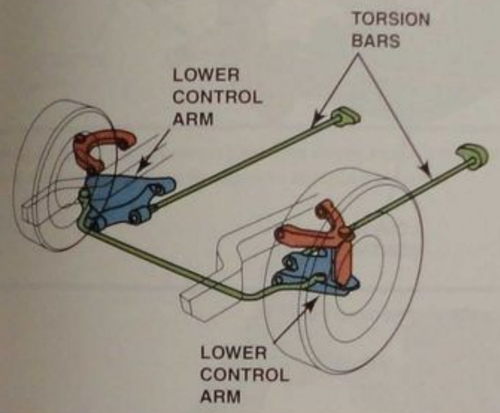


Figure 85–27 Longitudinal torsion bars attach at the lower control arm at the front and at the frame at the rear of the bar.

STEERING KNUCKLES

A **steering knuckle** is hard to classify either as part of the suspension or as part of the wheel. A knuckle serves two purposes:

- To join the suspension to the wheel
- To provide pivot points between the suspension and wheel

Knuckles are used with independent suspensions and at the wheels that steer the vehicle. See Figure 85–31.

The only knuckle that uses a **kingpin** is a steering knuckle on an I-beam or twin I-beam front suspension. See Figure 85–32. A kingpin steering knuckle keeps the wheel rigid in relation to the I-beam during up-and-down wheel movement, but rotates around the steering axis to turn the wheels left and right. The steering axis is the vertical center of the kingpin.

CONTROL ARMS

A **control arm** is a suspension link that connects a knuckle or wheel flange to the frame. One end of a control arm attaches to the knuckle or wheel flange, generally with either a ball joint or bushing. The opposite end of the arm, which attaches to a frame member, usually pivots on a bushing. See Figure 85–33 on page 1063. The end attached to the frame must pivot to allow the axle or knuckle to travel vertically.

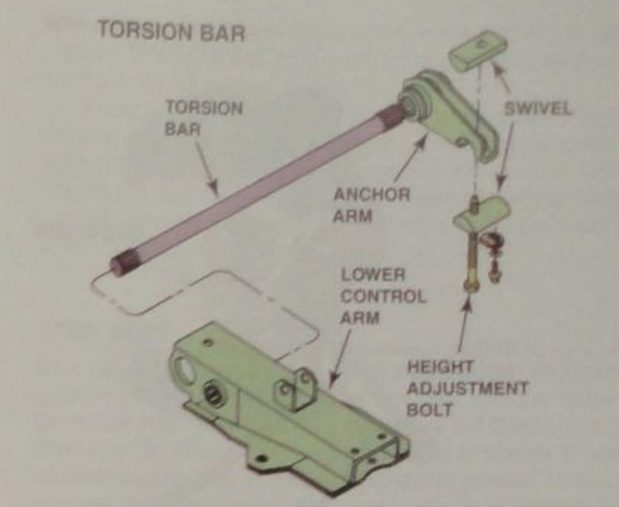


Figure 85–28 One end of the torsion bar attaches to the lower control arm and the other to an anchor arm that is adjustable.

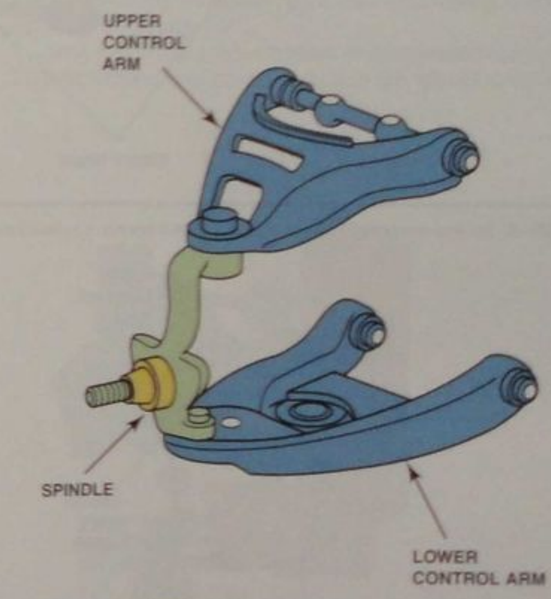


Figure 85–29 The spindle supports the wheels and attaches to the control arm with ball-and-socket joints called ball joints. The control arm attaches to the frame of the vehicle through rubber bushings to help isolate noise and vibration between the road and the body. (Courtesy of Cooper Automotive Company)

BALL JOINTS

Ball joints are actually ball-and-socket joints, similar to the joints in a person's shoulder. Ball joints allow the front wheels to move up and down, as well as side to side (for steering).

A vehicle can be equipped with coil springs, mounted either above the upper control arm *or* on the lower control arm. See Figure 85–34 on page 1063.

If the coil spring is attached to the top of the upper control arm, then the upper ball joint is carrying the weight of the vehicle and is called the **load-carrying ball joint.** The lower ball joint is called the **non-load-carrying,** or *follower,* **ball joint.** See Figure 85–35 on page 1064.

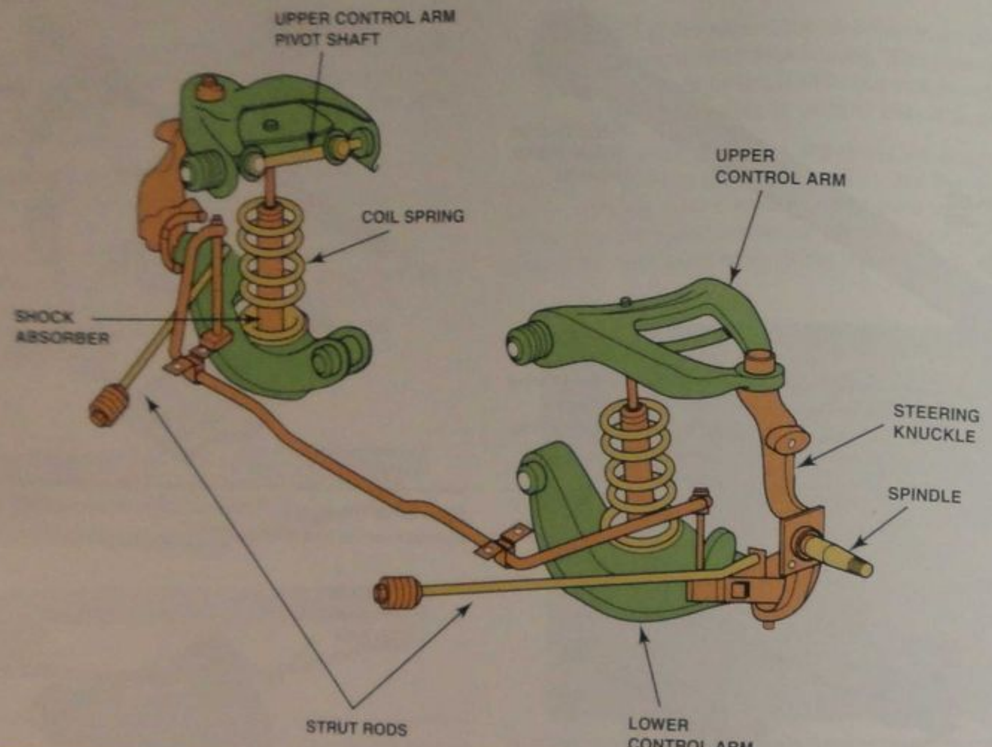


Figure 85–30 The strut rods provide longitudinal support to the suspension to prevent forward or rearward movement of the control arms.

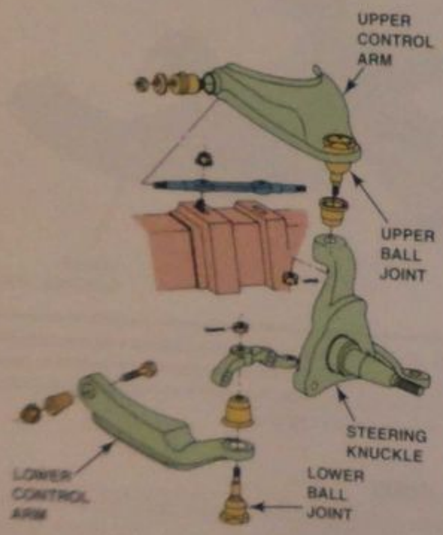


Figure 85–31 The steering knuckle used on a short/long-arm front suspension.

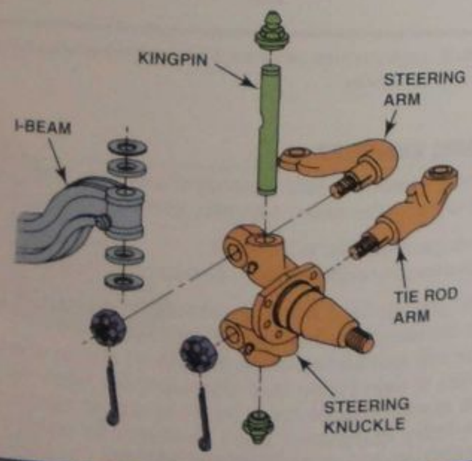


Figure 85–32 A kingpin is a steel shaft or pin that joins the steering knuckle to the suspension and allows the steering knuckle to pivot.

If the coil spring is attached to the lower control arm, then the lower ball joint is the load-carrying ball joint and the upper joint is the follower ball joint. See Figure 85–36 on page 1064.

If a torsion-bar-type spring is used, the lower ball joint is a load-carrying joint because the torsion bar is attached to the lower control arm on most vehicles that use torsion bars.

Ball Joint Design There are two basic designs of ball joints: compression loaded and tension loaded. If the control arm rests on the steering knuckle, the ball joint is *compressed* into the control arm by the weight of the vehicle. If the knuckle rests on the control arm, the weight of the vehicle tends to pull the ball joint back into the control arm by *tension*. The type used is determined

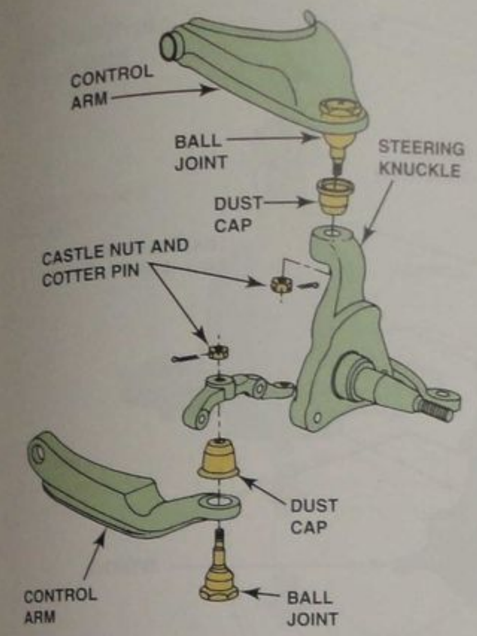


Figure 85–33 Control arms are used to connect the steering knuckle to the frame or body of the vehicle and provide the structural support for the suspension system.

by the chassis design engineer, and the service technician cannot change the type of ball joint used for a particular application. See Figure 85–37 on page 1065.

A specific amount of stud-turning resistance is built into each ball joint to stabilize steering. A ball joint that does not support the weight of the vehicle and acts as a suspension pivot is often called a follower ball joint or a friction ball joint. The load-carrying (weight-carrying) ball joint is subjected to the greatest amount of wear and is the most frequently replaced.

STRUT RODS

Some vehicles are equipped with round steel rods that are attached between the lower control arm at one end and the frame of the vehicle with rubber bushings, called strut rod bushings, at the other end. The purpose of these **strut rods** is to provide forward/backward support to the control arms. Strut rods are used on vehicles equipped with MacPherson struts and many short/long-arm-type suspensions. The bushings are very important in maintaining proper wheel alignment while providing the necessary up-and-down movement of the control arms during suspension travel. Strut rods prevent lower control arm movement back and forth during braking. See Figure 85–38 on page 1065.

Strut rods are also called tension or compression rods or simply TC rods. Tension rods attach in *front* of the wheels to the body or

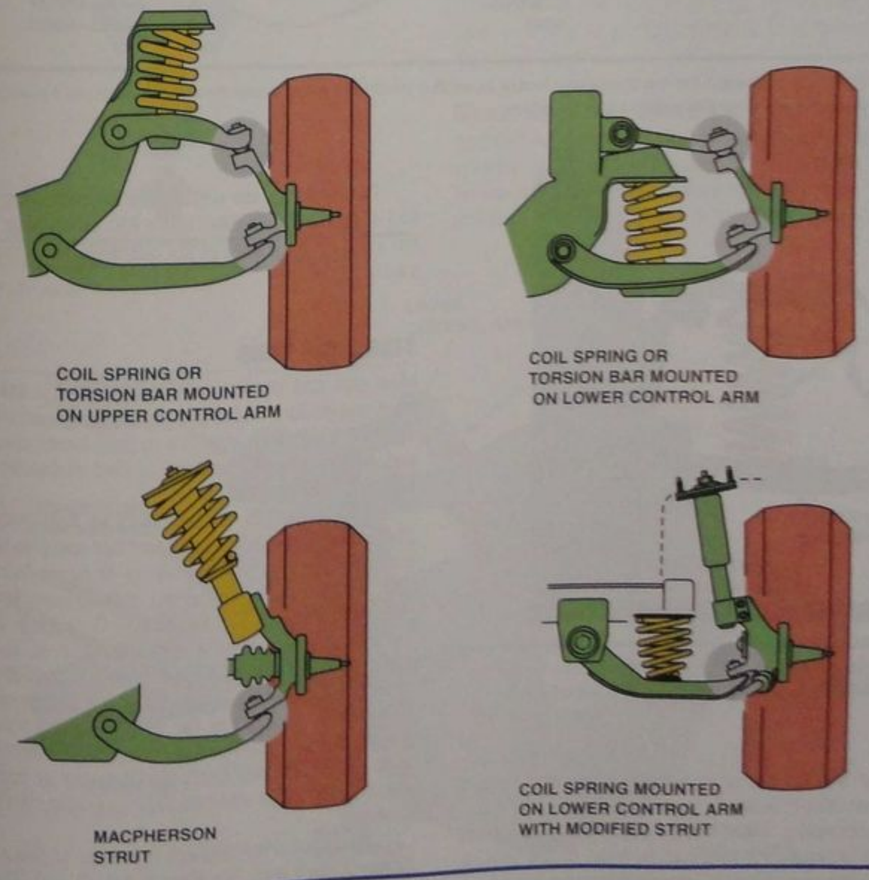


Figure 85–34 Ball joints provide the freedom of movement necessary for steering and suspension movements.

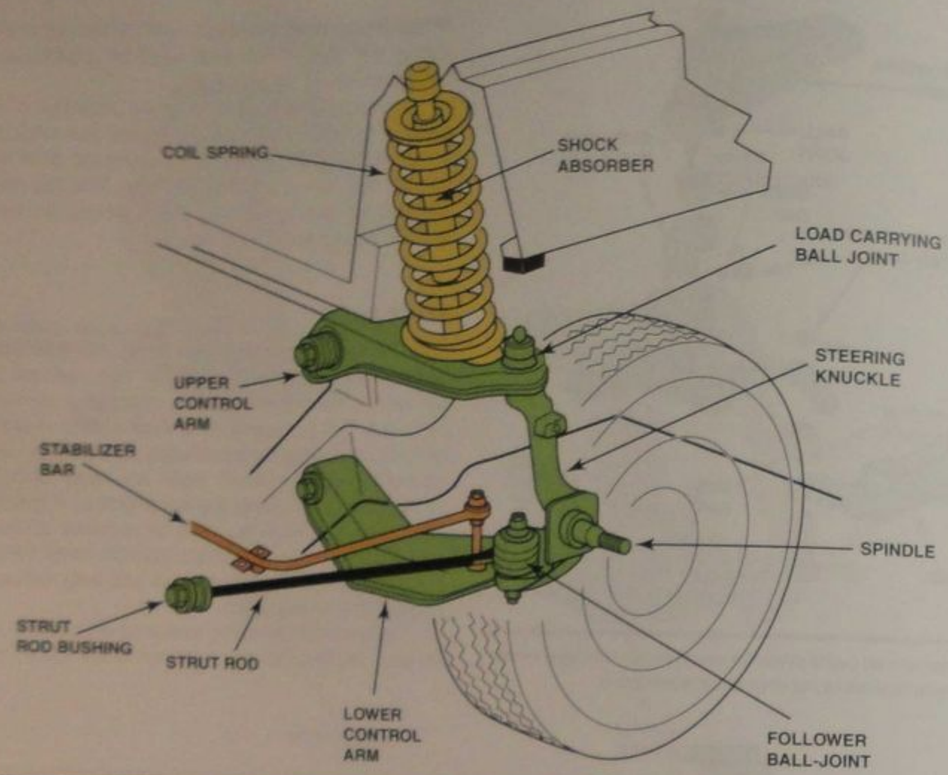


Figure 85–35 The upper ball joint is load carrying in this type of suspension because the weight of the vehicle is applied through the spring, upper control arm, and ball joint to the wheel. The lower control arm is a lateral link, and the lower ball joint is called a follower ball joint.

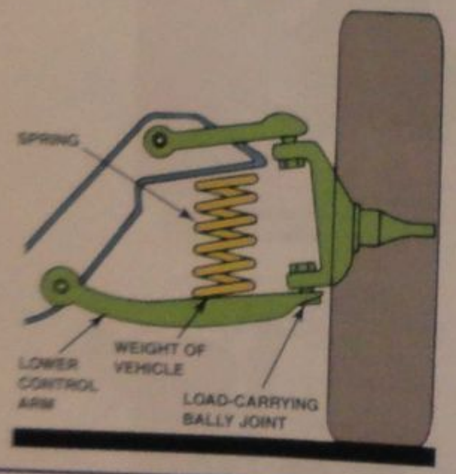


Figure 85–36 The lower ball joint is load carrying in this type of suspension because the weight of the vehicle is applied through the spring, lower control arm, and ball joint to the wheel.

frame where the rod is being pulled in tension. Compression rods attach to the body or frame behind the wheels where the rod is being pulled or compressed. Some vehicle manufacturers call the strut rod a drag rod because it is attached in front of the wheels, and therefore acts on the lower control arms as if to drag the wheels behind their attachment points.

The bushings are replaceable by removing a nut on the frame end of the strut rod. See Figure 85–39 on page 1066. If a strut rod has a nut on *both* sides of the bushings, then the strut rod is used to adjust *caster.*

STABILIZER BARS

Most cars and trucks are equipped with a **stabilizer bar** on the front suspension, which is a round, hardened steel bar (usually SAE 4560 or 4340 steel) attached to both lower control arms with bolts and rubber bushing washers called stabilizer bar bushings. See Figure 85–40 on page 1066.

A stabilizer bar is also called an anti-sway bar (sway bar) or anti-roll bar (roll bar). A stabilizer bar operates by *twisting* the bar if one side of the vehicle moves up or down in relation to the other side, such as during cornering, hitting bumps, or driving over uneven road surfaces. See Figure 85–41 on page 1066.

The purpose of the stabilizer bar is to prevent excessive body roll while cornering and to add to stability while driving over rough road surfaces. The stabilizer bar is also used as a longitudinal (front/back) support to the lower control arm on many vehicles equipped with MacPherson struts. The effective force of a stabilizer bar is increased with the diameter of the bar. Therefore, optional suspensions often include larger-diameter stabilizer bars and bushings.

Stabilizer links connect the ends of the stabilizer bar to the lower control arm. See Figures 85–42 and 85–43 on page 1067. Careful inspection of the stabilizer bar links is important. Links are commonly found to be defective (cracked rubber washers or

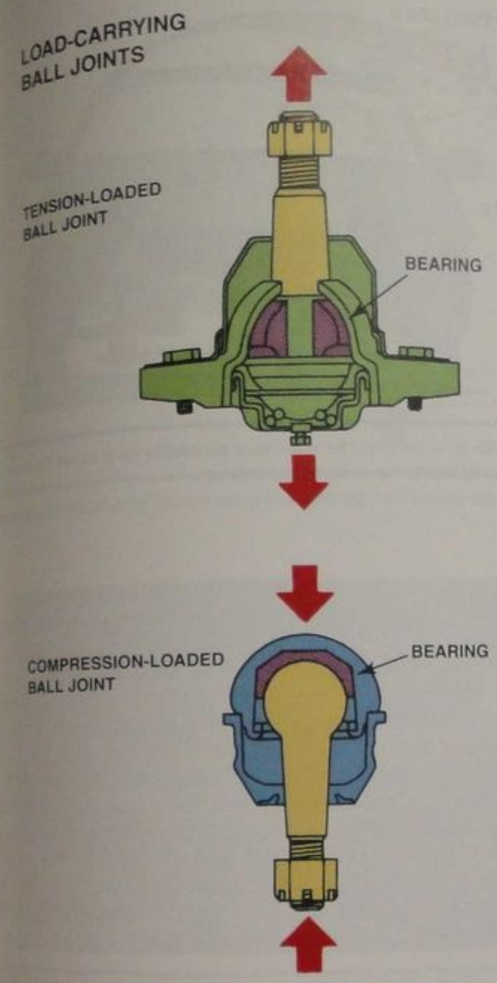


Figure 85–37 All ball joints, whether tension or compression loaded, have a bearing surface between the ball stud and socket.

broken spacer bolts) because of the great amount of force that is transmitted through the links and the bushings. Defective links and/or bushings can cause unsafe vehicle handling and noise.

SHOCK ABSORBERS

Shock absorbers are used on all conventional suspension systems to dampen and control the motion of the vehicle's springs. Without shock absorbers (dampers), the vehicle would continue to bounce after hitting bumps. See Figure 85–44 on page 1067.

The major purpose of any shock or strut is to control ride and handling. Standard shock absorbers *do not* support the weight of a vehicle. *The springs support the weight of the vehicle; the shock absorbers control the actions and reactions of the springs.* Shock absorbers are also called dampers.

Most shock absorbers are *direct acting* because they are connected directly between the vehicle frame or body and the axles. See Figure 85–45 on page 1068.

As a wheel rolls over a bump, the wheel moves toward the body and compresses the spring(s) of the vehicle. As the spring compresses, it stores energy. The spring then releases this stored energy, causing the body of the vehicle to rise (rebound). See Figure 85–46 on page 1068.

After the energy in the spring is used up, the body starts downward, causing the spring to compress. Without shock absorbers, the energy released from the spring would be very rapid and violent. The shock absorber helps dampen the rapid up-and-down movement of the vehicle springs by converting energy of movement into heat by forcing hydraulic fluid through small holes inside the shock absorber.

Shock Absorber Operation The hydraulic shock absorber operates on the principle of fluid being forced through a small opening (orifice). See Figures 85–47 and 85–48 on page 1069. Besides small openings, pressure relief valves are built into most shock absorbers to control vehicle ride under all operating conditions. The

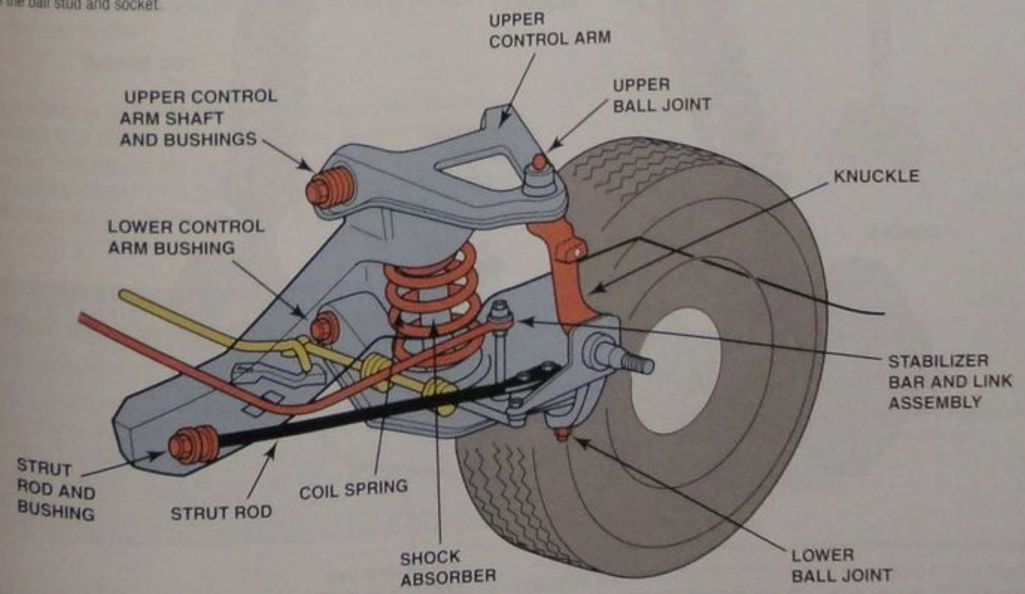


Figure 85–38 A strut rod is the longitudinal support to prevent front-to-back wheel movement.

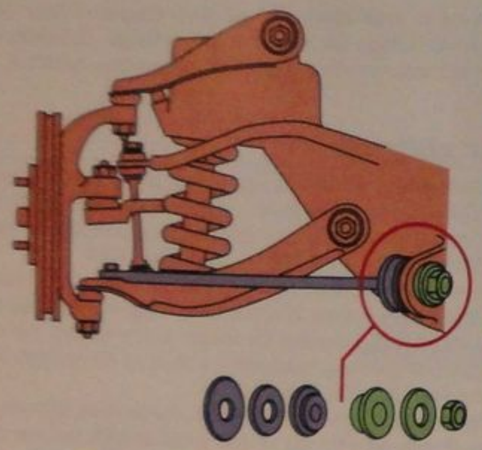


Figure 85–39 Strut rod bushings insulate the steel bar from the vehicle frame or body.

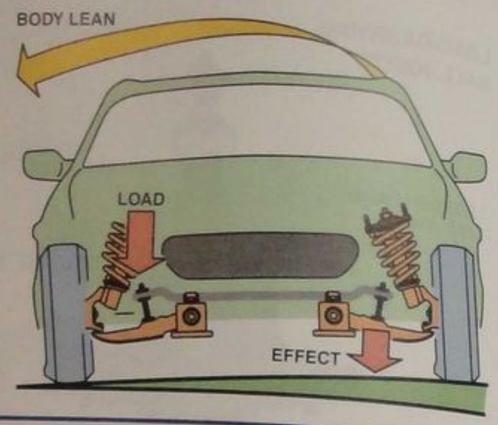


Figure 85–41 As the body of the vehicle leans, the stabilizer bar is twisted. The force exerted by the stabilizer bar counteracts the body lean.

greater the pressure drop of the fluid inside the shock and the greater the amount of fluid moved through the orifice, the greater the amount of dampening; therefore, larger shock absorbers can usually provide better dampening than smaller units.

Gas-Charged Shocks Most shock absorbers on new vehicles are gas charged. Pressurizing the oil inside the shock absorber helps smooth the ride over rough roads. This pressure helps prevent air pockets from forming in the shock absorber oil as it passes through the small passages in the shock. After the oil is forced through small passages, the pressure drops and the oil expands. As the oil expands, bubbles are created. The oil becomes foamy. This air-filled oil does not effectively provide dampening. The result of all of this aeration (air being mixed with the oil) is lack of dampening and a harsh ride.

The use of higher-pressure radial tires and lighter vehicle weight has created the need for more effective shock absorbers. To meet this need, shock absorber design engineers use a pressurized gas that does not react chemically with the oil in the shock. If a substance does not react with any other substances, it is called *inert*. The gas most often used is nitrogen, which is about 78% of our atmosphere. Typical gas-charged shocks are pressurized with 130 to 150 PSI (900 to 1,030 kPa) to aid in both handling and ride control. Some shocks use higher pressures, but the higher the pressure, the greater the possibility of leaks and the harsher the ride.

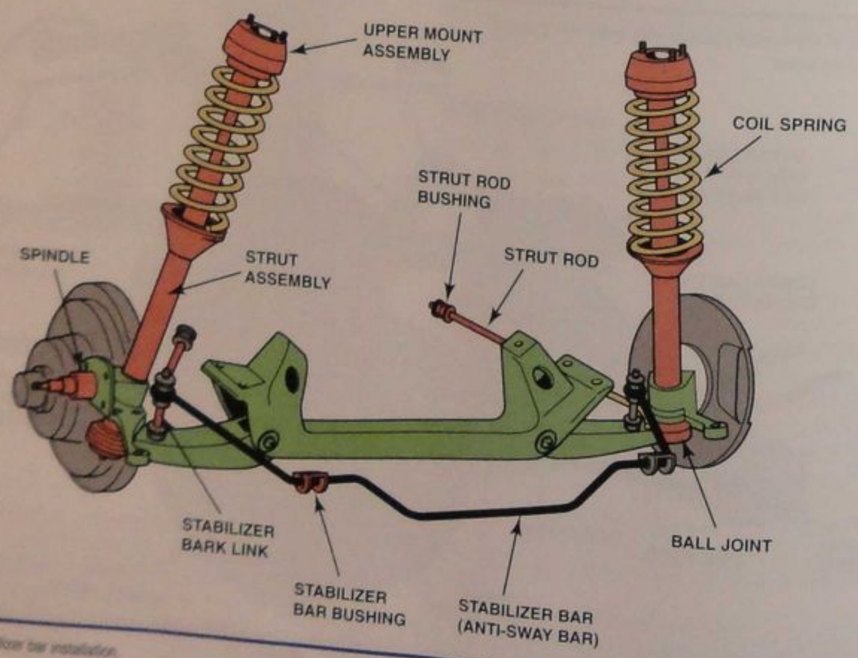


Figure 85–40 Typical stabilizer bar installation.

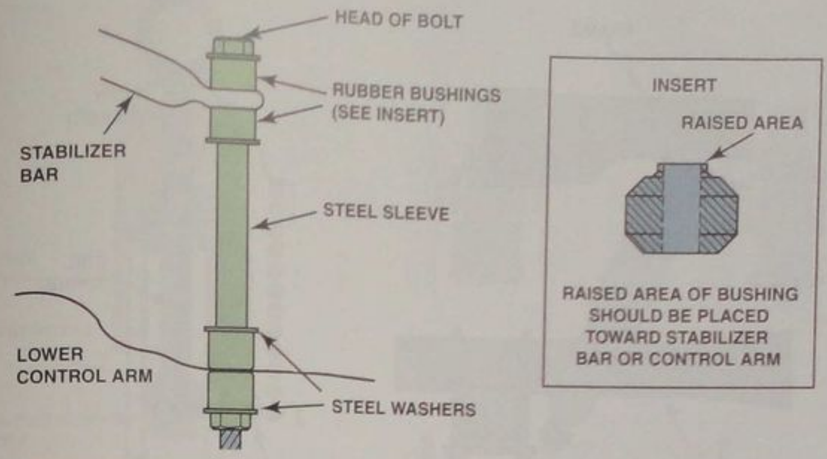


Figure 85–42 Stabilizer bar links are sold as a kit consisting of the long bolt with steel sleeve and rubber bushings. Steel washers are used on both sides of the rubber bushings as shown.

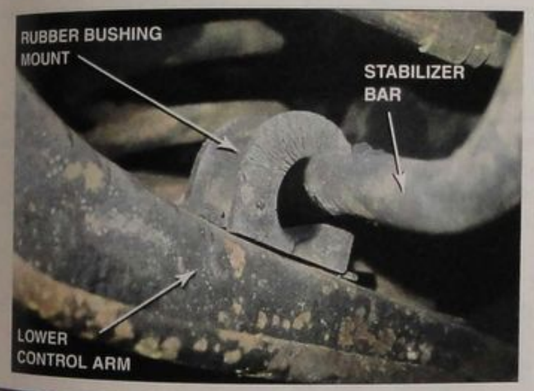


Figure 85–43 Notice how the stabilizer bar pulls down on the mounting bushing when the vehicle is hoisted off the ground, allowing the front suspension to drop down. These bushings are a common source of noise, especially when cold. Lubricating the bushings with paste silicone grease often cures the noise.

Some gas-charged shock absorbers use a single tube that contains two pistons that separate the high-pressure gas from the working fluid. Single-tube shocks are also called monotube or DeCarbon after the French inventor of the principle and manufacturer of suspension components. See Figure 85–49 on page 1070.

FREQUENTLY ASKED QUESTION ???

What Are Remote Reservoir Shocks?

Remote reservoir shock absorbers are units designed for heavy-duty use that use a separate container for the working fluid. See Figure 85–50 on page 1070.

The purpose of the remote fluid reservoir is to keep the temperature of the fluid stable, which helps the shock absorber provide consistent dampening under all conditions.

Air Shocks/Struts Air-inflatable shock absorbers or struts are used in the rear of vehicles to provide proper vehicle ride height while carrying heavy loads. Many air shock/strut units are

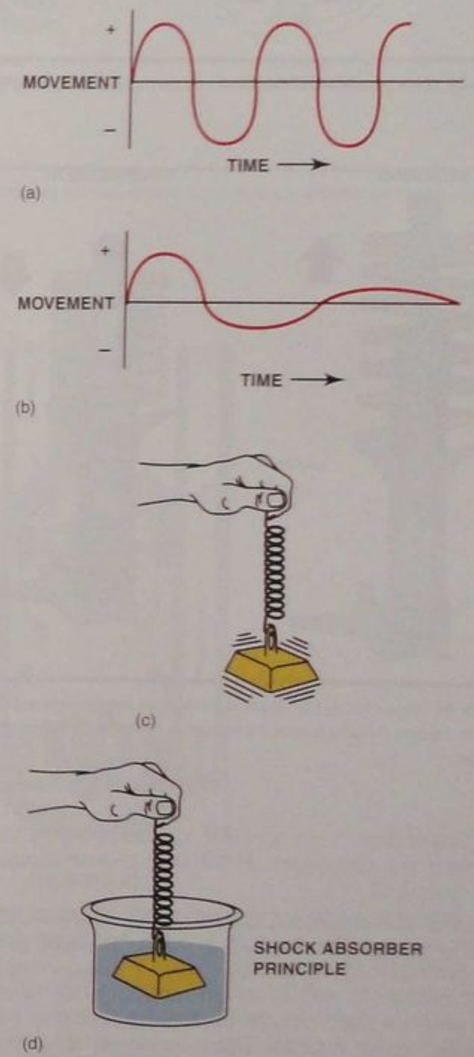


Figure 85–44 (a) Movement of the vehicle is supported by springs without a dampening device. (b) Spring action is dampened with a shock absorber. (c) The function of any shock absorber is to dampen the movement or action of a spring, similar to using a liquid to control the movement of a weight on a spring.

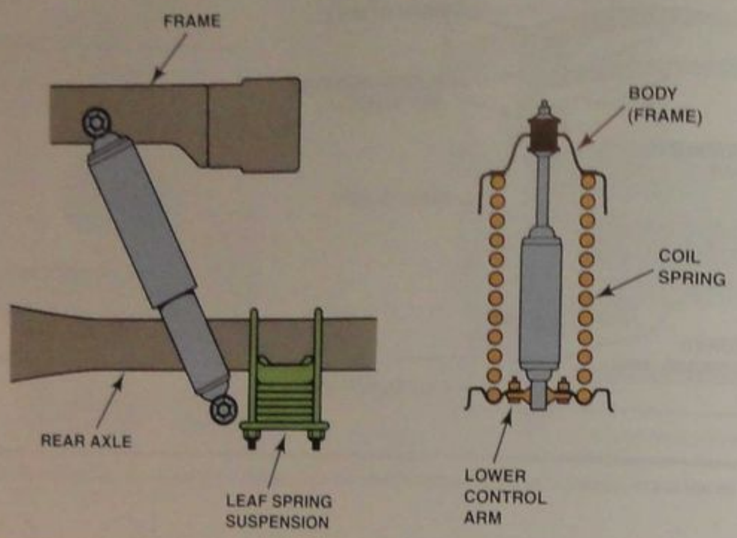


Figure 85–45 Shock absorbers work best when mounted as close to the spring as possible. Shock absorbers that are mounted straight up and down offer the most dampening.

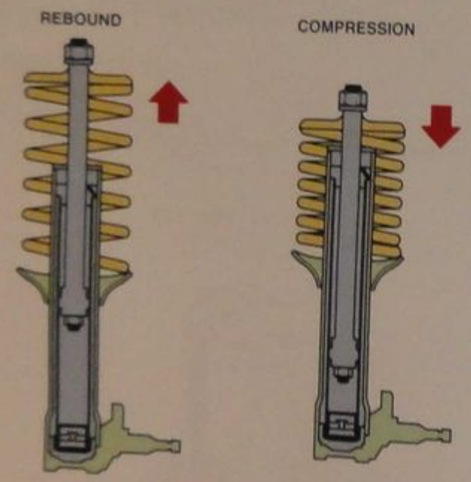


Figure 85–46 When a vehicle hits a bump in the road, the suspension moves upward. This is called compression. Rebound is when the spring (coil, torsion bar, or leaf) returns to its original position.

original equipment. They are often combined with a built-in air compressor and ride height sensor(s) to provide automatic ride height control.

Air-inflatable shocks are standard shock absorbers with an air chamber with a rubber bag built into the dust cover (top) of the shock. See Figure 85–51 on page 1070.

Air pressure is used to inflate the bag, which raises the installed height of the shock. As the shock increases in height, the rear of the vehicle is raised. Typical maximum air pressure in air shocks ranges from 90 to 150 PSI (620 to 1,030 kPa). As the air pressure increases in the air-inflatable reservoir of the shock, the stiffness of the suspension increases. This additional stiffness is due to the shock taking weight from the spring, and therefore the air in the air shock becomes an air spring. Now, with two springs to support the vehicle, the spring rate increases and a harsher ride often results. *It is important that the load capacity of the vehicle not be exceeded or serious damage can occur to the vehicle's springs, axles, bearings, and shock support mounts.*

Air Springs Some electronically controlled suspension systems use air springs. A basic **air spring** consists of a rubber air chamber, generally closed at the bottom by a piston fitted into a control arm, or by a strut shock absorber. See Figure 85–52 on page 1071.

Electronically controlled suspension systems that use air springs as the only springs are available on some Hummer, and many Ford, Mercury and Lincoln vehicles.

Some air springs are in effect auxiliary springs inside a coil-spring strut. In these designs, the coil spring supports the weight of the vehicle, while the air spring raises or lowers the body to adjust ride height according to load. See Figure 85–53 on page 1071.

Coil-Over Shocks A coil-over shock absorber uses the force of an external coil spring to boost the performance of the basic shock absorber. See Figure 85–54 on page 1071. The spring usually extends from the upper shock mount to a seat on the lower portion of the cylinder. The spring rate added to the hydraulic resistance makes the shock stiffer.

STRUTS

A **strut** is a sturdy shock absorber that is also a structural component of the suspension. A strut is a suspension link as well as a shock absorber. The casing of a strut must be strong and rigid to function as a suspension link. The shock absorber assembles inside the casing of a strut, and may be either a removable cartridge or an integral part of the strut.

MacPherson Struts The MacPherson strut, which is named after Earle S. MacPherson, who developed the suspension design in the late 1940s and patented it in 1953, is the most commonly used type. A MacPherson strut includes the suspension spring—a coil

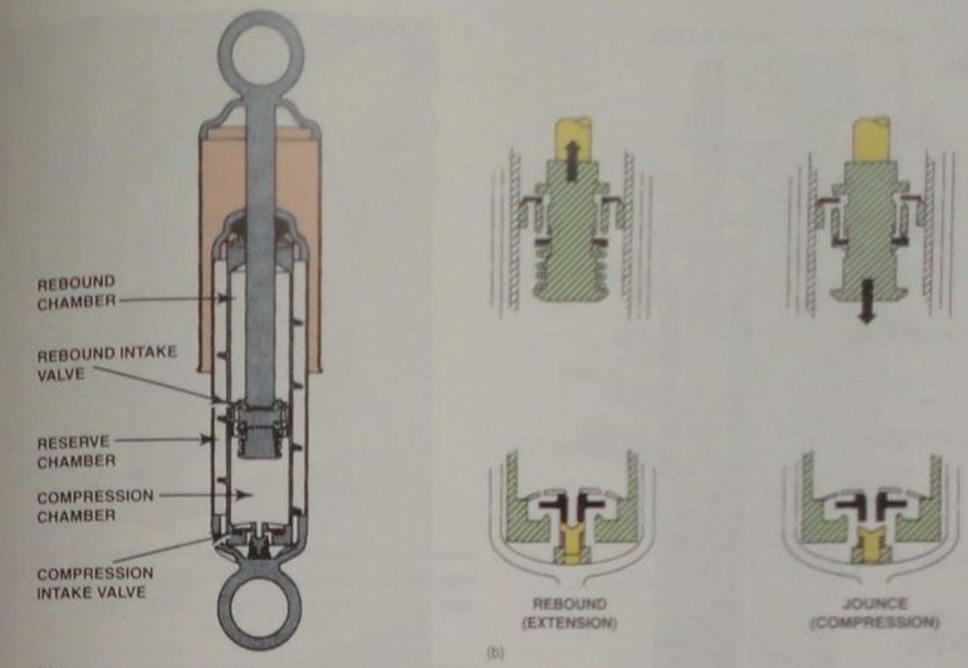


Figure 85–47 (a) A cutaway drawing of a typical double-tube shock absorber. (b) Notice the position of the intake and compression valve during rebound (extension) and compression.

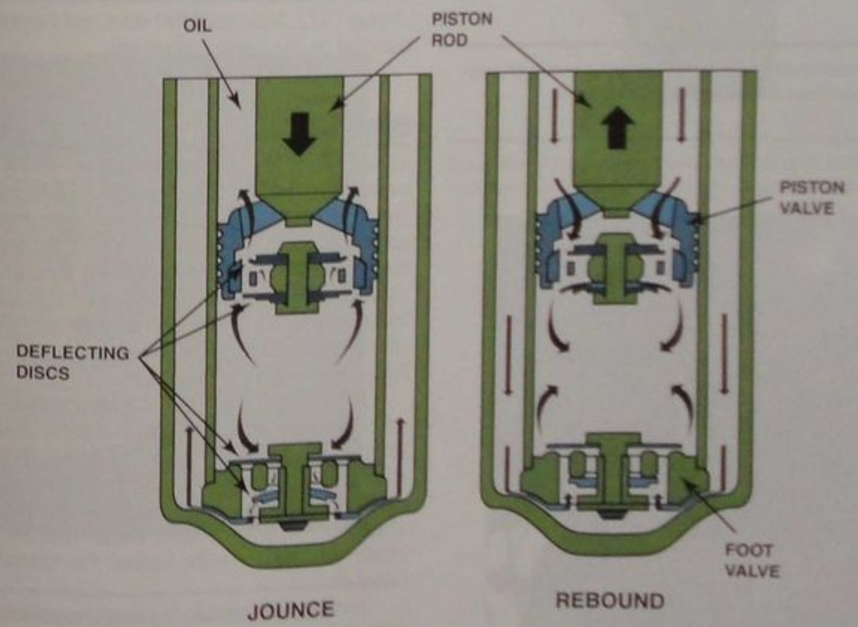


Figure 85–48 Oil flow through a deflected disc-type piston valve. The deflecting disc can react rapidly to suspension movement. For example, if a large bump is hit at high speed, the disc can deflect completely and allow the suspension to reach its maximum jounce distance while maintaining a controlled rate of movement.

spring that surrounds the strut casing—so that it transfers the weight of the body to the wheel. See Figure 85–55 on page 1072.

A MacPherson strut typically incorporates an upper and a lower spring seat, a shock absorber mount and dust cap, a dust cover for the piston rod, and a bump stop. The upper mount secures the upper spring seat to the strut tower. A rubber bushing at the top of the strut absorbs vibrations. A bearing on a front wheel strut allows it to rotate on the vertical steering axis without rubbing

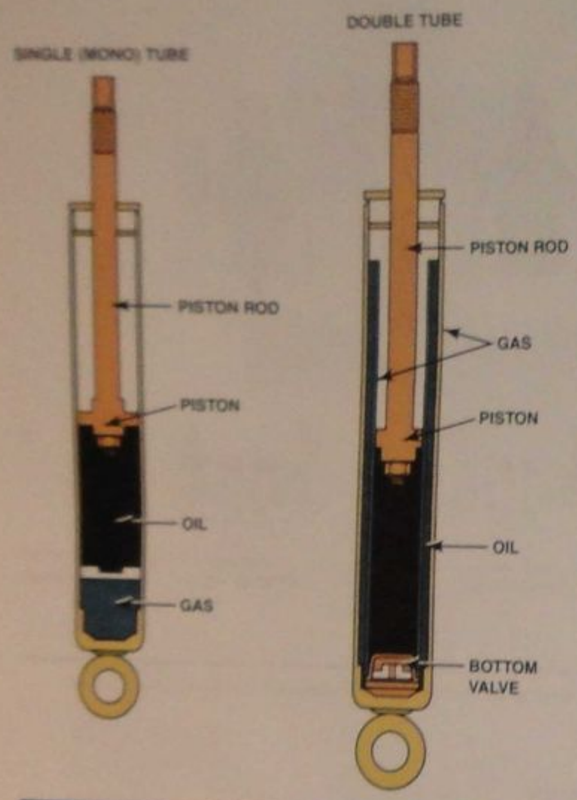


Figure 85–49 Gas-charged shock absorbers are manufactured with a double-tube design similar to conventional shock absorbers and with a single or monotube design.



Figure 85–50 The shock absorber is on the right and the fluid reservoir for the shock is on the left.

AIR SHOCK ABSORBER

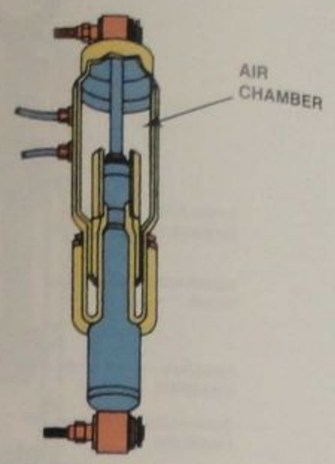


Figure 85–51 A rubber tube forms an inflatable air chamber at the top of an air shock. The higher the air pressure in the chamber, the stiffer the shock.

against the strut tower when the steering knuckle turns. The lower spring seat is attached to the strut casing.

Modified Struts Unlike a MacPherson unit, a modified strut does not include a spring as part of the assembly and is used in the front on some vehicles and on the rear of others. See Figure 85–56 on page 1072. Most modified strut rear suspensions use coil springs mounted on the lower control arm.

BUMP STOPS

All suspension systems have a limit of travel. If the vehicle hits a large bump in the road, the wheels are forced upward toward the vehicle with tremendous force. This force is absorbed by the springs of the suspension system. If the bump is large enough, the suspension is compressed to its mechanical limit. Instead of allowing the metal components of the suspension to hit the frame or body of the vehicle, a rubber or foam bumper is used to absorb and isolate the suspension from the frame or body. See Figure 85–57 on page 1072.

These bumpers are called **bump stops,** suspension bumpers, strike-out bumpers, or jounce bumpers. *Jounce* means jolt, or to cause to bounce or move up and down. Bumpers are made from rubber or microcellular urethane. Urethane is a high-strength material with good resistance to wear and tear as well as good chemical resistance to most fluids. Forming urethane foam with small, regular air cells makes the material ideal for jounce bumpers.

Damaged suspension-limiting bump stops can be caused by the following:

1. Sagging springs that result in lower-than-normal ride (trim) height
2. Worn or defective shock absorbers

Most suspensions also use a rubber or foam stop to limit the downward travel of the suspension during rebound. The rebound stop also prevents metal-to-metal contact of the suspension on the frame when the vehicle is on a body-contact-type hoist and the wheels are allowed to hang or droop down. Some stops are built into the shock absorber or strut.

(a)



(b)

Figure 85–52 (a) The front suspension of a Lincoln with an air-spring suspension. (b) Always check in the trunk for the cutoff switch for a vehicle equipped with an air suspension before hoisting or towing the vehicle.

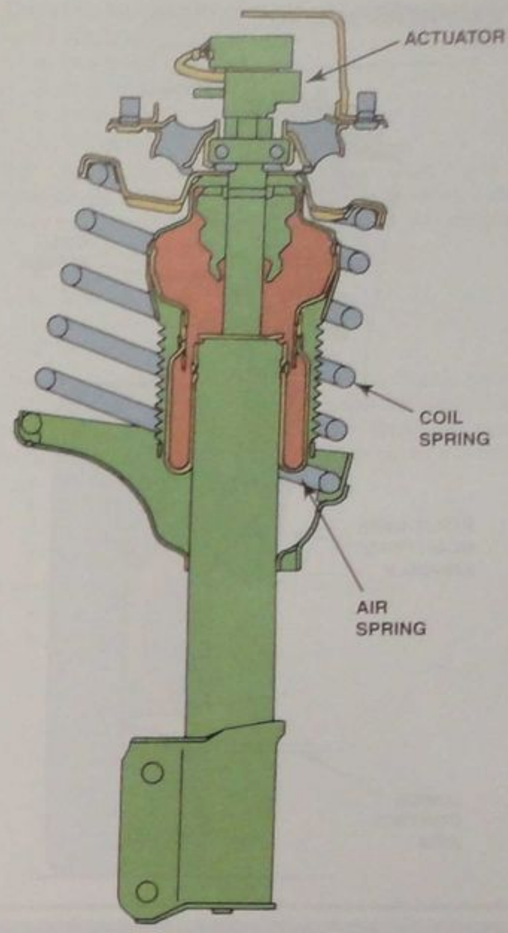


Figure 85–53 Some air springs are auxiliary units to the coil spring and are used to control ride height while the coil spring is the weight-bearing unit.

COIL-OVER SHOCK ABSORBER



Figure 85–54 A coil-over shock is a standard hydraulic shock absorber with a coil spring wrapped around it to increase stiffness and/or take some of the carrying weight off of the springs.

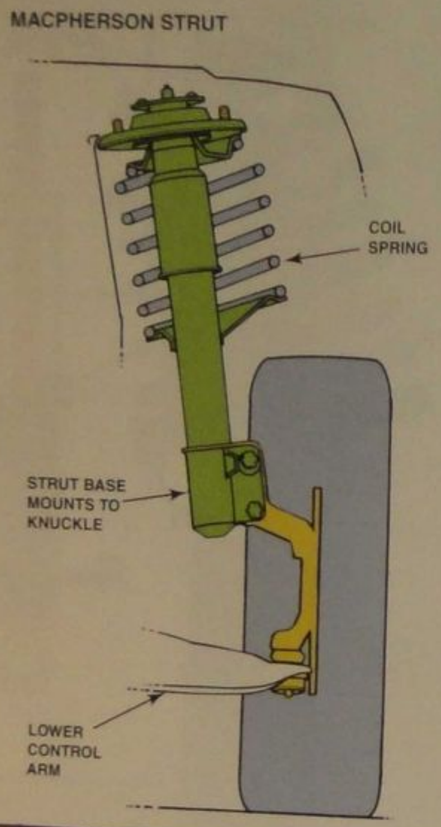


Figure 85–55 A strut is a structural part of the suspension and includes the spring and shock absorber in one assembly.

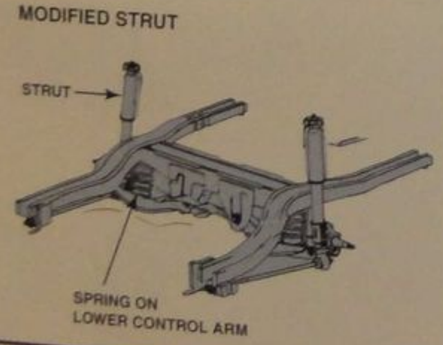


Figure 85–56 A modified strut used on the rear suspension. It is part of the structural part of the assembly.

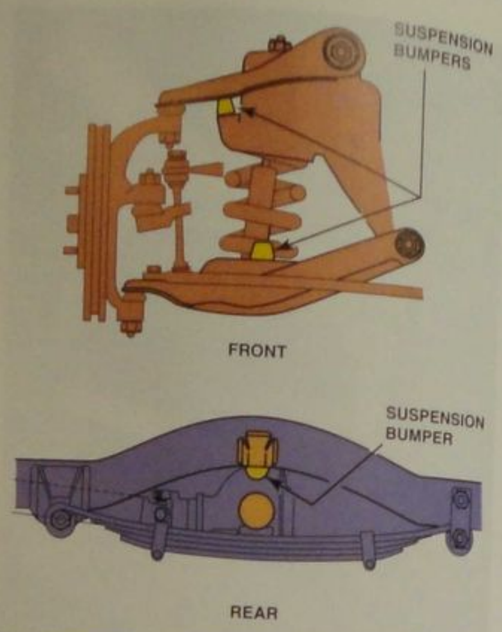


Figure 85–57 Suspension bumpers are used on all suspension systems to prevent metal-to-metal contact between the suspension and the frame or body of the vehicle when the suspension "bottoms out" over large bumps or dips in the road.

SUMMARY

1. The lighter the wheel/tire combination, the lower the unsprung weight and the better the ride and handling of the vehicle.
2. All springs—including the coil, leaf, and torsion bar types—share Hooke's Law, which states that the force exerted by the spring is directly proportional to the amount the spring is deflected.
3. All springs are similar to torsion bars. As the torsion bar becomes longer or smaller in diameter, it becomes easier to twist. If a coil spring is cut, the remaining spring is shorter, yet stiffer.
4. Ball joints attach to control arms and allow the front wheels to move up and down, as well as turn.
5. Suspension designs include a straight or solid-axle, two-control-arm-type called an SLA or a MacPherson strut.
6. All shock absorbers dampen the motion of the suspension to control ride and handling.

REVIEW QUESTIONS

1. List the types of suspensions and name their component parts.
2. Explain Hooke's Law.
3. Describe the purpose and function of a stabilizer bar.
4. Explain the difference between a load-carrying and a friction ball joint.

CHAPTER QUIZ

1. The spring rate of a spring is measured in units of _____.
   a. lb per inch
   b. ft-lb
   c. PSI
   d. in.-lb
2. Two technicians are discussing torsion bars. Technician A says that many torsion bars are adjustable to allow for ride height adjustment. Technician B says that torsion bars are usually marked left and right and should not be switched side to side. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. A vehicle makes a loud noise while traveling over bumpy sections of road. Technician A says that worn or deteriorated control arm bushings could be the cause. Technician B says that worn or deteriorated strut rod bushings could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Two technicians are discussing MacPherson struts. Technician A says that in most applications the entire strut assembly rotates when the front wheels are turned. Technician B says a typical MacPherson strut suspension system uses only one control arm and one ball joint per side. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that regular replacement shock absorbers will raise the rear of a vehicle that is sagging down. Technician B says that replacement springs will be required to restore the proper ride height. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. A vehicle used for 24-hour-a-day security was found to have damaged suspension-limiting rubber jounce bumpers. Technician A says sagging springs could be the cause. Technician B says defective or worn shock absorbers could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. The part of many rear suspension systems that controls side-to-side movement is called the _____.
   a. Rear control arm
   b. Track rod or panhard rod
   c. Stabilizer bar
   d. Trailing arm
8. Two technicians are discussing air shocks. Technician A says that air is forced through small holes to dampen the ride. Technician B says that air shocks are conventional hydraulic shock absorbers with an airbag to control vehicle ride height. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. The owner of a pickup truck wants to cut the coil springs to lower the vehicle. Technician A says that the ride will be harsher than normal if the springs are cut. Technician B says that the springs could be damaged, especially if a cutting torch is used to cut the springs. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A MacPherson strut is a structural part of the vehicle.
    a. True
    b. False

CHAPTER 86 Front Suspension and Service

OBJECTIVES: After studying Chapter 86, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "B" (Suspension System Diagnosis and Repair). • Explain how to perform a road test, a dry park test, a visual inspection, and a bounce test. • Discuss the procedures for testing load-carrying and follower-type ball joints. • Describe ball joint replacement procedures. • List the steps required to replace control arm and stabilizer bar bushings. • Explain routine service procedures of the suspension system.

KEY TERMS: A-arm • cow catcher • cuppy tire wear • dry park test • durometer • indicator ball joints • kingpin • pinch bolt • radius rod • SLA • steering knuckle • strut suspension • twin I-beam

FRONT SUSPENSION TYPES

Solid Axles Early cars and trucks used a solid (or *straight*) front axle to support the front wheels. See Figure 86–1.

A solid-axle front suspension is very strong and is still being used in the manufacture of medium and heavy trucks. The main disadvantage of solid-axle design is its lack of ride quality. When one wheel hits a bump or dip in the road, the forces are transferred through the axle to the opposite wheel. Solid axles are currently used in the rear of most vehicles.

Kingpins At the end of many solid I-beam or tube axles are **kingpins** that allow the front wheels to rotate for steering. Kingpins are hardened steel pins that attach the steering knuckle to the front axle, allowing the front wheels to move for steering. Kingpins usually have grease fittings to lubricate the kingpin bushings. Failure to keep these bushings lubricated with chassis grease can cause wear and freeplay or can cause the pins to become galled (seized or frozen), resulting in hard steering and/or loud noise while turning. See Figure 86–2.



Figure 86–1 Most early vehicles used single straight axles.

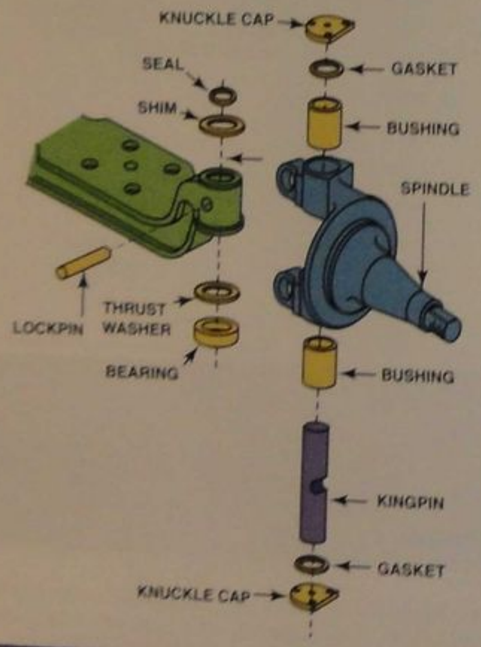


Figure 86–2 Typical kingpin used with a solid axle.

Twin I-Beams A **twin I-beam** front suspension was used for over 30 years on Ford pickup trucks and vans, beginning in the mid-1940s. Strong steel twin beams that cross provide independent front suspension operation with the strength of a solid front axle. Early versions of the twin I-beam systems used kingpins, while later models used ball joints to support the **steering knuckle** and spindle. Coil springs are usually used on twin I-beam suspensions, even though the original design and patent used leaf springs. See Figure 86–3.

To control longitudinal (front-to-back) support, a **radius rod** is attached to each beam and is anchored to the frame of the truck using rubber bushings. These bushings allow the front axle to move up and down, while still insulating road noise and vibration from the frame and body.

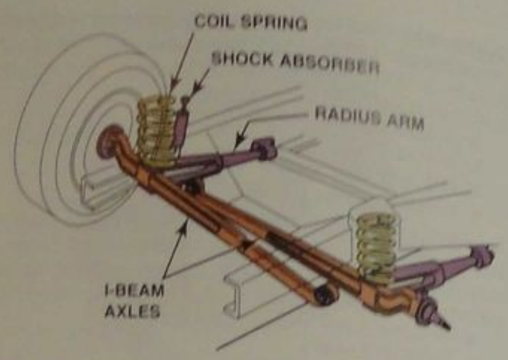


Figure 86–3 Twin I-beam front suspension.

TECH TIP ✔ **Radius Rod Bushing Noise**

When the radius rod bushing on a Ford truck or van deteriorates, the most common complaint from the driver is noise. See Figure 86–4. Besides causing tire wear, worn or defective radius rod bushing deterioration can cause the following:

1. A clicking sound when braking (it sounds as if the brake caliper may be loose).
2. A clunking noise when hitting bumps.

When the bushing deteriorates, the axles can move forward and backward with less control. Noise is the first sign that something is wrong. Without proper axle support, handling and cornering can also be affected.

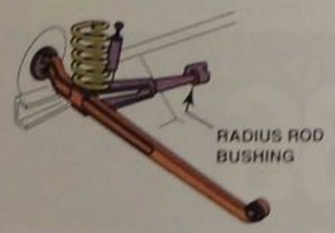


Figure 86–4 The rubber radius rod bushing absorbs road shocks and helps isolate road noise.

SHORT/LONG-ARM SUSPENSIONS

The short/long-arm suspension uses a short upper control arm and a longer lower control arm and usually is referred to as the *SLA type suspension.*

The two main links in a **short/long-arm (SLA)** suspension are the upper control arm and the lower control arm. The upper control arm is shorter than the lower one. See Figure 86–5. This type of suspension system goes by a variety of names, including unequal-arm suspension, double-wishbone suspension, or **A-arm** suspension. Unequal arm refers to the fact that the two arms are of different lengths, while double-wishbone and A-arm derive from the shape of the arms, which are frequently triangular with one mounting point at the knuckle and two at the frame. When an SLA suspension uses a straight, two-point lower control arm, there is almost always a strut rod that braces the lower arm against the frame. The strut rod can attach to the frame at a point either forward or to the rear of the control arm.

SHORT/LONG-ARM (SLA) SUSPENSION

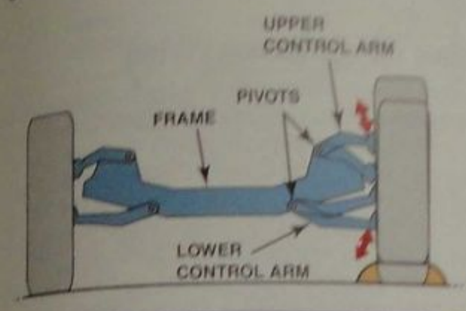


Figure 86–5 The upper control arm is shorter than the lower control arm on a short/long-arm (SLA) suspension.

A strut rod, also called a *reaction rod,* provides support to the side during braking and acceleration forces.

Using a strut rod provides triangulation between the wheel and the frame. *Triangulation* means that the front suspension has a three point brace that resists forces from every direction, while still allowing the wheels to pivot on the steering axis.

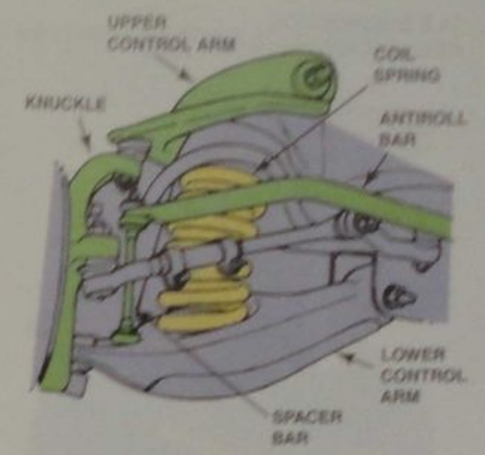
Locating the coil spring on the lower control arm is the most common SLA-type suspension configuration. See Figure 86–6.

The upper control arm is A-shaped, with two mounting points at the frame side member and one at the steering knuckle. The inboard ends of the arm attach to a pivot bar that is rigidly bolted to the frame, and the outboard end connects to the steering knuckle with a ball joint. Bushings between the inner arm mounts and the pivot bar allow the arm to swing vertically. The lower control arm is also A-shaped with two inboard pivot mounts and a ball joint connection at the knuckle. Bolts attach the inboard ends of the lower arm to brackets that extend from the bottom of the frame crossmember. Bushings on the inboard mounts allow the arm to pivot vertically.

The coil springs seat between the lower control arm and a bracket below the frame side member. The shock absorber attaches to the lower control arm and the frame side member.

In a typical coil spring on the upper control arm design, a portion of the unit-body wheel well is reinforced to withstand spring force and act as the upper spring seats. See Figure 86–7. Short/long-arm suspensions use longitudinal torsion bars, especially in trucks.

The forward end of the torsion bar has external splines and mates the splined socket of the torque arm with the control arm through a bolt. Because the torque arm is rigidly bolted to the control arm, motion transfers to the torsion bar whenever the control arm pivots. The torsion bar extends rearward from the control arm and connects to an anchor arm that attaches to a frame crossmember. The torsion bar splines to the anchor arm and the anchor arm is secured to the frame by a bolt and adjusting nut. The adjusting nut varies the spring force of the torsion bar to establish the ride height of the vehicle. See Figure 86–8 on page 1077.



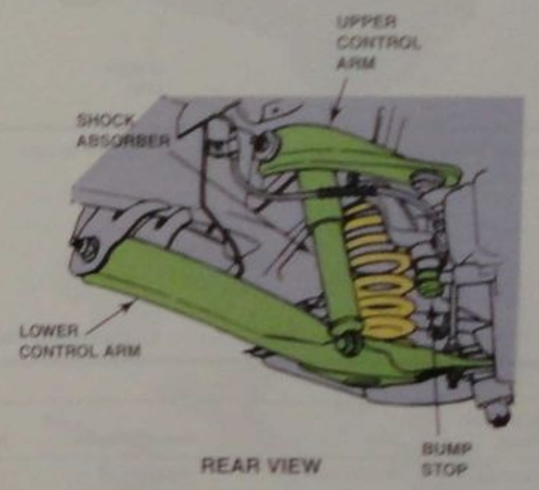


Figure 86–6 A typical SLA front suspension using coil springs.

STRUT SUSPENSION

Strut suspension can be of several types. A MacPherson strut includes the suspension spring that transfers the weight of the body to the wheel. A MacPherson strut is the main, load-carrying suspension spring. See Figure 86–9 on page 1077.

A MacPherson strut typically incorporates an upper and a lower spring seat, a shock absorber mount and dust cap, a dust cover for the piston rod, and a bump stop. The upper mount secures the upper spring seat to the strut tower. A rubber bushing at the top of the strut absorbs vibrations. In most applications, a bearing on a front-wheel strut allows it to rotate on the vertical steering axis without rubbing against the strut tower when the steering knuckle turns. The lower spring seat is attached to the strut casing. The piston rod dust cover is similar to the dust cover on a conventional shock absorber, and a bump stop at the top of the piston rod keeps the strut from bottoming out during suspension jounce.

A modified strut does not include a spring as part of the assembly. See Figure 86–10 on page 1078. A modified strut is used on the rear of some GM vehicles. Except for the lack of a spring and spring seats, the construction and function of a modified strut are basically the same as those of a MacPherson strut. When used on the front suspension, a modified strut also rotates on the steering axis when the wheels turn.

A multilink front suspension uses two control arms as well as a structural strut assembly. This type of suspension is also called

SLA SUSPENSION - COIL SPRING ON UPPER ARM

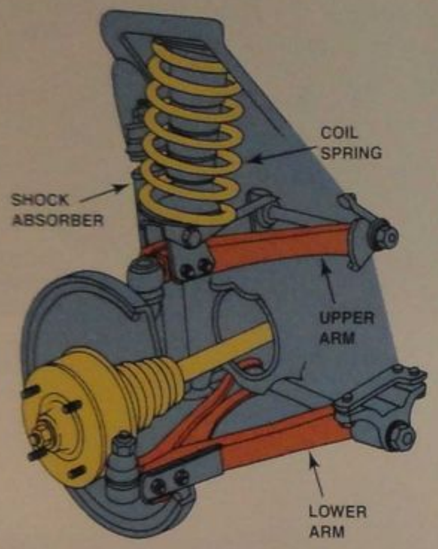


Figure 86–7 An SLA-type suspension with the coil spring placed on top of the upper control arm.

a strut/SLA or long spindle, short/long-arm suspension. See Figure 86–11 on page 1078.

SERVICING THE SUSPENSION SYSTEM

Suspension systems are designed and manufactured to provide years of trouble-free service with a minimum amount of maintenance. In fact, the suspension system is often "invisible" or "transparent" to the driver because the vehicle rides and handles as expected. It is when the driver notices that the vehicle is not riding or handling as it did, or should, that a technician is asked to repair or align the vehicle and fix the problem.

The smart technician should always road test any vehicle before and after servicing (see Tech Tip for details). *The purpose of any diagnosis is to eliminate known good components.* (See the suspension diagnostic chart for a list of components that can cause the problem or customer complaint.)

ROAD TEST DIAGNOSIS

If possible, perform a road test of the vehicle with the owner of the vehicle. It is also helpful to have the owner drive the vehicle. While driving, try to determine when and where the noise or problem occurs, such as the following:

1. In cold or warm weather
2. With cold or warm engine/vehicle
3. While turning, left only, right only

Suspension Problem Symptom Chart

Item or System to Check	Concern/Problem					
	Noise	**Instability/Wander**	**Pull to One Side**	**Excessive Steering Play**	**Hard Steering**	**Shimmy**
Tires/Wheels	Road/tire noise	Low/uneven air pressure	Low/uneven air pressure, mismatched tire sizes	Low/uneven air pressure	Low/uneven air pressure	Wheel out of balance/uneven tire wear/overworn tires
Shock Absorbers (Struts)	Loose/worn mounts/bushings	Loose/worn mounts/bushings, worn/damaged struts/shock absorbers	Loose/worn mounts/bushings		Loose/worn mounts/bushings on strut assemblies	Worn/damaged struts/shock absorbers
Strut Rods (If Equipped)	Loose/worn mounts/bushings	Loose/worn mounts/bushings	Loose/worn mounts/bushings			Loose/worn mounts/bushings
Springs	Brakes damaged	Brakes damaged	Brakes damaged, especially rear			
Control Arms	Steering knuckle contacting control arm stop, worn/damaged mounts/bushings	Worn/damaged mounts/bushings	Worn/damaged mounts/bushings		Worn/damaged mounts/bushings	Worn/damaged mounts/bushings
Steering System	Component wear/damage	Component wear/damage	Component wear/damage	Component wear/damage	Component wear/damage	Component wear/damage
Wheel Alignment		Front and rear, especially caster	Front, camber and caster	Front alignment	Front, especially caster	Front, especially caster
Wheel Bearings	Front-wheel bearings	Loose/worn (front and rear)	Loose/worn (front and rear)	Loose/worn (front and rear)		Loose/worn (front and rear)
Brake System			Stuck caliper/slide			
Other					Ball joint lubrication	Loose/worn friction ball joints

CAUTION: More than one factor may be the cause of a problem. Be sure to inspect all suspension components, and repair all parts that are worn or damaged. Failure to do so may allow the problem to reoccur and cause premature failure of other suspension components.

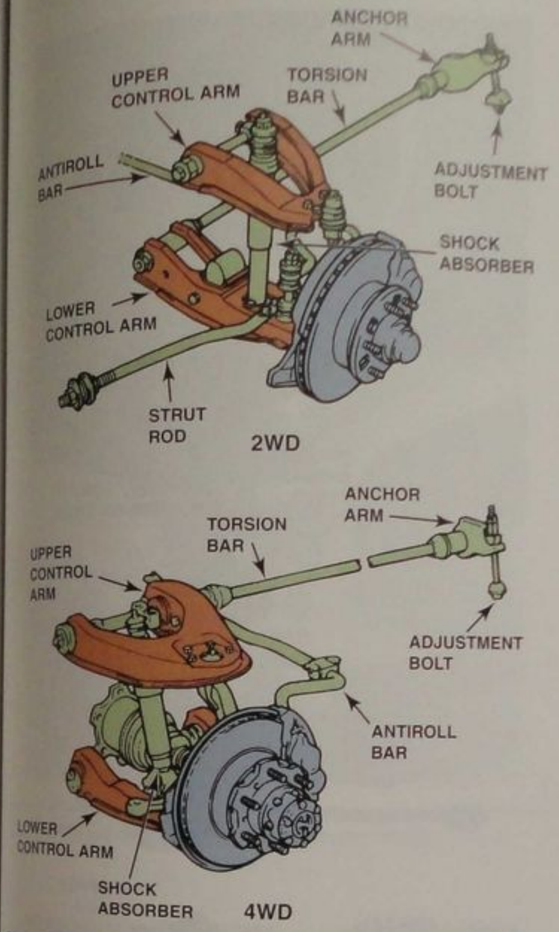


Figure 86–8 A torsion bar SLA suspension can use either the lower or the upper control arm.

A proper road test for any suspension system problem should include the following:

1. **Drive beside parked vehicles.** Any noise generated by the vehicle suspension or tires is reflected off solid objects, such as a row of parked vehicles along a street. For best results, drive with the windows down and drive close to the parked vehicles or a retaining wall on the left side. Repeat the drive for the right side. Defective wheel bearings or power steering pumps usually make noise and can be heard during this test.
2. **Drive into driveways.** Suspension problems often occur when turning at the same time the suspension hits a bump. This action is best repeated by driving slowly into a driveway with a curb. The curb causes the suspension to compress while the wheels are turned (see the Real World Fix titled "The Rock-Hard Problem" for an example). Defective stabilizer bar bushings, control arm bushings, and ball joints will usually make noise during this test procedure.
3. **Drive in reverse while turning.** This technique is usually used to find possible defective outer CV joints used on the drive axle shaft of front-wheel-drive vehicles. This technique also forces the suspension system to work in reverse of normal. Any excessive clearances in the suspension system are reversed and often make noise or cause a vibration during the test. Besides defective CV joints, this test can often detect worn control arm bushings, ball joints, stabilizer bar bushings, or links. This test can also detect defective or worn steering system components such as an idler arm, tie rod end, or center link.
4. **Drive over a bumpy road.** Worn or defective suspension (and steering) components can cause the vehicle to bounce or dart side to side while traveling over bumps and dips in the road. Worn or defective ball joints, control arm bushings, stabilizer bar bushings, stabilizer bar links, or worn shock absorbers can be the cause.

Once the problem has been confirmed, then a further inspection can be performed in the service bay.

MACPHERSON STRUT SUSPENSION

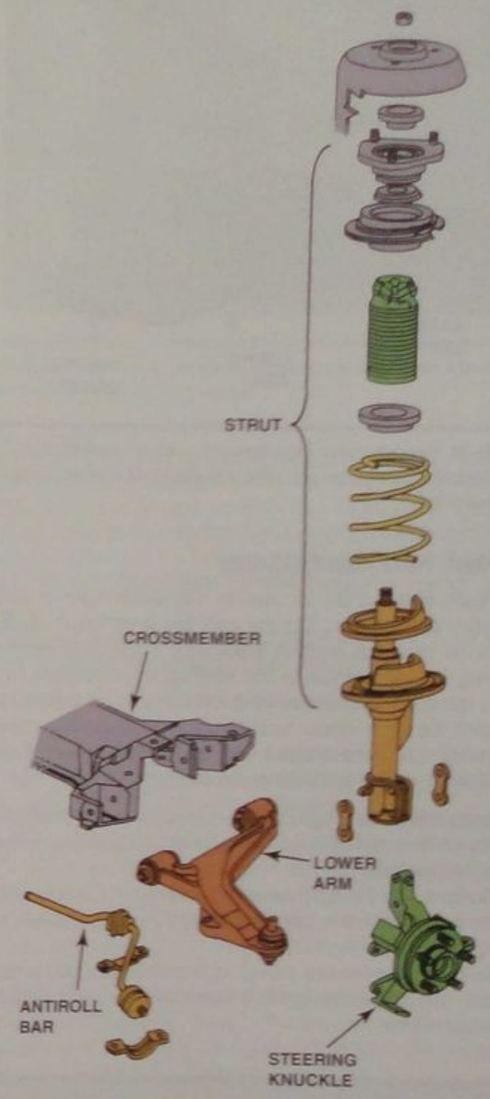


Figure 86–9 A typical MacPherson strut showing all of the components of the assembly.

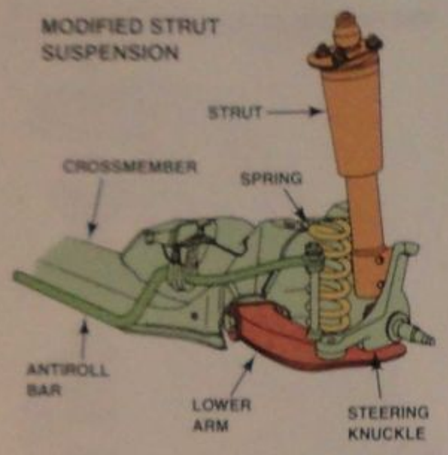


Figure 86–10 The modified strut front suspension is similar to a MacPherson strut suspension except that the coil spring is seated on the lower control arm and is not part of the strut assembly.

DRY PARK TEST (SUSPENSION)

A **dry park test** can also be used to help locate worn or defective suspension components. The dry park test is performed by having an assistant move the steering wheel side to side while feeling and observing for any freeplay in the steering or suspension. For best results, the vehicle should be on a level floor or on a drive-on-type hoist with the front wheels pointing straight ahead. In this suspension analysis using the dry park test, the technician should observe the following for any noticeable play or unusual noise:

1. **Front wheel bearings.** Loose or defective wheel bearings are often overlooked as a possible cause of poor handling or darting vehicle performance.
2. **Control arm bushing wear or movement.** Check for any abnormal movement in upper control arm bushings or lower control arm bushings.
3. **Ball joint movement.** Check for any noticeable play or noise from both load-carrying and follower-type ball joints on both sides of the vehicle.

NOTE: The dry park test [and many other chassis system tests] relies on the experience of the technician to be able to judge normal wear from abnormal wear. It is extremely important that all beginning technicians work closely with an experienced technician to gain this knowledge.

TECH TIP ✓ **Road Test—Before and After**

Many times technicians will start to work on a vehicle based on the description of the problem by the driver or owner. A typical conversation was overheard where the vehicle owner complained that the vehicle handled "funny," especially when turning. The owner wanted a wheel alignment, and the technician and shop owner wanted the business. The vehicle was aligned, but the problem was still present. The real problem was a defective tire. The service technician should have road-tested the vehicle before any service work was done to confirm the problem and try to determine its cause. Every technician should test drive the vehicle *after* any service work is performed to confirm that the service work was performed correctly and that the customer complaint has been resolved. This is especially true for any service work involving the steering, suspension, or braking systems.

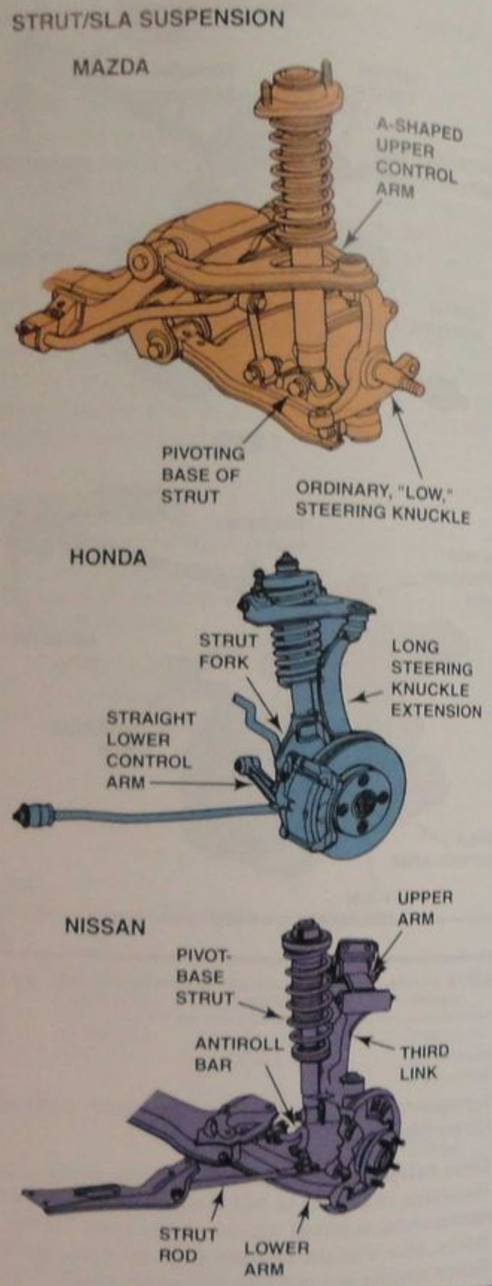


Figure 86–11 Multilink front suspension design varies depending on the vehicle manufacturer.

VISUAL INSPECTION

All suspension components should be carefully inspected for signs of wear or damage. A thorough visual inspection should include checking all of the following:

1. Shock absorbers. See Figure 86–12.
2. Springs. See Figure 86–13.
3. Stabilizer bar links
4. Stabilizer bar bushings
5. Upper and lower shock absorber mounting points
6. Bump stops
7. Body-to-chassis mounts
8. Engine and transmission (transaxle) mounts
9. Suspension arm bushings. See Figure 86–14.

Alignment equipment and procedures can often determine if a suspension component is bent or has been moved out of position. A careful *visual* inspection can often reveal suspected damaged components by observing scrape marks or rusty sections that could indicate contact with the road or another object.

While an assistant bounces the vehicle up and down, check to see if there is any freeplay in any of the suspension components.



Figure 86–12 A leaking shock absorber. This shock absorber definitely needs to be replaced.



Figure 86–13 This front coil spring looks as if it has been heated with a torch in an attempt to lower the ride height of the vehicle. Both front springs will require replacement.



Figure 86–14 It is easy to see that this worn control arm bushing needed to be replaced. The new bushing is shown next to the original.

BALL JOINTS

Diagnosis and Inspection The life of ball joints depends on driving conditions, vehicle weight, and lubrication. Even with proper care and lubrication, the load-carrying (weight-carrying) ball joints wear more than the follower ball joints. Ball joints should be replaced in pairs, both lower or both upper, to ensure the best handling.

Defective or worn ball joints can cause looseness in the suspension and the following common driver complaints:

1. Loud popping or squeaking whenever driving over curbs, such as into a driveway
2. Shimmy-type vibration felt in the steering wheel
3. Vehicle wander or a tendency not to track straight
4. Excessive freeplay in the steering wheel

A ball joint inspection should also be performed when an alignment is performed or as part of any other comprehensive vehicle inspection.

Many load-carrying ball joints have wear indicators with a raised area around the grease fitting, called **indicator ball joints.** See Figures 86–15 and 86–16.

Always check wear-indicator-type ball joints with the wheels of the vehicle on the ground. If the raised area around the grease fitting is flush or recessed with the surrounding area, the ball joint is worn more than 0.050 in. and must be replaced.

NOTE: Most ball joints must be replaced if the joint has more than 0.050 in. axial (up-and-down) movement. To help visualize this distance, consider that the thickness of an American nickel coin is about 0.060 in. It is helpful to know that maximum wear should be less than the thickness of a nickel. There are dial indicators (gauges) available that screw into the grease-fitting hole of the ball joint that can accurately measure the wear. See Figure 86–17.

To perform a proper non-indicator-type ball joint inspection, the force of the vehicle's springs *must* be *unloaded* from the ball joint. If this force is not relieved, the force of the spring pushes the ball and socket joint tightly together and any wear due to movement will not be detected.

NOTE: The location of the load-carrying ball joint is closest to the seat of the spring or torsion bar.



Figure 86–15 Grease fitting projecting down from the surrounding area of a ball joint. The ball joint should be replaced when the area around the grease fitting is flush or recessed.

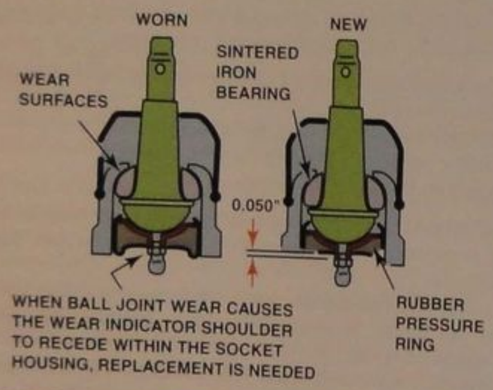


Figure 86–16 Indicator ball joints should be checked with the weight of the vehicle on the ground.

If the coil spring or torsion bar is attached to the *lower* control arm, the *lower* ball joint is the load-carrying ball joint. See Figure 86–18. This includes vehicles equipped with modified MacPherson-strut-type suspension. See Figure 86–19.

1. Place the jack under the lower control arm as close to the ball joint as possible and raise the wheels approximately 1 to 2 in. (2.5 to 5 cm) off the ground to unload the lower ball joint.
2. Using a pry bar under the tire, lift the wheel up. If there is excessive vertical movement in the ball joint itself, it must be replaced. Most manufacturers specify a maximum vertical play of approximately 0.050 in. (1.3 mm), or the thickness of a nickel. Always check the manufacturer's specifications for exact maximum allowable movement. Vertical movement of a ball joint is often called axial play because the looseness is in the same axis as the ball joint stud. To check for *lateral* play, grip the tire at the top and bottom and move your hands in opposite directions.

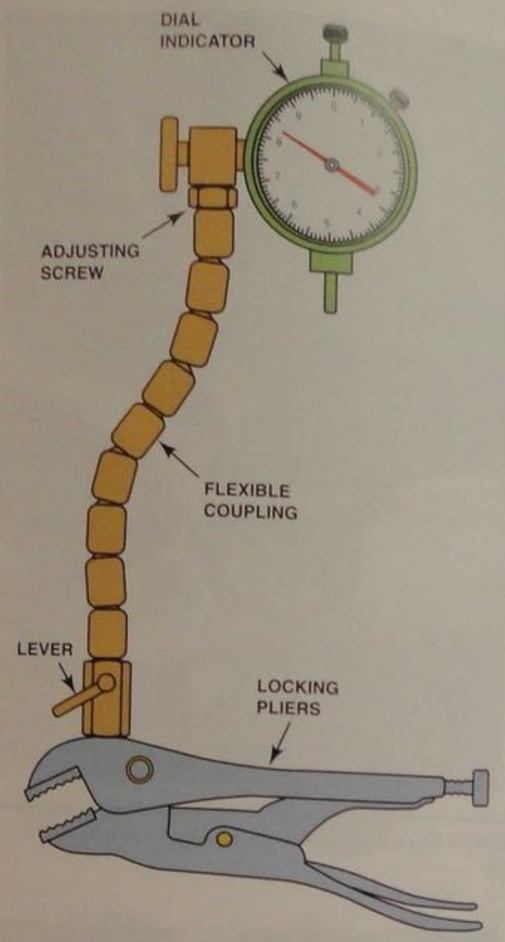


Figure 86–17 Typical dial indicator used to measure the suspension component movement. The locking pliers attach the gauge to a stationary part of the vehicle and the flexible coupling allows the dial indicator to be positioned at any angle.

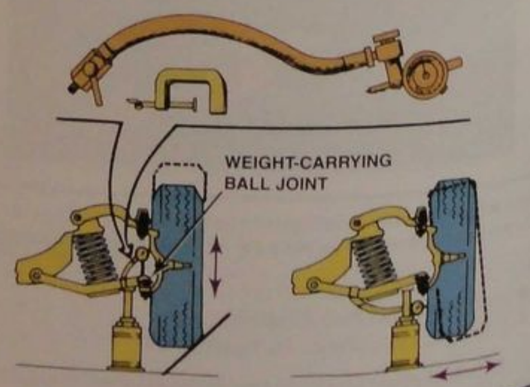


Figure 86–18 If the spring is attached to the lower control arm as in this SLA suspension, the jack should be placed under the lower control arm as shown. A dial indicator should be used to measure the amount of freeplay in the ball joints. Be sure that the looseness being measured is not due to normal wheel bearing endplay.

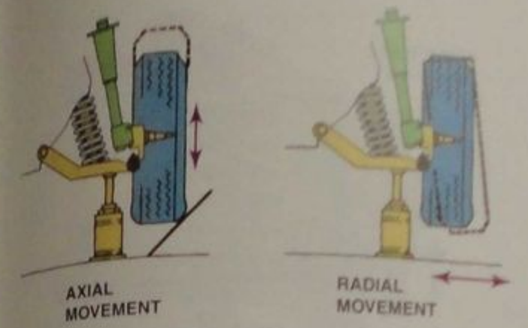
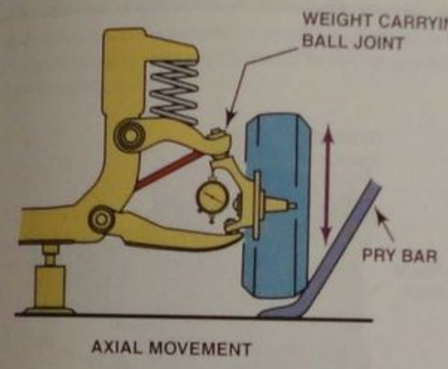


Figure 86–19 The jack should be placed under the lower control arm of this modified MacPherson-type suspension.



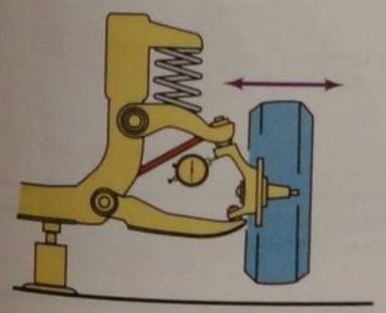


Figure 86–20 If the spring is attached to the upper control arm, the jack should be placed under the frame to check for ball joint wear.

NOTE: Be sure that the cause of any freeplay or looseness is not due to the wheel bearing. Closely observe the exact source of the freeplay movement.

If the coil spring is attached to the *upper* control arm, the upper ball joint is the load-carrying ball joint. See Figure 86–20.

1. Place a block of wood (2 × 4 in.) between the upper control arm and the frame, or use a special tool designed for this purpose. See Figure 86–21.
2. Place the jack under the vehicle's *frame* and raise the wheel approximately 1 in. to 2 in. off the ground. (The wood block or special tool keeps the weight of the vehicle off the upper ball joint.)
3. Using a pry bar under the tire, lift the wheel. If there is excessive vertical movement in the ball joint itself, it must be replaced.

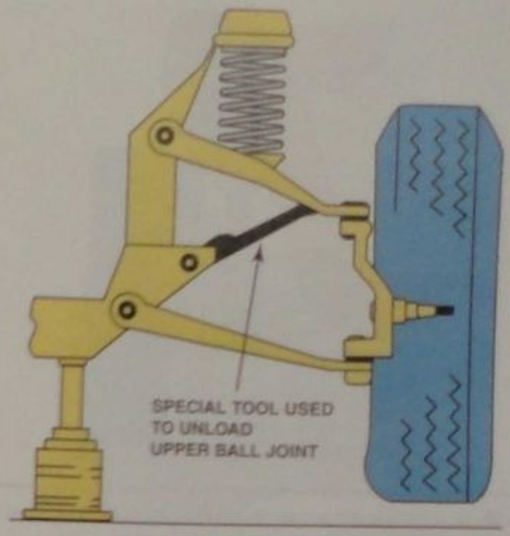


Figure 86–21 A special tool or a block of wood should be inserted between the frame and the upper control arm before lifting the vehicle off the ground. This tool stops the force of the spring against the upper ball joint so that a true test can be performed on the condition of the ball joint.

Always check the manufacturer's specifications for exact maximum allowable movement.

Follower ball joints (friction ball joints) should also be inspected while testing load-carrying ball joints. Grasp the tire at the top and the bottom and attempt to shake the wheel assembly while looking directly at the follower ball joint. Generally, there should be no lateral or axial movement at all in the follower ball joint. However, some manufacturers specify a maximum of 0.250 in. (1/4 in. or 0.6 cm) measured at the top of the tire. Always check the manufacturer's specifications before condemning a ball joint because of excessive play.

MacPherson-strut-equipped vehicles do not have a load-carrying ball joint. The weight of the vehicle is carried through the upper strut mount and bearing assembly. See Figure 86–22.

After checking axial play in a ball joint, grasp the tire from the side at the top and bottom and alternately push and pull. *Any* lateral movement at the ball joint should generally be considered a good reason to replace the ball joints. See Figure 86–23.

FREQUENTLY ASKED QUESTION ???

What Is the Difference Between a Low-Friction Ball Joint and a Steel-on-Steel Ball Joint?

Before the late 1980s, most ball joints were constructed with a steel ball that rubbed on a steel socket. This design created friction and provided for a tight high-friction joint until wear caused looseness in the joint.

Newer designs use a polished steel ball that is installed in a hard plastic polymer, resulting in a low-friction joint assembly. Because of the difference in friction characteristics, the vehicle may handle differently than originally designed if incorrect-style ball joints are installed. Most component manufacturers state that low-friction ball joints in a vehicle originally equipped with steel-on-steel high-friction ball joints are usually acceptable, but high-friction replacement ball joints should be avoided on a vehicle originally equipped with low-friction ball joints.

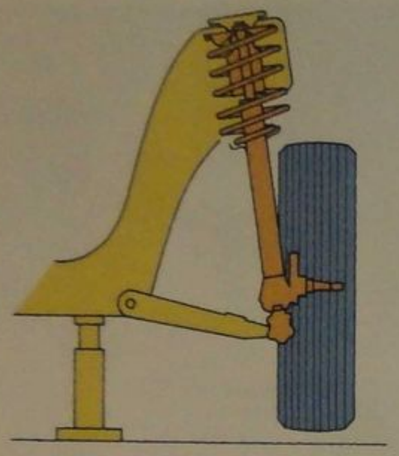


Figure 86–22 The jacking point is under the frame for checking the play of a lower ball joint used with a MacPherson strut.



Figure 86–23 This worn and rusty ball joint was found by moving the wheel and looking for movement in the joint.

Ball Joint Removal Take care to avoid damaging grease seals when separating ball joints from their mounts. *The preferred method to separate tapered parts is to use a puller-type tool that applies pressure to the tapered joint as the bolt is tightened on the puller.* See Figure 86–24.

Sometimes the shock of a hammer can be used to separate the ball joint from the steering knuckle. For best results, another hammer should be used as a backup while striking the joint to be separated on the side with a heavy hammer.

CAUTION: The use of tapered "pickle forks" should be avoided, unless the part is to be replaced, because they often damage the grease seal of the part being separated.

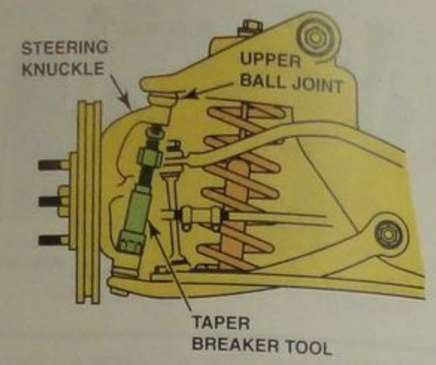


Figure 86–24 Taper breaker tool being used to separate the upper ball joint from the steering knuckle. This is especially important for vehicles equipped with aluminum alloy control arms.

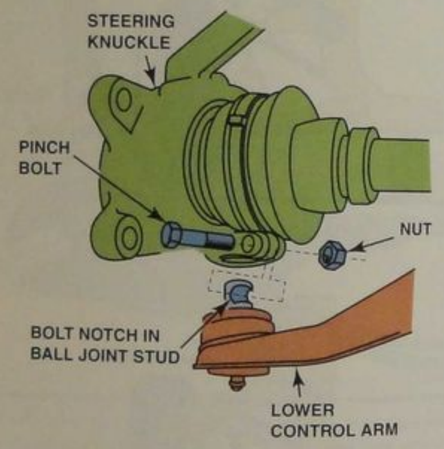


Figure 86–25 A pinch bolt attaches the steering knuckle to the ball joint. Remove the pinch bolt by turning the nut, not the bolt.

Some ball joint studs have a slot or groove where a **pinch bolt** is used to hold the ball joint to the steering knuckle. See Figure 86–25. Use penetrating oil in the steering knuckle groove and rotate the knuckle several times. Do not use a hammer on the pinch bolt because this can cause damage to the bolt and the ball joint. Do not widen the slot in the steering knuckle. Once separated, check the shape of the steering knuckle. See Figure 86–26. If the pinch bolt has been deformed by overtightening, the steering knuckle should be replaced.

When removing ball joints that are riveted in place, always cut off or drill rivet heads before separating the ball joint from the spindle. This provides a more solid base to assist in removing rivets. *The preferred method to remove rivets from ball joints is to center punch and drill out the center of the rivet before using a drill or an air-powered chisel to remove the rivet heads.* Be careful not to drill or chisel into the control arms. See Figures 86–27 through 86–29.

Press-in-type ball joints are removed and installed using a special C-clamp-type tool. See Figure 86–30.

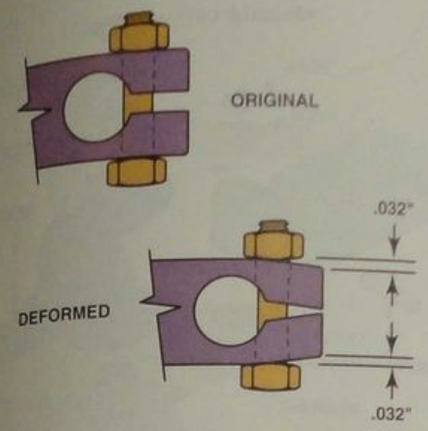


Figure 86–26 If the pinch bolt is overtightened, the steering knuckle can be deformed. A deformed knuckle can cause the pinch bolt to break and the ball joint could become separated from the steering knuckle.



Figure 86–27 By drilling into the rivet, the holding force is released.

NOTE: Many replacement press-in-type ball joints are slightly larger in diameter—about 0.050 in. (1.3 mm)—than the original ball joint to provide the same press fit. If the ball joints have been replaced before, then the control arm must be replaced.

Avoid using heat to remove suspension or steering components. Many chassis parts use rubber and plastic that can be damaged if heated with a torch. *If heat is used to remove a part, it must be replaced.* For best results, try soaking with a penetrating oil and use the proper tools and procedures as specified by the manufacturer.

Many vehicles are equipped with nonreplaceable ball joints, and the entire control arm must be replaced if the ball joint is worn or defective.

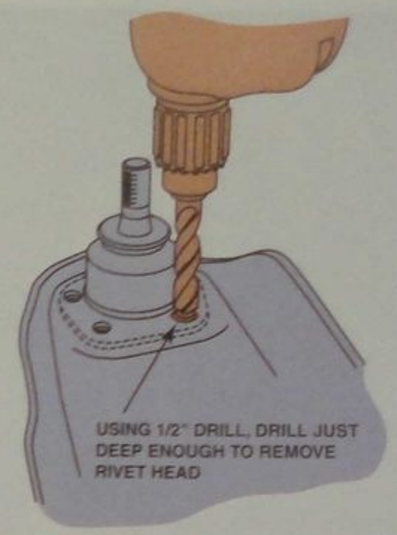


Figure 86–28 The head of the rivet can be removed by using a larger-diameter drill bit as shown.

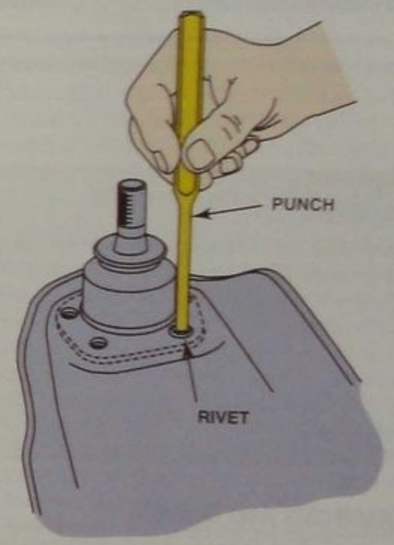


Figure 86–29 Using a punch and a hammer to remove the rivet after drilling down through the center and removing the head of the rivet.

CAUTION: Always follow manufacturers' recommended installation instructions whenever replacing any suspension or other chassis component part. Tie rod ends and ball joints use a taper to provide the attachment to other components. Whenever a nut is used to tighten a tapered part, it is important not to back off (loosen) the nut after tightening. As the nut is being tightened, the taper is being pulled into the taper of the adjoining part. The specified torque on the nut ensures that the two pieces of the taper are properly joined. If the cotter key does not line up with the hole in the tapered stud when the nut has been properly torqued, tighten it more to line up a hole—never loosen the nut.



Figure 86–30 Press-in ball joints are best removed using a large C-clamp press, as shown.

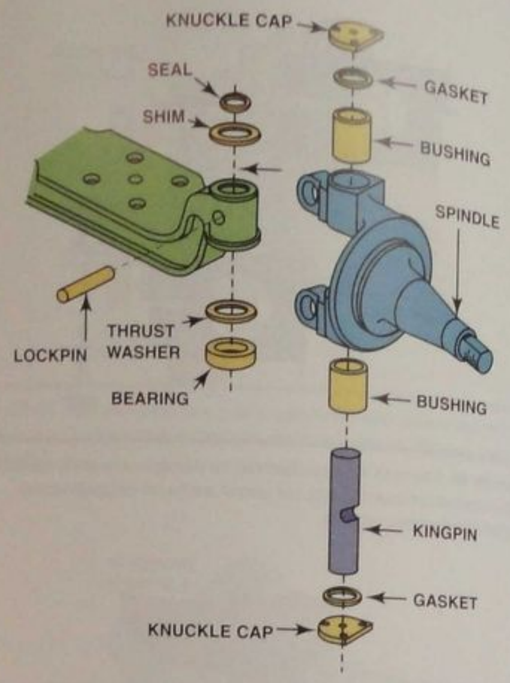


Figure 86–31 Typical kingpin assembly.

REAL WORLD FIX **The Rattle Story**

A customer complained that a rattle was heard every time the vehicle hit a bump. The noise sounded as if it came from the rear. All parts of the exhaust system and suspension system were checked. Everything seemed okay until the vehicle was raised with a frame-type hoist instead of a drive-on type. Then, whenever the right rear wheel was lifted, the noise occurred. The problem was a worn (elongated) shock absorber mounting hole. A washer with the proper-size hole was welded over the worn lower frame mount and the shock absorber was bolted back into place.

KINGPIN DIAGNOSIS AND SERVICE

Kingpins are usually used on trucks, sport utility vehicles, and other heavy-duty vehicles. See Figure 86–31.

Kingpins are designed to rotate inside kingpin bushings with a clearance between them of approximately 0.001 to 0.003 in. (0.025 to 0.075 mm). As wear occurs, this clearance distance increases and the kingpin becomes loose. Looseness in the kingpin causes looseness in the wheels and steering. *Kingpins can also gall or seize due to lack of lubrication, resulting in very hard steering.*

After supporting the vehicle safely off the ground, inspect for looseness by positioning a dial gauge (indicator) on the extreme inside bottom of the edge of the wheel and rock the tire. If the dial indicator registers more than 1/4 inch (6 mm), replace the kingpin and/or kingpin bushings.

To remove a typical kingpin, follow these basic steps:

Step #1 Remove the tire, brake drum, and backing plate or caliper.

Step #2 Remove the lockpin. The lockpin is usually tapered with a threaded end for the nut. Drive the lockpin out with a drift (punch).

Step #3 Remove the grease caps and drive the kingpin from the steering knuckle and axle with a hammer and a brass punch or a hydraulic press, if necessary. See Figure 86–32.

To replace the kingpin bushings and/or kingpin, refer to the manufacturer's procedure and specifications. See Figure 86–33.

Some bronze bushings must be sized by reaming or honing to provide from 0.001 to 0.003 in. (0.025 to 0.075 mm) clearance between the kingpin and the bushing.

SHOCK ABSORBERS AND STRUTS

Diagnosis Shock absorber life depends on how and where the vehicle is driven. Original equipment (OE) shock absorbers are carefully matched to the vehicle springs and bushings to provide the best ride comfort and control. As the control arm bushings and ball joints age, the energy built up in the springs of the vehicle is controlled less by the friction of these joints and bushings, requiring more control from the shock absorbers. Shock absorber action is also reduced as the seals inside wear. Replacement shock absorbers may be required when any or all of the following symptoms appear:

TECH TIP **The Shock Stud Trick**

Front shock absorbers used on many rear-wheel-drive vehicles equipped with an SLA-type front suspension are often difficult to remove because the attaching nut is rusted to the upper shock stub. A common trick is to use a deep-well 9/16-in. socket and a long extension and simply bend the shock stud until it breaks off. At first you would think that this method causes harm, and it does ruin the shock absorber—but the shock absorber is not going to be reused and will be discarded anyway.

The usual procedure followed by many technicians is to simply take a minute or two to break off the upper shock stud, then hoist the vehicle to allow access to the lower two shock bolts, and then the shock can easily be removed. To install the replacement shock absorber, attach the lower bolts, lower the vehicle, and attach the upper rubber bushings and retaining nut.

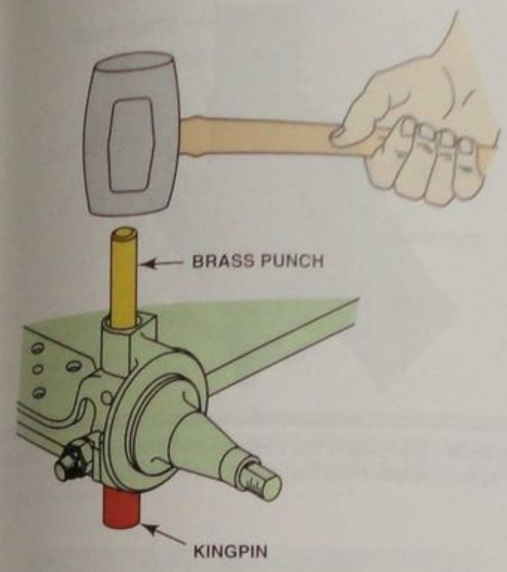


Figure 86–32 Driving a kingpin out with a hammer.



Figure 86–33 This galled kingpin bushing must be replaced.

1. **Ride harshness.** As the effectiveness of the shock absorber decreases, the rapid forces of the springs are not as dampened or controlled. Worn shocks can cause ride harshness and yet not cause the vehicle to bounce after hitting a bump.
2. **Frequent bottoming out on rough roads.** Shock absorbers provide a controlled movement of the axle whenever the vehicle hits a bump or dip in the road. As fluid is lost or wear occurs, the shock absorber becomes weaker and cannot resist the forces acting on the axle. The worn shock absorber can allow the spring to compress enough so that the axle contacts the jounce bumper (bump stop) on the body or frame of the vehicle.

NOTE: Frequent bottoming out is also a symptom of reduced ride height due to sagging springs. Before replacing the shock absorbers, always check for proper ride height as specified in the vehicle service manual or any alignment specification booklet available from suppliers or companies of alignment or chassis parts and equipment.

3. **Extended vehicle movement after driving on dips or a rise in the road.** The most common shock absorber test is the bounce test. Push down on the body of the vehicle and let go; the vehicle should return to its normal ride height and stop. Worn shock absorbers can cause poor driver control due to excessive up-and-down suspension movements. If the vehicle continues to bounce two or three times, then the shocks or struts are worn and must be replaced.
4. **Cuppy-type tire wear.** Defective shock absorbers can cause **cuppy tire wear.** This type of tire wear is caused by the tire's bouncing up and down as it rotates.
5. **Leaking hydraulic oil.** When a shock or strut leaks oil externally, this indicates a defective seal. The shock absorber or strut cannot function correctly when low on oil inside.
6. **Springs and shock absorbers should be replaced in pairs.** Both front or both rear shocks should be replaced together to provide the best handling and control.

NOTE: Shock absorbers do not affect ride height except where special air shocks or coil overload carrying shocks are used. If a vehicle is sagging on one side or in the front or the rear, the springs should be checked and replaced if necessary.

Shock absorbers are filled with fluid and sealed during production. They are not refillable; if worn, damaged, or leaking, they must be replaced. A slight amount of fluid may bleed by the rod seal in cold weather and deposit a light film on the upper area of the shock absorber. This condition will not hurt the operation of the shock and should be considered normal. If noisy when driving, always check the tightness and condition of all shock absorber mounts.

Replacement shock absorbers and/or struts should match the original equipment unit in physical size.

Front Shock Replacement Front shock absorbers provide ride control and are usually attached to the lower control arm by bolts and nuts. The upper portion of the shock usually extends through the spring housing and is attached to the frame of the vehicle with rubber grommets to help insulate noise, vibration, and harshness.

Most front shock absorbers can be replaced either with the vehicle still on the ground or while on a hoist. The front suspension of most vehicles allows the removal of the shocks without the need to support the downward travel of the lower control arm. The downward travel limit is stopped by a rubber stop or by the physical limit of the suspension arms.

Special sockets and other tools are available to remove the nut from the shocks that use a single mounting stem. The removal of the lower mounting of most front shock absorbers usually involves the removal of two bolts. After removal of the attaching hardware, the shock absorber is simply pulled through the front control arm. See Figure 86–34.

Reverse the removal procedure to install replacement shock absorbers. Always consult the manufacturer's recommended procedures and fastener tightening torque.

MACPHERSON STRUT REPLACEMENT

On most vehicles equipped with MacPherson strut suspensions, strut replacement involves the following steps.

CAUTION: Always follow the manufacturer's recommended methods and procedures whenever replacing a MacPherson strut assembly or component.

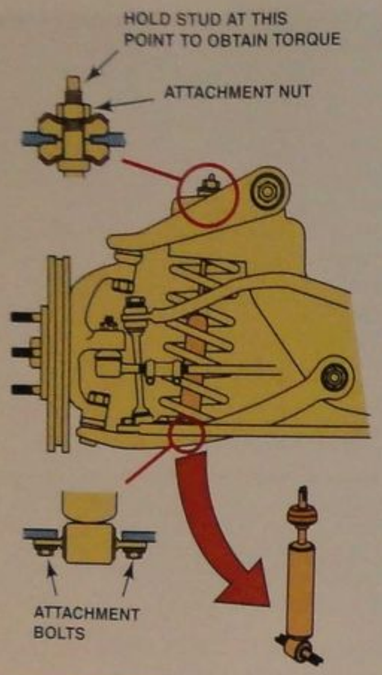


Figure 86–34 Most shock absorbers used on the front suspension can be removed from underneath the vehicle after removing the attaching bolts or nuts.



Figure 86–35 Removing the upper strut mounting bolts. Some experts recommend leaving one of the upper strut mount nuts loosely attached to prevent the strut from falling when the lower attaching bolts are removed.

1. Hoist the vehicle, remove the wheels, and mark the attaching bolts/nuts.
2. Remove the upper strut mounting bolts except for one to hold the strut until ready to remove the strut assembly. See Figure 86–35.
3. Remove the brake caliper or brake hose from the strut housing. See Figure 86–36.
4. After removing all lower attaching bolts, remove the final upper strut bolt and remove the strut assembly from the vehicle. Place the strut assembly into a strut spring compressor fixture or use manual spring compressors as shown in Figure 86–37.
5. Compress the coil spring enough to relieve the tension on the strut rod nut. Remove the strut rod nut as shown in Figure 86–38.

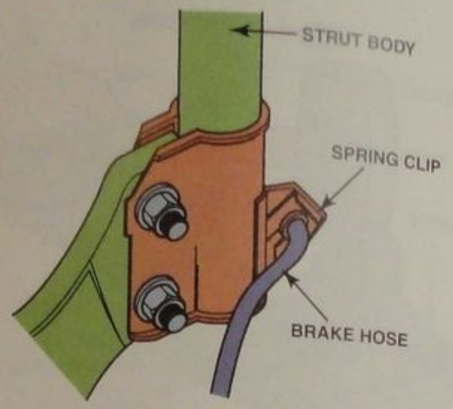


Figure 86–36 A brake hydraulic hose is often attached to the strut housing. Sometimes all that is required to separate the line from the strut is to remove a spring clip.



Figure 86–37 Use a strut spring compressor fixture to compress the spring on a MacPherson strut before removing the strut retaining nut.

6. After removing the strut rod nut, remove the upper strut bearing assembly and the spring. See Figure 86–39.

NOTE: The bearing assembly should be carefully inspected and replaced if necessary. Some automotive experts recommend replacing the bearing assembly whenever the strut is replaced.

7. Many MacPherson struts are replaced as an entire unit assembly. Other struts can have the cartridge inside the housing replaced. The cartridge is installed after removing the gland nut at the top of the strut tube and removing the original strut rod, valves, and hydraulic oil. Always replace the cartridge assembly per the manufacturer's recommended procedure. See Figures 86–40, 86–41, and 86–42.
8. Reinstall the strut in the vehicle.

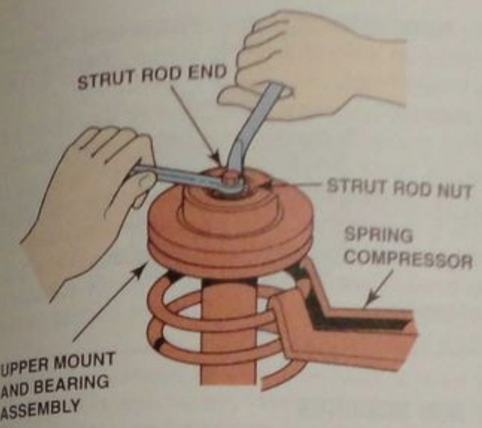


Figure 86–38 Removing the strut rod nut. The strut shaft is being helped with one wrench while the nut is being removed with the other wrench. Notice that the spring is compressed before the nut is removed.

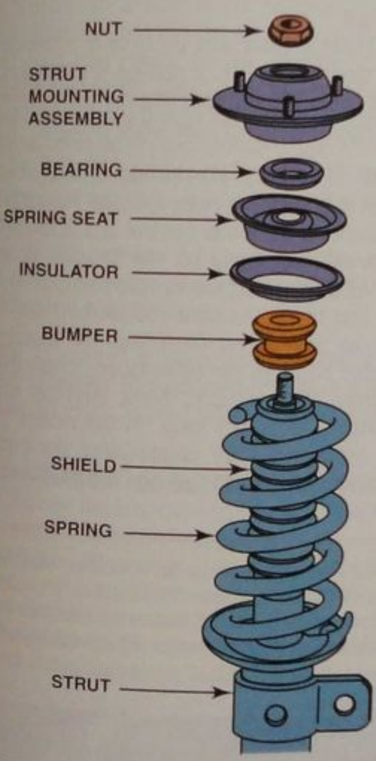


Figure 86–39 Typical MacPherson strut showing the various components.

CAUTION: Many GM front-wheel-drive vehicles use a MacPherson strut with a large-diameter spring seat area. GM chassis engineers call this a **cow catcher** design. If the coil spring breaks, the extra-large cow catcher will prevent the end of the broken spring from moving outward where it could puncture a tire and possibly cause an accident. Always use a replacement strut that has this feature.

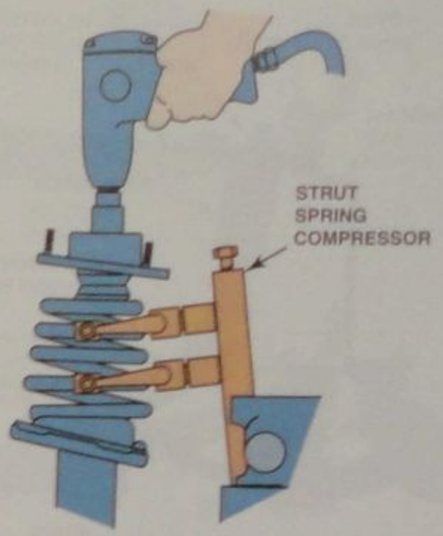


Figure 86–40 After installing the replacement strut cartridge, reinstall the spring and upper bearing assembly after compressing the spring. Notice that the strut is being held in a strut spring compressor fixture.

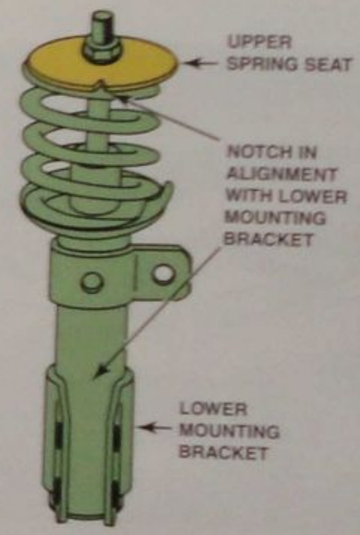


Figure 86–41 Before final assembly, make sure the marks you made are aligned. Some struts are manufactured with marks to ensure proper reassembly.

STABILIZER BAR LINK AND BUSHINGS

Diagnosis Stabilizer bars twist whenever a vehicle turns a corner or whenever one side of the vehicle rises or lowers. The more the body of the vehicle leans, the more the bar twists, and the more the bar counteracts the roll of the body. A great deal of force is transferred from the stabilizer bar to the body or frame of the vehicle through the stabilizer links at the control arm and the stabilizer bar mounting bushings on the body or frame. *The most common symptom of defective stabilizer bar links or bushings is noise while turning, especially over curbs.* When driving up and over a curb at an angle, one wheel is pushed upward. Since the stabilizer bar connects both wheels, the bar tends to resist this motion by twisting. If one or both links are broken, a loud knock or clanking sound is heard as the bar contacts the control arm. Any sound

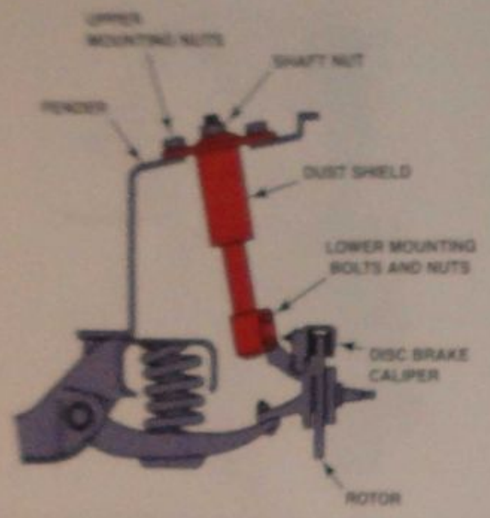


Figure 86–42 The strut on a modified MacPherson strut assembly can be replaced by removing the upper mounting nuts.

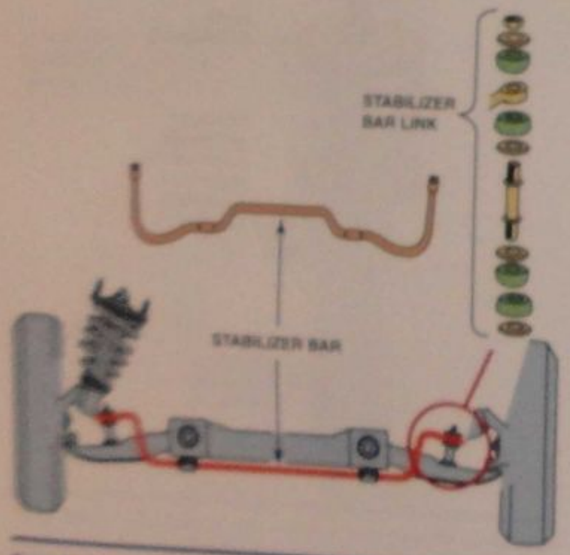


Figure 86–43 Stabilizer bar links should be replaced as a pair.

insert when driving should be investigated and the cause determined by a thorough visual inspection.

Replacement Stabilizer links are usually purchased as a kit consisting of replacement rubber bushings, retainers, a long bolt, and spacer with a nut and lock nut. General Motors recommends that stabilizer links be replaced in pairs and two kits purchased so that the links on both the left and the right can be replaced at the same time. See Figure 86–43.

Stabilizer links are replaced by simply reversing the old parts and installing replacement parts. Special precautions are usually not necessary, but, as always, consult a service manual for the exact recommended procedure and fastener torque.

If the mounting bushings (also called isolator bushings) on the body or frame are worn or defective, a loud squeaking or knocking sound is usually heard.

Stabilizer bar bushings often fail because the rubber has deteriorated from engine oil or other fluid leaks. Before replacing defective bushings, make certain that all other fluid leaks are stopped. Stabilizer bar bushing replacement involves the removal (unbolting) of the bushing retainers that surround the bushing and attach to the vehicle body or frame. The bushings are usually split so that they can be easily removed and replaced on the stabilizer bar and can slide into proper position. Reinstall the bushing retainer bolts and tighten to the specified torque.

STRUT ROD BUSHINGS

Diagnosis Strut rods are used on the front suspension of many front-wheel-drive and rear wheel-drive vehicles. As with any rubber suspension component, strut rod bushings can deteriorate and crack. When strut rod bushings fail, the lower control arm can move forward and backward during braking or when hitting bumps in the road.

Since the lower control arm position is important to vehicle control, when the bushing fails, a pulling or drifting of the vehicle often occurs. *A common symptom of a defective strut rod bushing is noise and a pull toward one side while braking.*

Replacement To replace a strut rod bushing, the nut on the end of the strut rod has to be removed. See Figure 86–44. As the nut is being removed, the lower control arm is likely to move forward or backward, depending on the location of the strut rod frame mount. After removing the strut rod nut, remove the one or two fasteners that retain the strut rod to the lower control arm. The strut rod can now be removed from the vehicle and the replacement rubber bushings can be installed. Install the strut rod in the reverse order of installation. Most bushings use a serrated spacer to maintain the proper force on the rubber bushings; this prevents the technician from compressing the rubber bushing when the strut rod nut is tightened. See Figure 86–45.

CAUTION: Some suspension bushings are directional and must be installed according to the vehicle manufacturer's instructions. For example, on some vehicles, the bushings have a slit or void which must face the front of the vehicle. Always check service information when installing new bushings.



Figure 86–44 A strut rod as viewed from the front of the vehicle.

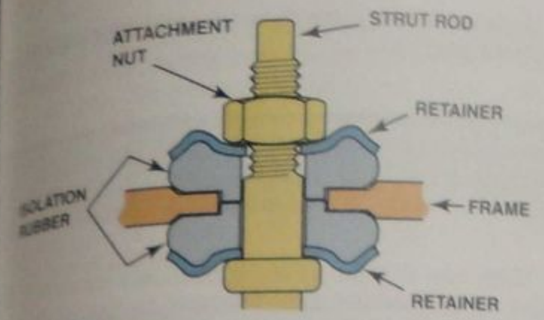


Figure 86–45 Typical strut rod bushing with rubber on both sides of the frame to help control noise, vibration, and harshness from being transferred to the passengers.

FRONT COIL SPRINGS

Diagnosis Coil springs should be replaced in pairs if the vehicle ride height is lower than specifications. Sagging springs can cause vehicles to slide laterally (side to side) across the pavement, causing excessive tire wear. See Figure 86–46. Sagging springs can also cause the vehicle to bottom out against the suspension bumpers when traveling over normal bumps and dips in the road.

If a vehicle is overloaded, the springs of the vehicle can *take a set* and not recover to the proper ride height. This commonly occurs with all types of vehicles whenever a heavy load is carried, even on a short trip.

It is normal for the rear of a vehicle to sag when a heavy load is carried, but it can permanently damage the spring by exceeding the yield point of the steel spring material.

Replacement The only solution recommended by the vehicle manufacturer is to replace the damaged springs in pairs (both front or both rear, or all four). Several aftermarket alternatives include the following:

- **Helper or auxiliary leaf springs.** These helper springs are usually designed to increase the load-carrying capacity of leaf springs or to restore the original ride height to sagging springs.
- **Spring inserts for coil springs.** Hard rubber or metal spacers are not recommended because they create concentrated pressure points on the coils that can cause the spring to break. Hard rubber cushions that bridge the gap between two coils without raising the ride height stiffen the ride by locking two coils together. With two coils connected, the spring rate increases and the spring becomes stiffer.
- **Air shocks or airbag devices.** Air shocks or airbags are generally used to restore or increase the load-carrying capacity to the rear of the vehicle. While these devices do allow the ride height to be maintained, the extra load is still being supported by the tires and rear axle bearings. Caution should be used not to overload the basic chassis or power train of the vehicle.

There are two designs for vehicles that use coil springs. The most commonly used design places the coil spring between the vehicle frame and the lower control arm.

Both front-suspension designs require that the front shock absorbers be removed in order to replace the coil springs. This first step in the coil spring removal procedure can be performed on the floor or on any type of hoist. After removing the shock absorber, install a coil spring compressor and install it through the center of the coil spring. See Figure 86–47. Hook the arms of the coil spring compressor over the rungs of the coil spring and rotate the adjusting nut

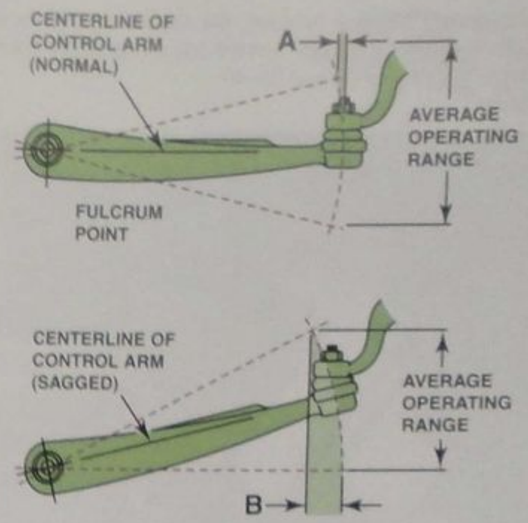


Figure 86–46 Notice that if the front coil springs are sagging, the resulting angle of the lower control arm causes the wheels to move from side to side as the suspension moves up and down. Note the difference between the distance at "A" with good springs and the distance at "B" with sagging springs.



Figure 86–47 Spring compressing tool in place to hold the spring as the ball joint is separated. Note that the stabilizer bar links have been removed to allow the lower control arm to move downward enough to remove the coil spring.

on the spring compressor with a wrench to shorten the spring. Coil spring clips can also be used to retain the coil spring.

CAUTION: When compressed, all springs contain a great deal of stored energy. If a compressed spring were to become disconnected from its spring compressor or clips, it could be projected outward with enough force to cause injury or death.

After the coil spring is retained, the control arm can be separated from the steering knuckle and the coil spring can be removed as shown in Figures 86–48 and 86–49.



Figure 86–48 The steering knuckle has been disconnected from the ball joints. The lower control arm and coil spring are being held up by a floor jack.



Figure 86–49 The spring is being held with a spring compressor as the lower control arm is being pushed down to release the spring.

Replacement springs should be compressed and installed using the reverse procedure.

NOTE: Many automotive experts recommend that new coil insulators be installed every time the coil springs are replaced.

Make sure that the spring is positioned correctly in the control arm and that the spring insulators are installed correctly. See Figure 86–50. Most control arms use two holes for the purpose of coil spring seating. The end of the spring should cover one hole completely and partially cover the second hole. See Figure 86–51.

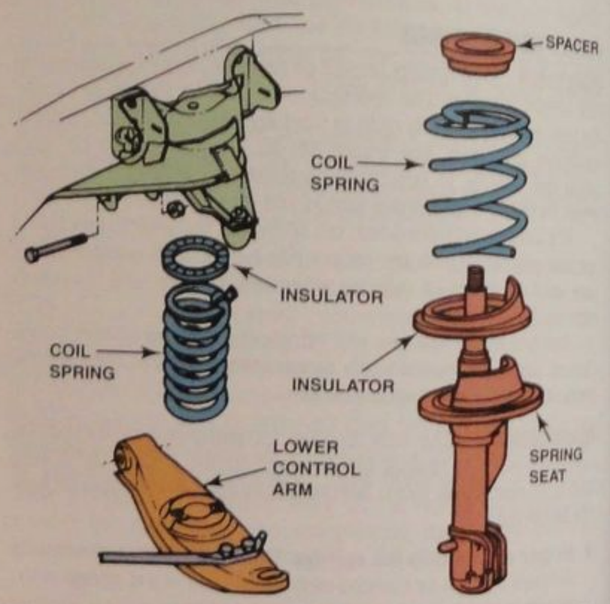


Figure 86–50 Spring insulators install between the spring seat and the coil spring to reduce noise.



Figure 86–51 The holes in the lower arm are not only used to allow water to drain from the spring seat, but also are used as a gauge to show the service technician that the coil spring is correctly seated.

STEERING KNUCKLES

Diagnosis Most steering knuckles are constructed of cast or forged cast iron. The steering knuckle usually incorporates the wheel spindle and steering arm. The steering knuckle/steering arm can become bent if the vehicle is in an accident or hits a curb sideways. Often this type of damage is not apparent until vehicle handling or excessive tire wear is noticed. Unless a thorough inspection is performed during a wheel alignment, a bent steering knuckle is often overlooked.

REAL WORLD FIX — **The Rock-Hard Problem**

The owner of a six-month-old full-size pickup truck complained that occasionally when the truck was driven up into a driveway, a loud grinding sound was heard. Several service technicians worked on the truck, trying to find the cause for the noise. After the left front shock absorber was replaced, the noise did not occur for two weeks, and then started again. Finally, the service manager told the technician to replace anything and everything in the front suspension in an attempt to solve the customer's intermittent problem. Five minutes later, a technician handed the service manager a small, deformed rock. This technician had taken a few minutes to *carefully* inspect the entire front suspension. Around the bottom coil spring seat, the technician found the rock. Apparently, when the truck made a turn over a bump, the rock was forced between the coils of the coil spring, making a very loud grinding noise. But the rock did not always get between the coils. Therefore, the problem occurred only once in a while. The technician handed the rock to the very happy customer.

Replacement If the steering knuckle is bent or damaged, it must be replaced. It should *not* be bent back into shape or repaired. To replace the steering knuckle, both ball joints must be disconnected from the knuckle and the brake components removed. Be sure to support the control arm and spring properly during the procedure. See a factory service manual for the exact procedure and fastener torque for the vehicle you are servicing.

TORSION BARS

Adjustment Most torsion bar suspensions are designed with an adjustable bolt to permit the tension on the torsion bar to be increased or decreased to change the ride height. Unequal side-to-side ride height can be corrected by adjusting (turning) the torsion bar tension bolt. See Figure 86–52.

Torsion bar adjustment should be made if the difference in ride height from one side to another exceeds 1/8 in. (0.125 in. or 3.2 mm). If the ride height difference side to side is greater than 1/8 in., the vehicle will tend to wander or be unstable, with constant steering wheel movements required to maintain straight-ahead direction.

CONTROL ARM BUSHINGS

Diagnosis Defective control arm bushings are a common source of vehicle handling and suspension noise problems. Most suspension control arm bushings are constructed of three parts: an inner metal sleeve, the rubber bushing itself, and an outer steel sleeve. (Some vehicles use a two-piece bushing that does not use an outer sleeve.)

Replacement To remove an old bushing from a control arm, the control arm must first be separated from the suspension and/or frame of the vehicle. Several methods can be used to remove the bushing from the control arm, but all methods apply force to the *outer* sleeve. While an air chisel is frequently used to force the steel sleeve out of the suspension member, a puller tool is most often recommended by General Motors. See Figure 86–53. The puller can be used to remove the old bushing

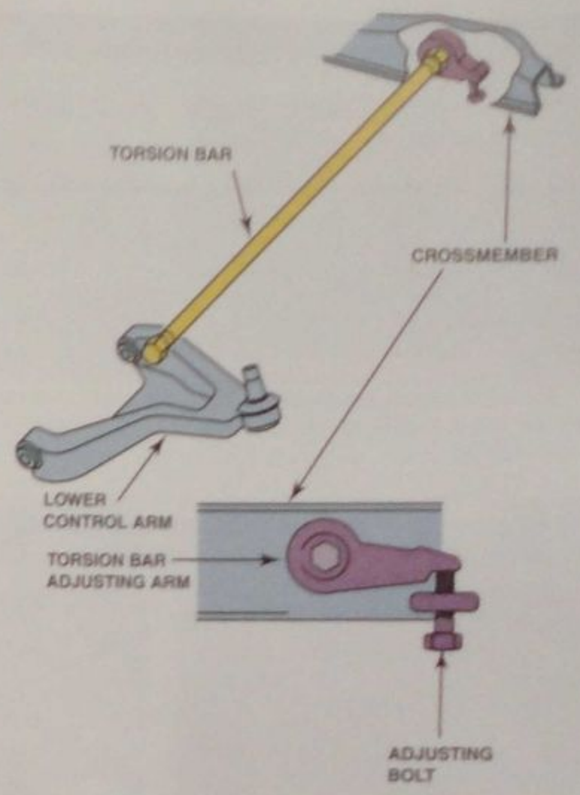


Figure 86–52 By rotating the adjusting bolt, the vehicle can be raised or lowered.

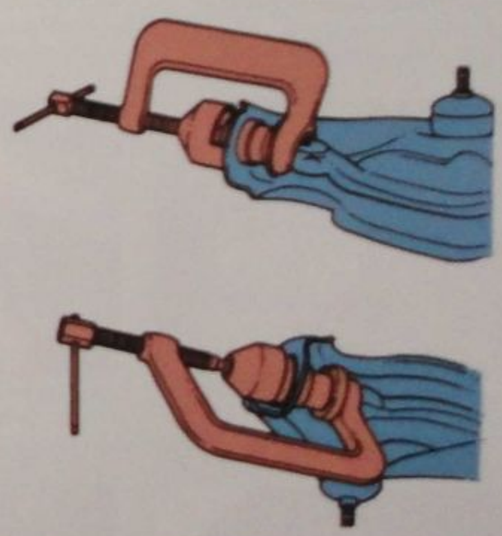


Figure 86–53 An adapter and a press or large clamp are used to remove the old bushing from the control arm and to install a new bushing.

and install the replacement bushing without harming the control arm or the new bushing. All bushings should be tightened with the vehicle on the ground and the wheels in a straight-ahead position; this prevents the rubber bushing from exerting a pulling force on the suspension.

NOTE: Some replacement control arm bushings have a higher **durometer,** or hardness, rating than the original. Urethane bushings are often used in sporty or race-type vehicles and deflect less than standard replacement bushings. These harder bushings also transfer more road noise, vibration, and harshness to the body.

The upper control arm bushings can be replaced in most vehicles that use a short/long-arm-type suspension by following just four easy steps:

Step #1 Raise the vehicle and support the lower control arm with a safety stand or floor jack.

Step #2 Disconnect the upper control arm from the frame by removing the frame-attaching nuts or bolts.

Step #3 Using the upper ball joint as a pivot, rotate the upper control arm outward into the wheel well area. With the control arm accessible, it is much easier to remove and replace the upper control arm pivot shaft and rubber bushings.

Step #4 After replacing the bushings, simply rotate the upper control arm back into location and reattach the upper control arm pivot shaft to the vehicle frame.

NOTE: An alignment should always be performed after making any suspension-related repairs.

PHOTO SEQUENCE Strut Replacement Step-by-Step



P86–1 The tools needed to replace a front strut assembly include several sockets and a ball-peen hammer, plus a strut compressor.



P86–2 After safely hoisting the vehicle to elbow height and removing the wheel covers, remove the front tire/wheel assembly.



P86–3 Remove the two strut retaining nuts.



P86–4 Before using a hammer to drive the retaining bolts from the steering knuckle, thread the nut into the bolt backwards to prevent causing damage to the threads.



P86–5 Remove the retaining bolts and separate the strut from the steering knuckle.



P86–6 Lower the vehicle and remove the upper strut retaining fasteners.



P86–7 Hold the strut while removing the last upper retaining nut and then remove the strut assembly.



P86–8 After the strut has been removed from the vehicle, install the assembly into a strut compressor.



P86–9 Position the jaws of the compressor under the bearing assembly as per the vehicle manufacturer's instructions.

PHOTO SEQUENCE Strut Replacement Step-by-Step—continued



P86–10 Turn the compressor wheel until all tension of the spring has been relieved from the upper mounting assembly.



P86–11 Remove the strut retaining nut.



P86–12 Remove the strut assembly.



P86–13 Before installing the replacement strut, check the upper bearing by exerting a downward force on the bearing while rotating and check for roughness. Replace if necessary.



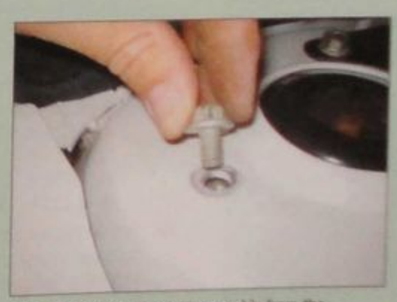
P86–14 Install the strut from underneath the spring compressor fixture.



P86–15 Install the strut retaining nut.



P86–16 Before loosening the tension, check that the coil spring is correctly located at both the top and the bottom, then release the tension on the spring.



P86–17 Remove the strut assembly from the compressor and back into the vehicle and install the upper fasteners. Do not torque to specifications until the lower fasteners have been installed.



P86–18 Attach the lower strut to the steering knuckle using the original hardened bolts and nuts.



P86–19 Using a torque wrench, torque all fasteners to factory specifications.



P86–20 Install the tire/wheel assembly, lower the vehicle, and torque the lug nuts to factory specifications. Align the vehicle before returning it to the customer.

SUMMARY

1. A thorough road test of a suspension problem should include driving beside parked vehicles and into driveways in an attempt to determine when and where the noise occurs.
2. A dry park test should be performed to help isolate defective or worn suspension components.
3. Ball joints must be unloaded before testing. The ball joints used on vehicles with a MacPherson strut suspension are *not* load carrying. Wear-indicator ball joints are observed with the wheels on the ground.
4. Always use a taper-breaker puller or two hammers to loosen tapered parts to remove them. Never use heat unless you are replacing the part; heat from a torch can damage rubber and plastic parts.
5. When installing a tapered part, always tighten the attaching nut to specifications. Never loosen the nut to install a cotter key. If the cotter key will not line up with a hole in the tapered part, tighten the nut more until the cotter key hole lines up with the nut and stud.
6. Defective shock absorbers can cause ride harshness as well as frequent bottoming out on rough roads.
7. Always follow manufacturers' recommended procedures whenever replacing springs or MacPherson struts. Never remove the strut end nut until the coil spring is compressed and the spring force is removed from the upper bearing assembly.

REVIEW QUESTIONS

1. Describe how to perform a proper road test for the diagnosis of suspension-related problems.
2. List four symptoms of worn or defective shock absorbers.
3. Explain the procedure for replacing front shock absorbers on an SLA-type suspension vehicle.
4. Describe the testing procedure for ball joints.
5. Describe the correct general procedure to remove and replace tapered suspension components.

CHAPTER QUIZ

1. Unusual noise during a test drive can be caused by _____.
   a. Defective wheel bearings or stabilizer bar links
   b. Defective or worn control arm bushings or ball joints
   c. Worn or defective CV joints
   d. All of the above
2. Two technicians are discussing non-indicator-type ball joint inspection. Technician A says that the vehicle should be on the ground with the ball joints *loaded*, then checked for freeplay. Technician B says that the ball joints should be *unloaded* before checking for freeplay. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Most manufacturers specify a maximum axial play for ball joints of about _____.
   a. 0.003 in. (0.076 mm)
   b. 0.010 in. (0.25 mm)
   c. 0.030 in. (0.76 mm)
   d. 0.050 in. (1.27 mm)
4. The preferred method to separate tapered chassis parts is to use _____.
   a. A pickle fork tool
   b. A torch to heat the joint until it separates
   c. A puller tool or two hammers to shock and deform the taper
   d. A drill to drill out the tapered part
5. A light film of oil is observed on the upper area of a shock absorber. Technician A says that this condition should be considered normal. Technician B says that a rod seal may bleed fluid during cold weather, causing the oil film. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Before the strut insert can be removed from a typical MacPherson strut assembly, which operation is necessary to prevent possible personal injury?
   a. The brake caliper and/or brake hose should be removed from the strut housing
   b. The coil spring should be compressed
   c. The upper strut mounting bolts should be removed
   d. The lower attaching bolts should be removed
7. What should the technician do when replacing stabilizer bar links?
   a. The stabilizer bar should be removed from the vehicle before replacing the links.
   b. The links can be replaced individually, yet the manufacturer often recommends that the links at both ends be replaced together.
   c. The stabilizer bar must be compressed using a special tool before removing or installing stabilizer bar links.
   d. Both b and c are correct.
8. A noise and a pull toward one side during braking is a common symptom of a worn or defective _____.
   a. Shock absorber
   b. Strut rod bushing
   c. Stabilizer bar link
   d. Track rod bushing
9. To help prevent vehicle wandering on a vehicle with torsion bars, the ride height (trim height) should be within _____ side to side.
   a. 0.003 in. (0.076 mm)
   b. 0.050 in. (1.27 mm)
   c. 0.100 in. (2.5 mm)
   d. 0.125 in. (3.2 mm)
10. Two technicians are discussing suspension bushings. Technician A says that replacing control arm bushings usually requires special tools. Technician B says using high-performance urethane bushings may cause excessive noise to be transferred to the passenger compartment. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 87

Rear Suspension and Service

OBJECTIVES: After studying Chapter 87, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "B" (Suspension System Diagnosis and Repair). • Describe the various types and styles of rear suspension. • Explain the difference among the different types of rear axles. • List the steps necessary to replace rear shock absorbers. • Explain how to replace rear leaf and coil springs.

KEY TERMS: axle windup • Chapman strut • Hotchkiss drive • IRS • live axle • Panhard rod • semi-independent suspension • semi-trailing arm • solid axle • torque arm • track rod • trailing arm • Watts linkage

All suspensions have two basic jobs: keeping the tires on the ground and providing a smooth ride.

SOLID REAR AXLES

A **solid axle** can be used at the rear of either a rear-wheel-drive or front-wheel-drive vehicle. See Figure 87–1. On a rear-wheel-drive vehicle, a solid rear axle consists of the differential gears and axle shafts inside a solid housing. On a front-wheel-drive vehicle, a solid axle is usually a simple U-shaped or tubular beam that may contain a torsion bar, rod, or tube to allow some twisting action.

Certain characteristics apply to any solid rear axle, while other characteristics vary by the type of suspension used to attach the axle to the frame.

Solid axles have some handling characteristics that are inferior to those of an independent suspension. Disadvantages of a solid axle include the following:

- Increased proportion of unsprung weight
- Side-to-side road shock transference
- Poorer tire adhesion

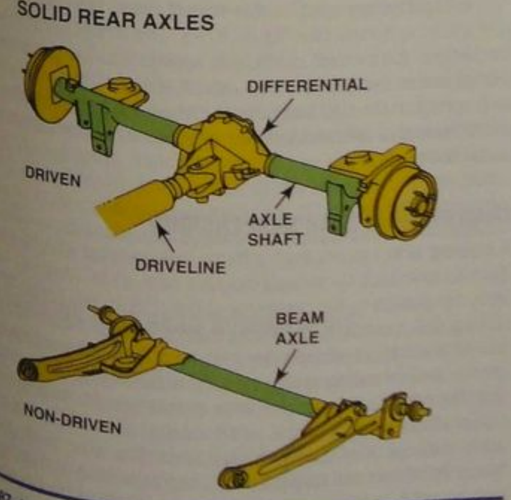


Figure 87–1 Solid axles are used on rear-wheel-drive vehicles as well as front-wheel-drive vehicles.

Increasing the proportion of unsprung weight decreases ride quality. Transferring road shock from side-to-side causes wheel tramp and shimmy, and poor tire adhesion accelerates tire wear. See Figure 87–2.

The sprung weight of the frame and body must be heavy to oppose the unsprung weight of a solid axle, especially on a driven axle. Unsprung weight, wheel tramp, and shimmy all reduce tire adhesion. The effects of these problems are more noticeable in rear-wheel-drive vehicles due to the weight of the rear axle and differential assembly. On a typical front-wheel-drive vehicle, the simple axle beam is not heavy enough to decrease ride quality or cause extreme tire wear. In fact, the rear tires of a front-wheel-drive model always wear more slowly than the front tires because the rear axle is so much lighter than the power train.

FREQUENTLY ASKED QUESTION ???

What Is Axle Windup?

Axle windup is a product of the law of physics, which states that every action produces an equal and opposite reaction. As the axle shafts rotate in one direction to drive the wheels, the axle housing attempts to rotate in the opposite direction. The force of this reaction tends to lift the front end of the vehicle during acceleration. See Figure 87–3. Axle windup is a particular problem with a solid, driven rear axle because the axle housing concentrates the reacting force. Under extreme acceleration, the reacting force can actually tilt the drive shaft upward and lift the front wheels off the ground. Leaf springs, control arms, pinion snubbers, and torque arms all are means of controlling axle windup.

If engine torque is applied to the rear axle to drive the vehicle, the axle is referred to as a **live axle.**

LEAF SPRING REAR SUSPENSIONS

A leaf spring suspension is a simple system because it does not require control arms to brace and position the axle. The leaf springs link the axle to the frame and effectively serve two purposes:

- Absorbing road shock
- Locating the axle under the vehicle

Most rear-wheel-drive trucks use a solid rear axle with leaf springs in an arrangement called a **Hotchkiss drive.** See Figure 87–4. Leaf springs on a driven axle control axle windup by

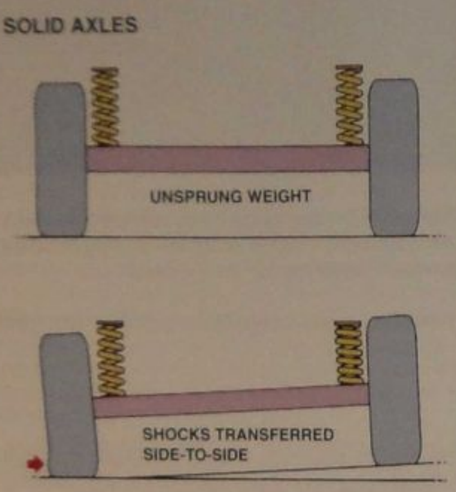


Figure 87–2 A solid axle supports the springs, so the axle and suspension components are unsprung weight. When one wheel rides over a bump, the shock transfers through the solid axle to the opposite side, leading to unstable handling.

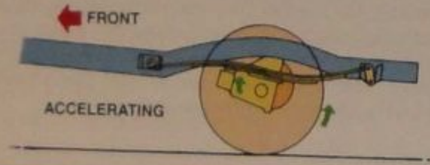


Figure 87–3 When the axle housing reacts against the force of axle shaft rotation, the front of the differential tilts upward, creating axle windup.

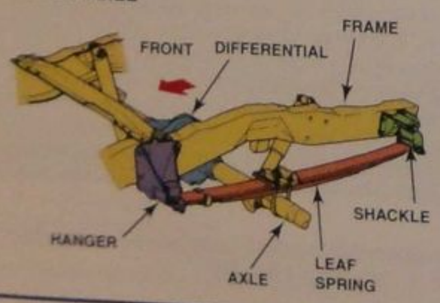


Figure 87–4 A typical rear-wheel-drive pickup truck rear suspension equipped with leaf springs. This type of arrangement is called a Hotchkiss drive and the drive train forces are controlled by the rear suspension components.

transferring force from the axle housing to the frame. The front portion of the leaf spring, from the axle housing to the frame mount, acts like a trailing control arm. However, if the front section of the leaf spring is too flexible, it may not control axle windup as well. To compensate, some manufacturers make the front section of the spring shorter, and therefore less flexible, than the rear section.

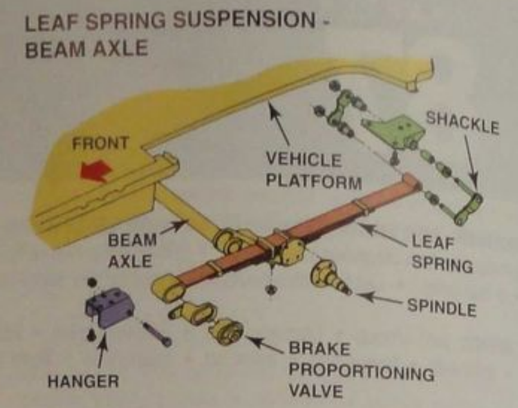


Figure 87–5 An exploded view of a beam axle with multi-leaf springs.



Figure 87–6 A trailing arm rear suspension with a solid axle used on a front-wheel-drive vehicle.

Leaf springs are used on the rear of many light- and medium-duty trucks and vans. See Figure 87–5. The wheel spindles bolt to the flanges, the centers of the leaf springs rest on the seats, and U-bolts secure the springs to the axle. A shackle attaches the rear of each spring to the unit-body frame, while the front of each spring pivots through a bolt and bushing connected to a hanger that bolts to the body.

TRAILING ARM REAR SUSPENSIONS

A **trailing arm** extends from a frame crossmember located ahead of the rear axle back to the axle housing or a wheel knuckle. Trailing arms run parallel to the centerline of the chassis. See Figure 87–6. A trailing arm mounts to the frame with bushings, which allows the arm to pivot as the wheel rides over bumps. Some rear suspensions use two sets of trailing arms, one set positioned higher in the chassis than the other. Although the arms in this type of arrangement are commonly referred to as the *upper control arms* and *lower control arms*, they are usually called trailing arms. The word *trailing* applies to any link where the supported member trails the arm. Trailing arms may be used to brace either a driven or nondriven solid rear axle against front-to-rear forces, but they do not provide much resistance to side-to-side, or lateral, forces. The axle itself is one means of

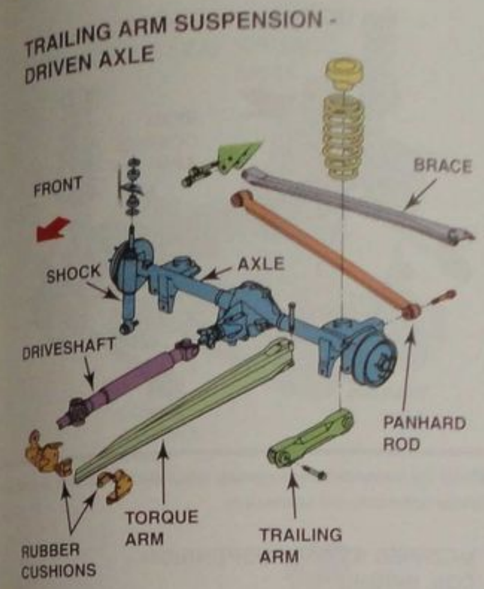


Figure 87–7 The Camaro and Firebird rear suspension systems use a torque arm to control axle windup.

locating the wheels side-to-side, and solid rear suspensions frequently use another rod to provide additional support. Trailing arms transfer axle windup force to the frame and control front-to-rear axle movement. On a few models, especially those with a high-performance suspension, a **torque arm** provides additional resistance to axle windup. See Figure 87–7. The torque arm extends parallel to the drive shaft between the rear axle and the transmission. One end of the torque arm is rigidly bolted to the differential housing, while the other end attaches to the transmission through a cushioned bracket to allow some flex.

A trailing arm rear suspension on a nondriven solid axle virtually always includes a **track rod,** also called a **Panhard rod.** A track rod is a rod attached to the body or frame on one end and the rear axle on the other. The purpose of the track rod is to keep the rear axle centered under the vehicle. The suspension may use either coil springs or struts.

The rear axle is a U-shaped steel beam that is open on the bottom. See Figure 87–8. Flat metal axle end plates, to which the wheel spindles bolt, are attached to each end of the beam. A torsion bar or rod fits inside the beam and is welded to the axle end plates. The trailing arms, which are welded to the outboard ends of the axle, extend forward and attach to the frame with pivot bushing mounts. A bracket on top of the beam axle locates the ring-type lower strut mount, and the upper strut mount attaches to a reinforced area of the wheel well.

SEMI-TRAILING ARM REAR SUSPENSIONS

A **semi-trailing arm** is similar to a trailing arm in that it extends back from a frame member to the axle. However, a trailing arm is parallel to the vehicle centerline whereas a semi-trailing arm pivots at an angle to the vehicle centerline. Semi-trailing arms have an advantage over trailing arms because they control both side-to-side and front-to-rear motion. Typically, a semi-trailing arm suspension uses coil springs, air springs, or pivot-base struts.

A semi-trailing arm suspension may be used with either a solid axle or an independent suspension.

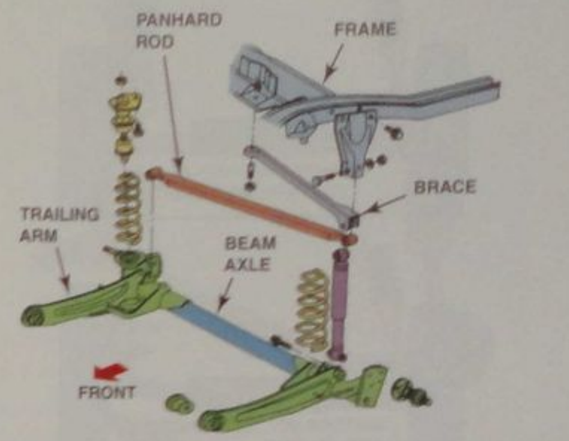


Figure 87–8 A typical beam axle rear suspension, which uses trailing arms and coil springs along with a track rod, also called a Panhard rod, to control side-to-side axle movement.

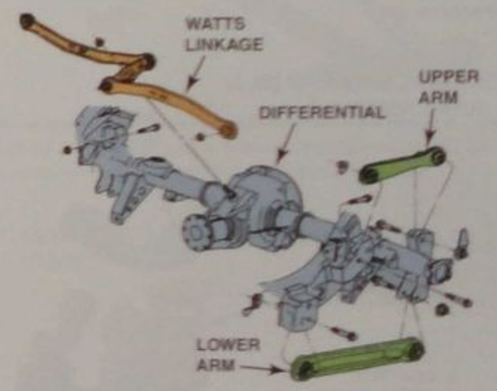


Figure 87–9 This Ford rear suspension uses upper and lower semi-trailing arms to mount the rear axle and a Watts linkage to control side-to-side movement.

The Ford suspension uses two pairs, upper and lower, of semi-trailing arms and a center pivot arrangement to locate the driven rear axle. This axle centering pivot bracket and linkage is called a **Watts linkage.** See Figure 87–9.

INDEPENDENT REAR SUSPENSIONS

The use of **independent rear suspension,** called **IRS,** has grown dramatically over the past several decades to the point where such systems are now fairly common, especially on front-wheel-drive vehicles and some rear-wheel-drive vehicles. Although rarely used on trucks, a number of rear-wheel-drive vehicles do feature an independent rear suspension.

The reduction in unsprung weight is particularly noticeable for driven axles, which are constructed to transfer the weight of the differential and axles to the frame. See Figure 87–10. A vehicle with an independent rear suspension rides and holds better than a similar vehicle equipped with a solid rear axle. An SLA type of independent suspension may be used at the rear of a rear-wheel-drive vehicle. See Figure 87–11.

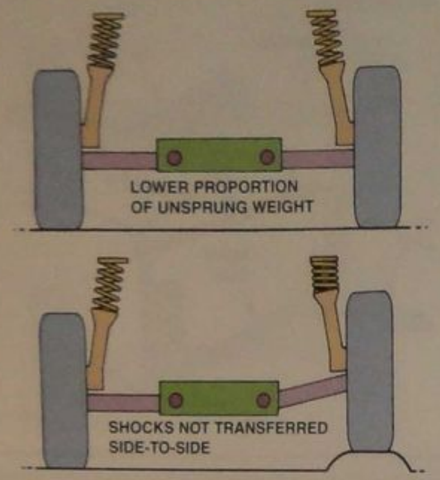


Figure 87–10 An independent rear suspension provides a better ride because less weight is unsprung and the suspension is able to react quickly to bumps in the road without affecting the opposite side.

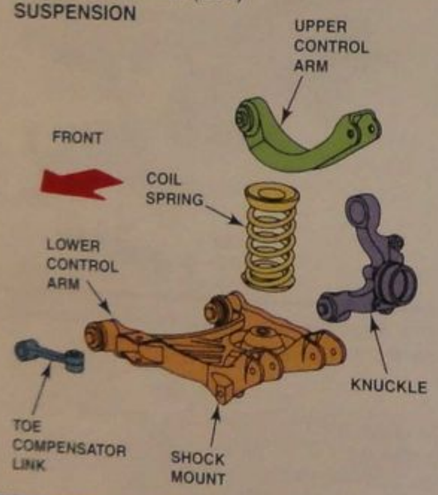


Figure 87–11 A typical short/long-arm independent rear suspension.

The differential carrier bolts to the rear subframe, which bears the weight of the axle. Equal-length axle shafts with constant-velocity (CV) joints at either end connect the differential to the rear wheels, and allow the wheels to move independently of each other.

The main benefit of an SLA suspension is that it reduces tire scrub and improves traction. The positioning of the control arms determines the suspension roll center location. In general, the lower the roll center, the less body roll.

Unit-body front-wheel-drive vehicles frequently use strut suspensions at the rear axle. Typically, the strut mounts to the knuckle and replaces the upper control arm. The first designer to put MacPherson-type struts in a rear suspension was an Englishman, Colin Chapman.

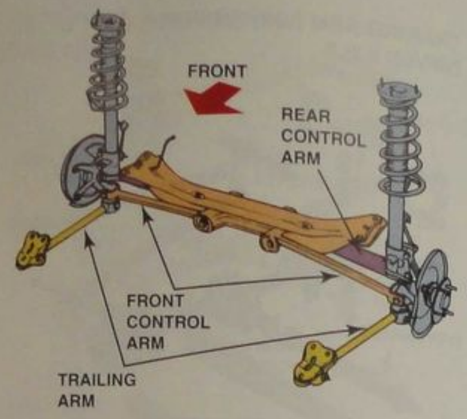


Figure 87–12 This independent rear suspension uses a MacPherson strut, two parallel lower transverse control arms, and a trailing arm.

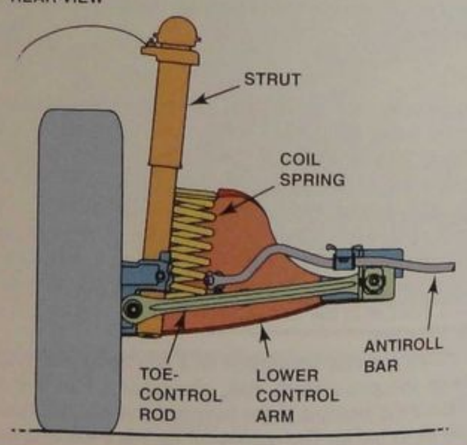


Figure 87–13 The toe-control rod provides an extra brace to keep the rear wheels straight ahead during braking and acceleration on this modified-strut-type independent rear suspension.

For this reason, a rear strut suspension is often referred to as a **Chapman strut** suspension by European manufacturers and engineers.

The MacPherson strut system is the most popular independent rear suspension for late-model front-wheel-drive vehicles. See Figure 87–12. Modified strut rear suspensions are found on a variety of front-wheel-drive models from a number of different manufacturers. See Figure 87–13.

General Motors produced two different rear modified strut systems with transverse leaf springs. See Figure 87–14. A transverse leaf spring is also used on the Chevrolet Corvette and the Cadillac XLR.

SEMI-INDEPENDENT REAR SUSPENSIONS

A **semi-independent suspension** is used only at a nondriven rear axle. The semi-independent design is based on a crossbeam that is similar to the beam axle of a solid, nondriven rear suspension. However, on a semi-independent design the crossbeam

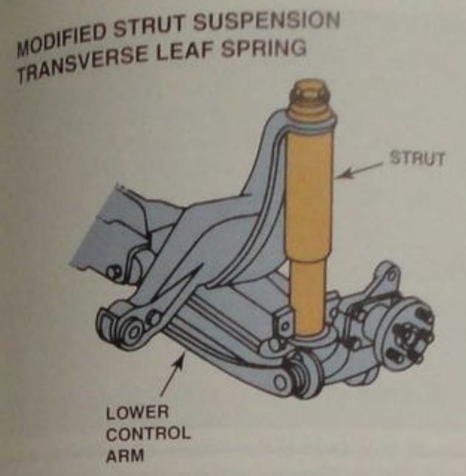


Figure 87–14 The upper drawing shows a transverse-leaf-spring-type independent rear suspension that uses an "H"-shaped lower control arm. The lower drawing shows a transverse leaf spring suspension that uses two parallel lower links and a trailing arm.

is placed ahead, rather than at the centerline, of the wheels. See Figure 87–15. Trailing arms extend rearward from the crossbeam to the wheels. The name *semi-independent* indicates that although an axle does not directly link the wheels, the wheels are not completely independent of each other because they are indirectly connected through the crossbeam.

Some semi-independent rear suspensions use struts. See Figure 87–16.

REAR SUSPENSION SERVICE

Rear suspension service starts with a thorough test drive, to observe any unusual noises or vibrations that may be caused by a fault with a rear suspension component.

After a test drive, safely hoist the vehicle and perform a thorough visual inspection. Use an appropriate prybar and move all of the bushings and joints, checking for deterioration or freeplay. See Figure 87–17.

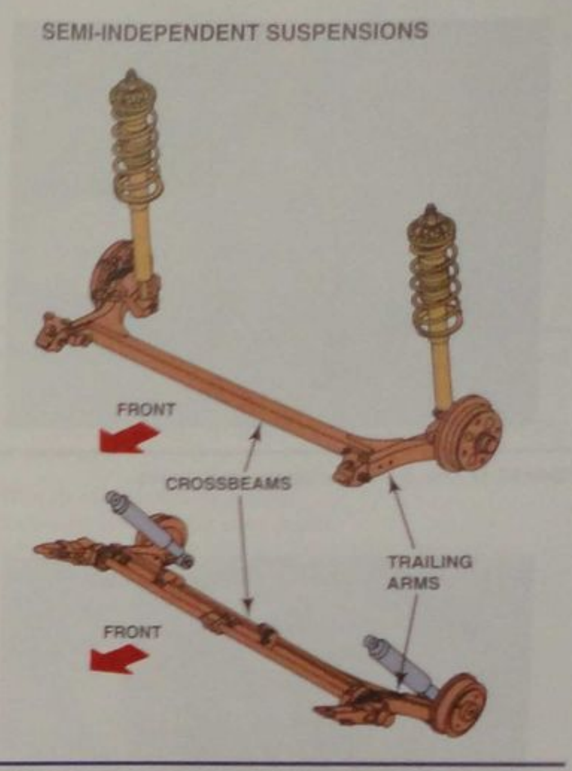


Figure 87–15 The crossbeam is placed toward the front of the vehicle rather than the centerline of the rear wheels on a semi-independent-type rear suspension.

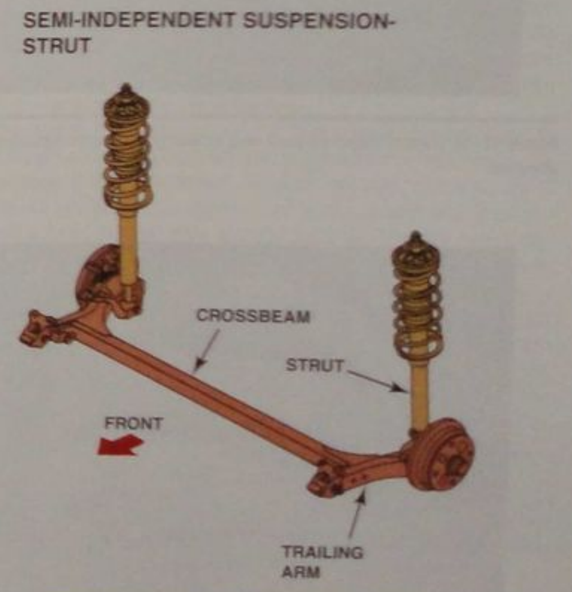


Figure 87–16 A semi-independent rear suspension with MacPherson struts.

Inspect the shock absorber or struts for leakage or damage. Inspect the bump stops for damage. See Figure 87–18. If the bump stops are damaged, this may indicate that the springs are fatigued and the vehicle is at lower-than-normal ride height, or that the shocks or struts are unable to control the springs. See Figure 87–19.



Figure 87–17 Check all rubber bushings for excessive cracking.

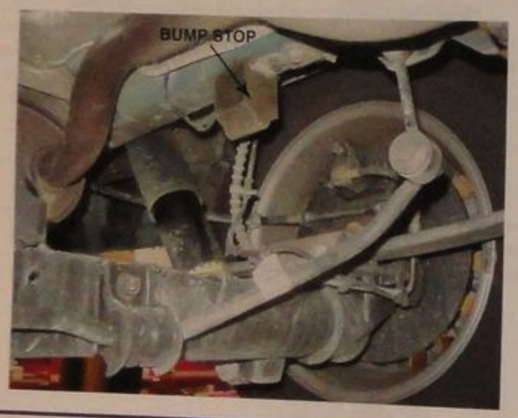


Figure 87–18 Carefully inspect the bump stops for damage during a thorough visual inspection.

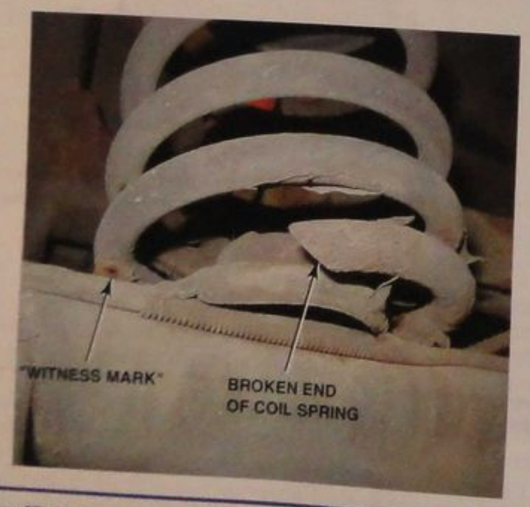


Figure 87–19 A broken spring was discovered during a routine under-vehicle visual inspection. Notice the witness marks that show that the spring coils have been hitting each other.

REAR SHOCK REPLACEMENT

Before removing the rear shock absorbers, the rear axle must be supported to prevent stretching of the rear brake flexible hose. Shocks are attached to the frame or body of the vehicle at the top and to a bracket on the rear axle housing at the bottom. Often, the top of the rear shock absorber is fastened *inside* the vehicle. Consult the vehicle manufacturer's service information for exact procedures and fastener torque values.

NOTE: Shock absorbers and/or struts should always be replaced as a pair.

Air Shock Installation Air-adjustable shock absorbers are a popular replacement for conventional rear shock absorbers. Air shocks can be used to level the vehicle while towing a trailer or when heavily loaded. When the trailer or load is removed, air can be released from the air shocks to return the vehicle height to normal.

Most replacement air shocks are directional and are labeled *left* and *right*. This ensures that the plastic air hose line exits the shock absorber toward the center or rear of the vehicle and is kept away from the wheels.

The plastic air shock line attaches to the shock absorber with an O-ring or brass ferrule and nut. An air leak can result if this O-ring or ferrule is not installed according to the manufacturer's recommendations. Route the plastic air line along the body, keeping it away from the exhaust and any other body parts where the line could be damaged. Attach the line to both shocks to a junction at a convenient location for adding or releasing air.

Rear Coil Springs

Replacement Coil springs in the rear are easily replaced on both front-wheel-drive and rear-wheel-drive vehicles. The procedure includes the following steps:

1. Raise the vehicle safely on a hoist.
2. Remove both rear wheels.
3. Support the rear axle assembly with tall safety stands.
4. Remove the lower shock absorber mounting bolts/nuts and disconnect the shock absorber from the rear axle assembly.
5. Slowly lower the rear axle assembly by either lowering the height of the adjustable safety stands or raising the height of the vehicle on the hoist.
6. Lower the rear axle just enough to remove the coil springs. See Figure 87–20.

CAUTION: The shock absorber is usually the only component that limits the downward movement of the rear axle to allow removal of the rear coil springs. Some vehicles may be equipped with rear suspension height sensors for the adjustable suspension system or an adjustable rear proportioning valve for the rear brakes. Some vehicles also require that the rear stabilizer bar or track rod be disconnected or removed before lowering the rear axle assembly. Always consult service information for the exact procedure and torque specifications for the vehicle being serviced.

Rear Leaf Springs

Replacement Rear leaf springs often need replacement due to one of the following common causes:

1. **Individual leaves of a leaf spring often crack, then break.** When a leaf spring breaks, the load-carrying capacity of the vehicle decreases and it often sags on the side with the broken spring.



Figure 87–20 The shock absorber needs to be disconnected before removing the coil spring.



Figure 87–21 The center bolt is used to hold the leaves of the leaf spring together. However, the hole for the center bolt also weakens the leaf spring. The crack shown is what a technician discovered when the leaf spring was removed during the diagnosis of a sagging rear suspension.

Metal fatigue, corrosion, and overloading are three of the most common causes of leaf spring breakage. See Figure 87–21.

NOTE: When one rear spring on one side sags, the opposite front end of the vehicle tends to *rise*. For example, if the right rear spring breaks or sags down, the left front of the vehicle tends to rise higher than the right front. This unequal vehicle height can make the vehicle difficult to handle, especially around corners or curves.

2. **If the center bolt breaks,** the individual leaves can move and the rear axle is no longer held in the correct location. When one side of the rear axle is behind the other side, the vehicle will dog track. Dog tracking refers to the sideways angle of the vehicle while traveling straight. It is commonly caused by the rear axle steering the vehicle toward one side, while the driver controls the direction of the vehicle with the front wheels.

NOTE: Leaf springs should be replaced in pairs.

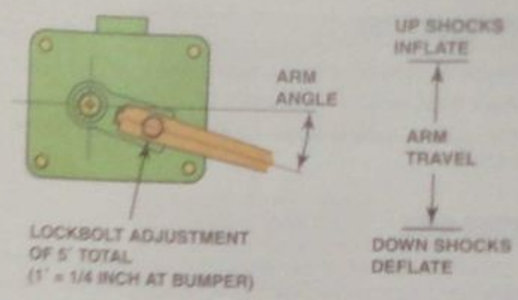


Figure 87–22 Most electronic level-control sensors can be adjusted, such as this General Motors unit.

To replace leaf springs in the rear of a rear-wheel-drive vehicle, follow these steps:

1. Raise the vehicle safely on a hoist.
2. Support the rear axle with safety stands.
3. Remove the rear shackle bolts and forward mounting bolt or mounting bracket.
4. Remove the U-bolts.
5. Being careful of any nearby brake line, remove the spring.
6. Install the new spring, being careful to position the center bolt correctly into the hole on the axle pedestal.

TROUBLESHOOTING REAR ELECTRONIC LEVELING SYSTEMS

The first step with any troubleshooting procedure is to check for normal operation. Some leveling systems require that the ignition key be on (run), while other systems operate all the time. Begin troubleshooting by placing approximately 300 lb (135 kg) on the rear of the vehicle. If the compressor does not operate, check to see if the sensor is connected to a rear suspension member and that the electrical connections are not corroded.

Also check the condition of the compressor ground wire. It must be tight and free of rust and corrosion where it attaches to the vehicle body. If the compressor still does not run, check to see if 12 volts are available at the power lead to the compressor. If necessary, use a fused jumper wire directly from the positive (+) of the battery to the power lead of the compressor. If the compressor does not operate, it must be replaced.

If the ride height compressor runs excessively, check the air compressor, the air lines, and the air shocks (or struts) with soapy water for air leaks. Most air shocks or air struts are not repairable and must be replaced. Most electronic leveling systems provide some adjustments of the rear ride height by adjusting the linkage between the height sensor and the rear suspension. See Figure 87–22.

SUMMARY

1. Solid rear axles are commonly used on rear-wheel-drive and front-wheel-drive vehicles.
2. A Hotchkiss rear suspension uses the leaf springs to absorb axle windup.
3. Trailing arms run parallel to the centerline of the vehicle and are used to locate a solid rear axle.
4. A track rod (Panhard rod) or Watts linkage is used to keep the rear axle centered under the vehicle.
5. Independent rear suspension (IRS) usually uses coil springs but can use a transversely mounted leaf spring.
6. The rear suspension should be supported whenever replacing the rear shock absorbers.

REVIEW QUESTIONS

1. What are the disadvantages of a solid rear axle?
2. What is the purpose of a torque arm?
3. What must be done to ensure safety when replacing the rear shock absorbers?

CHAPTER QUIZ

1. A vehicle equipped with a coil spring front suspension and a leaf spring rear suspension "dog tracks" while driving on a straight, level road. Technician A says that a broken center bolt could be the cause. Technician B says defective rear shock absorbers could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. When axle windup is controlled by the rear leaf spring during acceleration, this system is called _____.
   a. Trailing arm
   b. Semi-trailing arm
   c. Torque arm
   d. Hotchkiss drive
3. A loud "bang" is heard and felt every time the accelerator is depressed or released on a rear-wheel-drive vehicle. Technician A says that a leaf spring could be the cause. Technician B says a broken torque arm could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that all leaf springs are mounted lengthwise on the rear of many vehicles. Technician B says that some vehicles use a transversely mounted leaf spring on the rear. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. A strut-type suspension is used _____.
   a. In the front only
   b. In the rear only
   c. In both the front and rear
   d. In rare vehicles no longer in production
6. Two technicians are discussing rear shock absorbers. Technician A says that if one shock is leaking, then both rear shock absorbers should be replaced. Technician B says that the rear axle should be supported before removing rear shock absorbers. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Technician A says that installing new gas shock absorbers will raise the rear of the vehicle. Technician B says that the shock absorbers usually limit the downward travel of the rear suspension. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. The left front of the vehicle is higher than the right front and the right rear is lower than the left rear. What is the most likely cause of this problem?
   a. A weak right-rear shock absorber
   b. A broken track rod
   c. A broken left-front shock absorber
   d. A sagging right-rear spring
9. One rear leaf spring is broken. Technician A says that both rear leaf springs should be replaced. Technician B says that only the broken spring needs to be replaced. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Two technicians are discussing electronic leveling systems. Technician A says that a weight should be placed in the vehicle as part of the diagnostic procedure. Technician B says many ride height sensors are adjustable. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 88

Electronic Suspension Systems

OBJECTIVES: After studying Chapter 88, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "B" (Suspension System Diagnosis and Repair). • Describe how suspension height sensors function. • Explain the use of the various sensors used for electronic suspension control. • Discuss the steering wheel position sensor. • Explain how solenoids and actuators are used to control the suspension.

KEY TERMS: actuator • air suspension • armature • AS • automatic level control (ALC) • CCVRTMR • computer command ride (CCR) • desiccant • driver selector switch • EBCM • ECU • electromagnet • handwheel position sensor • height sensor • input • lateral accelerometer sensor • LED • magneto-rheological (MR) • mode select switch • motor • MRRTD • output • perform ride mode • photocell • phototransistor • pulse width • pulse-width modulation • real-time dampening (RTD) • RPO • RSS • selectable ride (SR) • solenoid • solenoid controlled damper • Stabilitrack • steering wheel position sensor • touring ride mode • vehicle stability enhancement system (VSES) • VS sensor • yaw rate sensor

Since the mid-1980s, many vehicle manufacturers have been introducing models with electronic suspension controls that provide variable shock stiffness or spring rate. The main advantage of electronic controls is that the suspension can react to different conditions. The system provides a firm suspension feel for fast cornering and quick acceleration and braking, with a soft ride for cruising. See Figure 88–1.

ELECTRONIC CONTROLS AND SENSORS

Sensors and switches provide **input** to the electronic control module (ECM), or system computer. The ECM, which may also be referred to as the **electronic control unit (ECU),** is a small computer that receives input in the form of electrical signals from the sensors and switches and provides **output** electrical signals to the system actuators. See Figure 88–2. The electrical signal causes an **actuator** to perform some type of mechanical action.

Height Sensors Sensors, which are the input devices that transmit signals to the ECM, monitor operating conditions and component functions. A **height sensor** senses the vertical relationship between the suspension component and the body. Its signal indicates to the ECM how high the frame or body is, or how compressed the suspension is. A number of sensor designs are used to determine ride height, including a **photocell** type of sensor. See Figure 88–3.

Four height sensors, one at each wheel, deliver an input signal to the ECM. All four sensors are similar and use a control link, lever, slotted disc, and four photo interrupters to transmit a signal. Each photo interrupter consists of a **light-emitting diode (LED)** and a **phototransistor,** which reacts to the LED.

Inside the sensor, the LEDs and phototransistors are positioned opposite each other on each side of the slotted disc. See Figure 88–4. When the system is activated, the ECM applies voltage to the LEDs, which causes them to illuminate. Light from an LED shining on the phototransistor causes the transistor to generate a voltage signal. Signals generated by the phototransistors are delivered to the ECM as an input that reflects ride height.

As suspension movement rotates the disc, the slots, or windows, in the disc either allow light from the LEDs to shine on the phototransistors or prevent it. The windows are positioned in such a manner that, in combination with the four LEDs and transistors, the sensor is capable of generating 16 different levels of voltage. This variable voltage, which is transmitted to the ECM as an input signal, directly corresponds to 1 of 16 possible positions of the suspension. This input signal tells the ECM the position of the suspension in relation to the body. Whether the input voltage signal is increasing

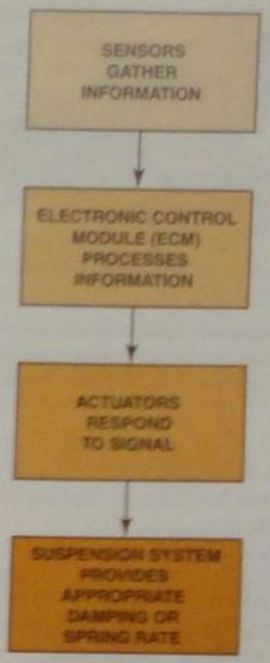


Figure 88–2 Input devices monitor conditions and provide information to the electronic control module, which processes the information and operates the actuators to control the movement of the suspension.

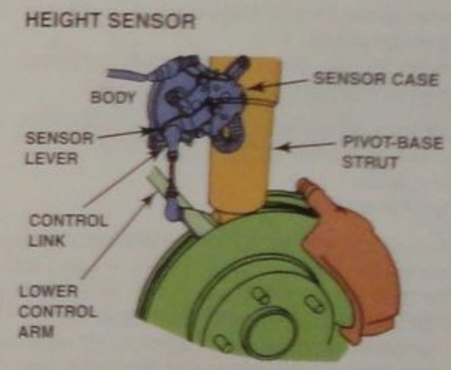


Figure 88–3 A typical electronic suspension height sensor, which bolts to the body and connects to the lower control arm through a control link and lever.

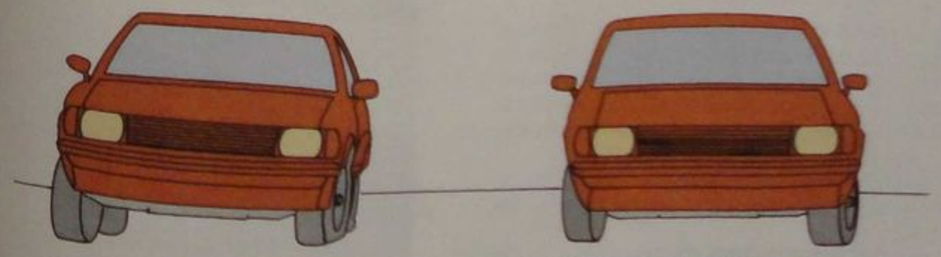


Figure 88–1 An electronically controlled suspension system can help reduce body roll and other reactions better than most conventional suspension systems.

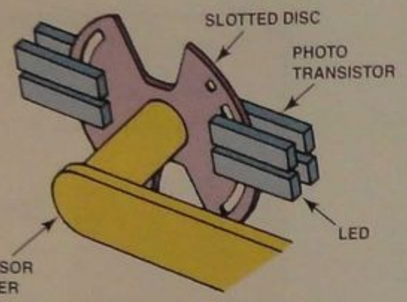


Figure 88–4 When suspension action moves the lever, it rotates the slotted disc and varies how much of the photo transistor is exposed to the LEDs, which vary the input signal.

or decreasing allows the ECM to determine if the suspension is compressing or extending.

The ECM can also determine the relative position of the body to the suspension, or the attitude of the vehicle, from the four height sensors. Comparing front-wheel input signals to those of the rear wheels determines the amount of pitch caused by forces of acceleration or deceleration. A side-to-side comparison allows the ECM to determine the amount of body roll generated by cornering force.

General Motors Electronic Suspension Sensors There are five different sensors found on electronic suspension systems, and GM vehicles can have between one and four of these sensors, depending on the system.

Depending on the vehicle, the *suspension position sensor* may be called by a different name. It can be called:

- An automatic level control sensor
- An electronic suspension position sensor
- A position sensor
- An air suspension sensor

The sensor provides the control module with information regarding the relative position and movement of suspension components. The common mounting location is between the vehicle body and the suspension control arm. See Figure 88–5.

The operation of the sensor is either an air suspension sensor two-wire type or a potentiometer three-wire type. The **air suspension** sensor is also known as a *linear Hall-effect* sensor. The air suspension sensor operation consists of a moveable iron core linked to the components. As the core moves, it varies the inductance of the internal sensor coil relative to suspension position.

The suspension control module energizes and de-energizes the coil approximately 20 times a second, thereby measuring sensor inductance as it relates to suspension position. The potentiometer three-wire sensor requires reference and ground voltage. Similar to the throttle position (TP) sensor, it produces a variable analog voltage signal. See Figure 88–6.

As the suspension moves up or down, an arm moves on the suspension position sensor through a ball-and-cup link. See Figure 88–7.

Suspension position sensor voltage changes relative to this movement. The sensor receives a 5-volt reference signal from the control module. The position sensor returns a voltage signal between 0 and 5 volts depending on suspension arm position.

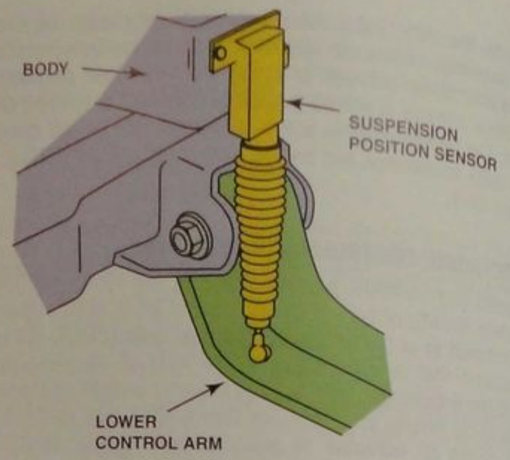


Figure 88–5 Typical suspension position sensor.

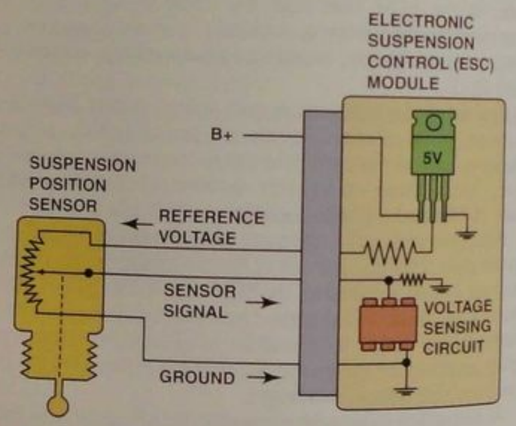


Figure 88–6 A three-wire suspension position sensor schematic.



Figure 88–7 A suspension height sensor.

NOTE: Some systems may require sensor learning or "reprogramming" after replacement. For instance, the sensor used on the Tahoe or Suburban needs to be programmed if replaced. Always check service information for the details and procedures to follow when replacing a sensor on the suspension.

Steering Wheel Position Sensor Depending on the vehicle, the **steering wheel position sensor** may also be called a **handwheel position sensor.** The function of this sensor is to provide the control module with signals relating to steering wheel position, the speed and direction of handwheel position.

The sensor is found on most **real-time dampening (RTD)** and **road-sensing suspension (RSS)** applications. The sensor is typically located at the base of the steering column. Always refer to service information for vehicle-specific information. See Figures 88–8 and 88–9.

The handwheel sensor produces two digital signals, which are used by the **electronic brake control module (EBCM).** These signals are produced as the steering wheel is rotated. The sensor can also produce more than two signals. As an example, the Cadillac Escalade handwheel sensor produces one analog and three digital signals.

The sensor uses a 5-volt signal reference. Analog signal voltage values increase or decrease, between 0 and 5 volts, as the steering wheel is moved left and right of center. The digital signal is also a standard power-to-ground circuit as shown in the schematic.

There are three possible digital signals:

- Phase A
- Phase B
- Index pulse

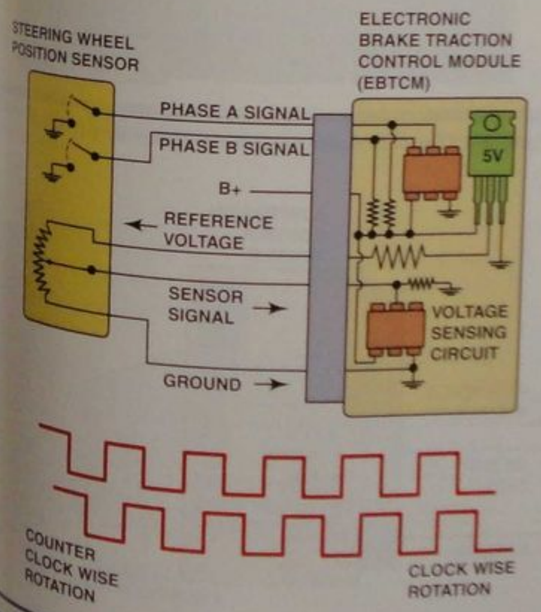


Figure 88–8 The steering wheel position (handwheel position) sensor wiring schematic and how the signal varies with the direction that the steering wheel is turned.

These signals provide the suspension control module with steering wheel speed and direction information. Digital signals are either high or low, 5 volts or 0 volts. See Figure 88–10.

The Tech 2 provides DTC faults for this sensor. If there is an intermittent concern with a steering wheel position sensor, select Tech 2 snapshot and slowly turn the steering wheel lock to lock. After the snapshot is complete, plot the analog sensor voltage to see if the signal dropped out. Any dropout is an indication of an intermittent problem.

Vehicle Speed Sensor The **vehicle speed (VS) sensor** is used by the EBCM to help control the suspension system. The vehicle speed sensor is a magnetic sensor and generates an analog signal whose frequency increases as the speed increases. The ride is made firmer at high speeds and during braking and acceleration and less firm at cruise speeds. See Figure 88–11.

Pressure Sensor A pressure transducer (sensor) is typically mounted on the compressor assembly. This sensor is typically



Figure 88–9 The handwheel position sensor is located at the base of the steering column.

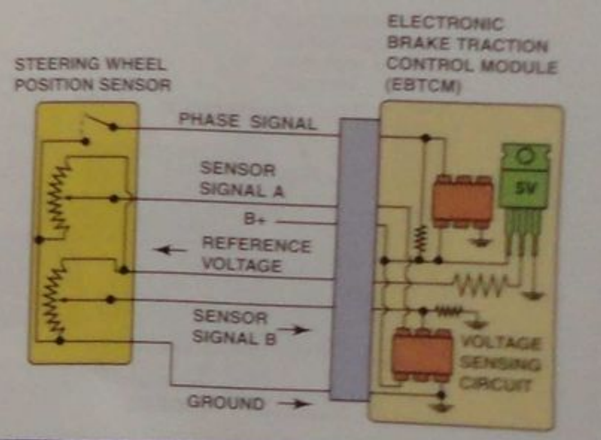


Figure 88–10 Steering wheel (handwheel) position sensor schematic.

found on suspension systems that use a compressor assembly. The main function of the pressure sensor is to provide feedback to the suspension control module about the operation of the compressor. The sensor assures both that a minimum air pressure is maintained in the system and that a maximum value is not exceeded. A pressure transducer (sensor) is typically mounted on the compressor assembly. This sensor is typically found on systems such as air suspension, real-time damping, and road-sensing suspension that use a compressor assembly. See Figure 88–12.

The operation of the pressure sensor requires a 5-volt reference, a ground, and a signal wire to provide feedback to the control module. The voltage output on the signal wire will vary from 0 to 5 volts based upon pressure in the system. A high voltage indicates high pressure and low voltage indicates a low pressure.

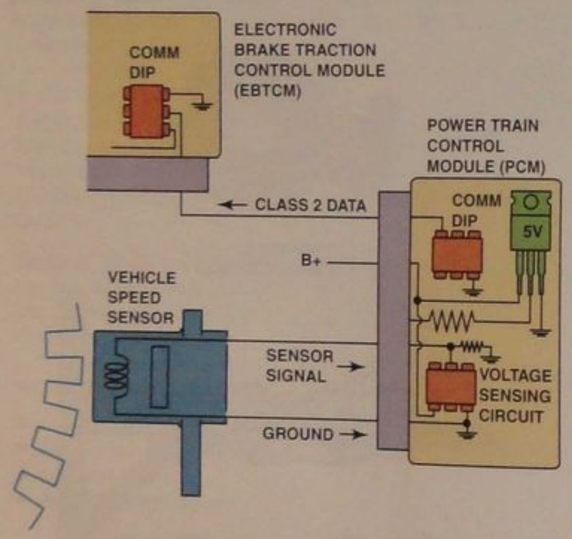


Figure 88–11 The VS sensor information is transmitted to the EBCM by Class 2 serial data.

Lateral Accelerometer Sensor The function of the **lateral accelerometer sensor** is to provide the suspension control module with feedback regarding vehicle cornering forces. This type of sensor is also called a G-sensor, with the letter "G" representing the force of gravity. For example, when a vehicle enters a turn, the sensor provides information as to how hard the vehicle is cornering. This information is processed by the suspension control module to provide appropriate damping on the inboard and outboard dampers during cornering events. The lateral accelerometer sensor is found on the more complex suspensions systems, such as RTD and RSS systems that incorporate the **vehicle stability enhancement system (VSES).**

This sensor can be either a stand-alone unit or combined with the yaw rate sensor. Typically, the sensor is mounted in the passenger compartment under a front seat, center console, or package shelf.

The sensor produces a voltage signal of 0 to 5 volts as the vehicle maneuvers left or right through a curve. The signal is an input to the EBCM. If zero lateral acceleration, the sensor input is 2.5 volts. Check service information for specific codes that can be set.

If driving the vehicle and the voltage values increase or decrease during cornering events, this indicates proper operation. See Figure 88–13.

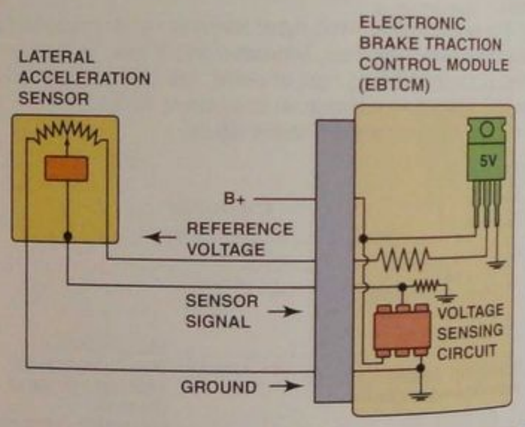


Figure 88–13 A schematic showing the lateral acceleration sensor and the EBCM.

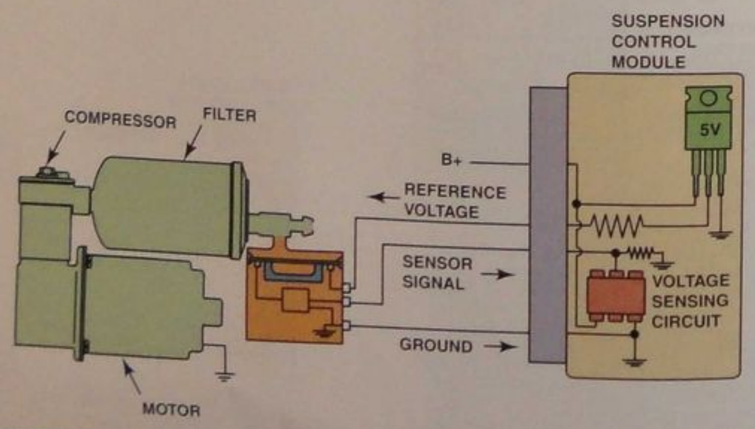


Figure 88–12 An air pressure sensor.

Yaw Rate Sensor The **yaw rate sensor** provides information to the suspension control module and the EBCM. This information is used to determine how far the vehicle has deviated from the driver's intended direction. The yaw sensor is used on vehicles equipped with Electronic Stability Control (ESC).

TECH TIP ✔ **Quick and Easy "G" Sensor Test**

Most factory scan tools will display the value of sensors, including the lateral accelerometer sensor (G-sensor). However, the G-sensor value will read zero unless the vehicle is cornering. A quick and easy test of the sensor is to simply unbolt the sensor and rotate it 90 degrees with the key on engine off. See Figure 88–14. Now the sensor is measuring the force of gravity and should display 1.0 G on the scan tool. If the sensor does not read close to 1.0 G or reads zero all of the time, the sensor or the wiring is defective.

This sensor can be either a stand-alone unit or combined with the lateral accelerometer sensor. Typically, the sensor is mounted in the passenger compartment under the front seat, center console, or on the rear package shelf.



Figure 88–14 The lateral accelerometer sensor (G-sensor) is usually located under the center console.

The sensor produces a voltage signal of 0 to 5 volts as the vehicle yaw rate changes. The voltage signal is an input to the EBCM. The yaw rate input to the EBCM indicates the number of degrees that the vehicle deviates from its intended direction.

For example, with a 0-degree yaw rate, the sensor output is 2.5 volts. During an emergency maneuver, the signal will vary above or below 2.5 volts. This sensor does set DTC codes. These codes can be found in service information. See Figure 88–15.

Driver Selector Switch The **driver selector switch** is a two- or three-mode switch, usually located in the center console, and is an input to the suspension control module.

The switch that is used to select either touring (soft) or performance (firm) ride is found on the **Selectable Ride (SR)** and the **Computer Command Ride (CCR)** systems. The mode select switch status is generally displayed on a scan tool. The three-position switch is used on the Corvette RTD system, and allows the driver to select three modes of operation:

- Tour
- Sport
- Performance

ELECTRONIC SUSPENSION SYSTEM ACTUATORS

Each actuator in an electronically controlled suspension system receives output signals from the ECM and responds to these signals, or commands, by performing a mechanical action. Actuators are usually inductive devices that operate using an electromagnetic field. A simple **electromagnet** consists of a soft iron core with a coil of wire, usually copper, wrapped around it. See Figure 88–16.

Electrical current traveling through the coiled wire creates a magnetic field around the core. All magnets are polarized; that is, they have a north, or positive, and a south, or negative, pole. When the opposite poles of two magnets are placed near each other—positive-to-negative—the magnets attract each other. Place the same poles together, positive-to-positive or negative-to-negative, and the magnets repel each other. See Figure 88–17. Magnets also attract and are attracted to certain types of metals, especially iron and steel.

When an electromagnet has more than one coil, the stronger primary coil can induce voltage into the weaker secondary coil. This inductive transfer occurs even though there is no physical connection between the two coils.

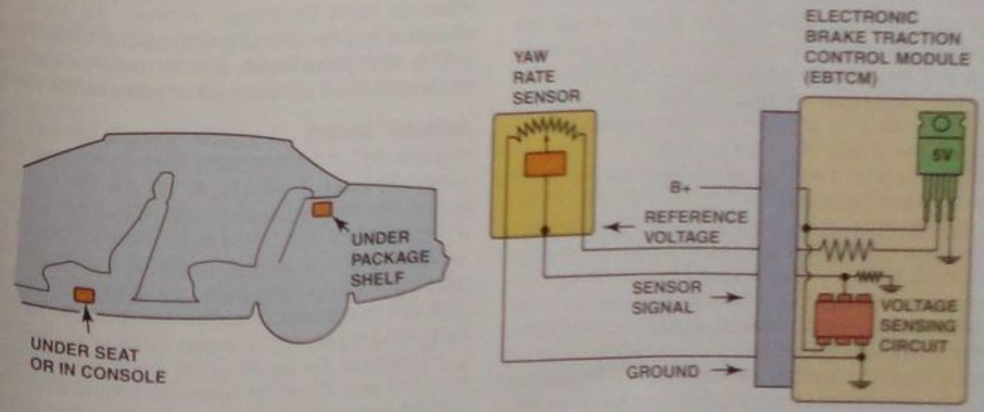


Figure 88–15 Yaw rate sensor showing the typical location and schematic.

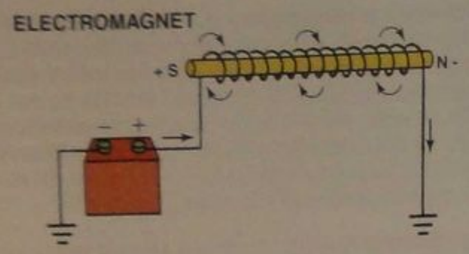


Figure 88–16 A magnetic field is created whenever an electrical current flows through a coil of wire wrapped around an iron core.

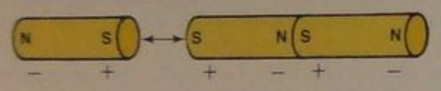


Figure 88–17 When magnets are near each other, like poles repel and opposite poles attract.

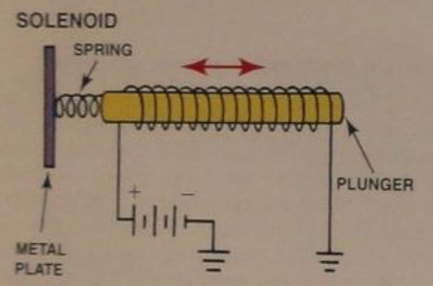


Figure 88–18 When electrical current magnetizes the plunger in a solenoid, the magnetic field moves the plunger against spring force. With no current, the spring pushes the plunger back to its original position.

Solenoids In a **solenoid,** the core of the electromagnet also acts as a plunger to open and close a passage or to move a linkage. Solenoids are cylindrically shaped with a metal plate at one end and open at the other end to allow the plunger to move in and out. The electromagnetic coils are placed along the sides of the cylinder. A preload spring forces the plunger toward one end of the device when the solenoid is de-energized, or there is no current in the coil.

When the solenoid is energized, current passes through the coil and magnetizes the core. The magnetized core is attracted to the metal plate and the strength of the magnetic field overcomes spring force to pull the plunger inward. See Figure 88–18. When the electrical current switches off, the solenoid de-energizes and spring force returns the plunger to its rest position.

An airflow control valve is an example of a solenoid used in an electronically controlled suspension. See Figure 88–19. As the solenoid plunger extends and retracts, it opens and closes air passages between the system air-pressure tank and the air springs. The position of the plunger determines whether the springs receive more pressure or whether pressure bleeds out of them. Increasing the pressure in the air springs lifts the body higher, and decreasing the pressure by bleeding air from the springs lowers the body.

Solenoids are digital devices that are either on or off. However, the ECM can vary the amount a solenoid opens by pulsing the output signal to the coil. If the signal is rapidly switched on and off, spring and magnetic forces do not have enough time to react and

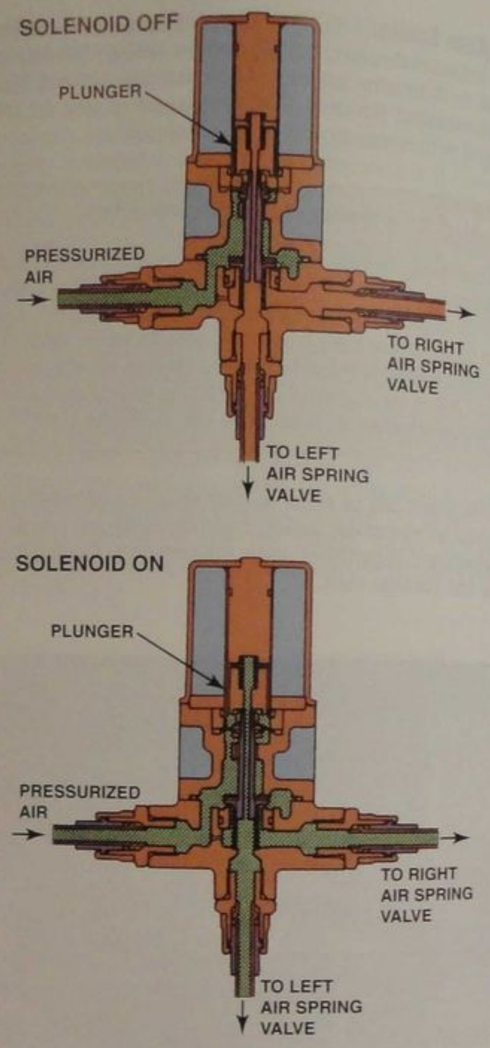


Figure 88–19 This air supply solenoid blocks pressurized air from the air spring valves when off. The plunger pulls upward to allow airflow to the air spring valves when the solenoid is energized.

effectively move the plunger between the signal changes. The amount of time the current is on compared to the amount of time it is off is called **pulse width,** and the control of a solenoid using this pulsing-on-and-off method is called **pulse-width modulation.**

Actuator Motors If a current-carrying conductor is placed in a magnetic field, it tends to move from the stronger field area to the weaker field area. A **motor** uses this principle to convert electrical energy into mechanical movement. Electrical current is directed through the field coils on the motor frame to create a magnetic field within the frame. By applying an electrical current to the **armature,** which is inside the motor frame, the armature rotates from a strong field area to a weaker field area. Armature movement can in turn move another part, such as a gear, pulley, or shaft, attached to it.

Located at the top mount of the air spring variable shock assembly of each wheel, the suspension control actuator moves a control rod that regulates air pressure to the spring, which determines ride height. The actuator is an electromagnetic device consisting of four stator coils and a permanent magnet core. See Figure 88–20.

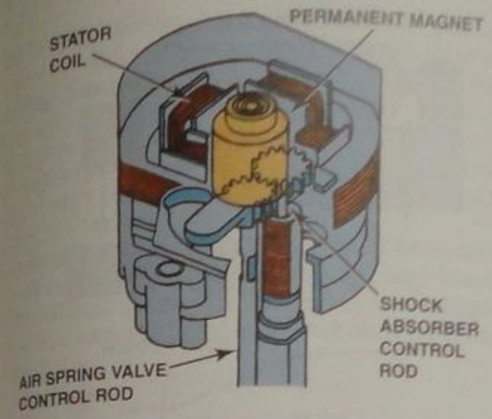


Figure 88–20 An actuator motor uses a permanent magnet and four stator coils to drive the air spring control rod.

The ECM applies current to two stator coils at a time to create opposing magnetic fields around the core, which causes the core to rotate into a new position. Which coils are energized determines how far and in which direction the core rotates. See Figure 88–21. By switching current from one pair of coils to the other, the ECM moves the core into a new position, and a third position is available by reversing the polarity of the coils.

A gear at the base of the permanent magnet connects to a rod that operates the air valve to the air spring. The gear also drives another gear, which operates the control rod of the variable shock absorber. Therefore, the three positions of the suspension control actuator motor provide three shock absorber stiffness settings in addition to a variable air spring.

TYPES OF ELECTRONIC SUSPENSION

The types of electronic suspension systems used on General Motors vehicles, as examples, include:

1. Selectable Ride
2. Automatic Level Control
3. Air Suspension
4. Computer Command Ride
5. Real-Time Dampening/Road-Sensing Suspension
6. Vehicle Stability Enhancement System
7. Magneto-Rheological Suspension (F55)

Selectable Ride (SR) The Selectable Ride (SR) system is the most basic of the electronic systems offered by General Motors. Selectable Ride (SR) allows the driver to choose between two distinct damping levels:

- Firm
- Normal

SR is found on Chevrolet and GMC full-size (C/K) trucks. See Figure 88–22.

A switch is used to control four electronically controlled gas-charged dampers. The **mode select switch** activates the bi-state (two settings) dampers at all four corners of the vehicle, allowing the driver to select vehicle ride characteristics. The system is either energizing or de-energizing the bi-state dampers to provide a firm or normal ride.

Automatic Level Control The **Automatic Level Control** (ALC) system automatically adjusts the rear height of the vehicle

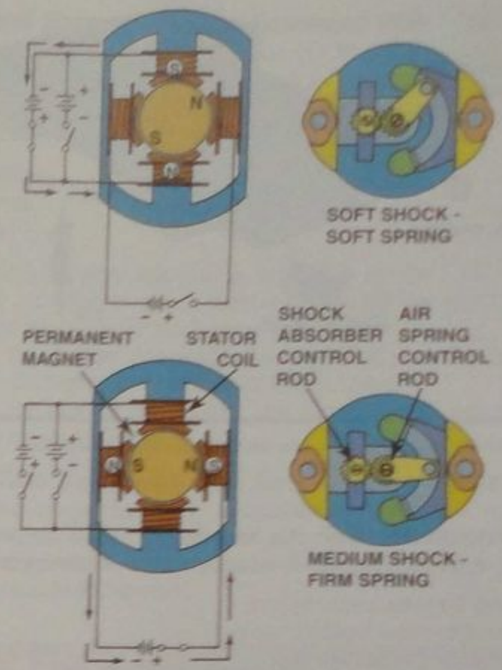


Figure 88–21 The stator coils of the actuator are energized in three ways to provide soft, medium, or firm ride from the air springs and shock absorbers.

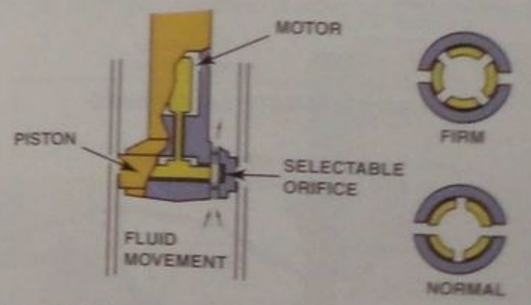


Figure 88–22 Selectable Ride as used on Chevrolet and GMC C/K trucks.

in response to changes in vehicle loading and unloading. Automatic Level Control is found on many General Motors vehicles. ALC controls rear leveling by monitoring the rear suspension position sensor and energizing the compressor to raise the vehicle or energizing the exhaust valve to lower the vehicle. ALC has several variations across the different platforms. See Figure 88–23.

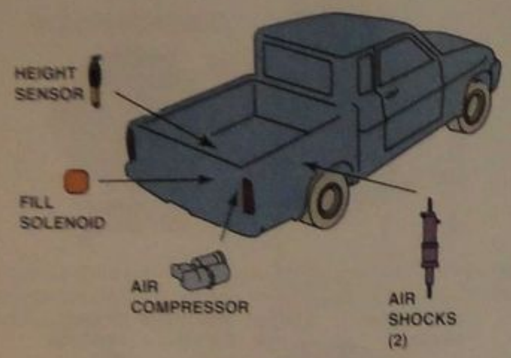


Figure 88–23 ALC maintains the same ride height either loaded or unloaded.

Air Suspension (AS) **Air Suspension (AS)** is a system very similar to the ALC system. The purpose of the AS system includes:

1. Keep the vehicle visually level
2. Provide optimal headlight aiming
3. Maintain optimal ride height

The AS system includes the following components:

- An air suspension compressor assembly
- Rear air springs
- Air suspension sensors

The AS system is designed to maintain rear trim height within 4 mm in all loading conditions, and the leveling function will deactivate if the vehicle is overloaded.

The AS system also includes an accessory air inflator found in the rear cargo area. See Figure 88–24.

Variable-Rate Air Springs In an air spring system with ordinary shock absorbers, the ECM uses the air springs to control trim height and is used on many Ford, Mercury, and Lincoln vehicles.

The three height sensors transmit a signal to the ECM that reflects trim height at each axle. See Figure 88–25. The ignition and brake light switches tell the ECM whether the ignition switch is on or off, and if the brake pedal is depressed. The dome light switch

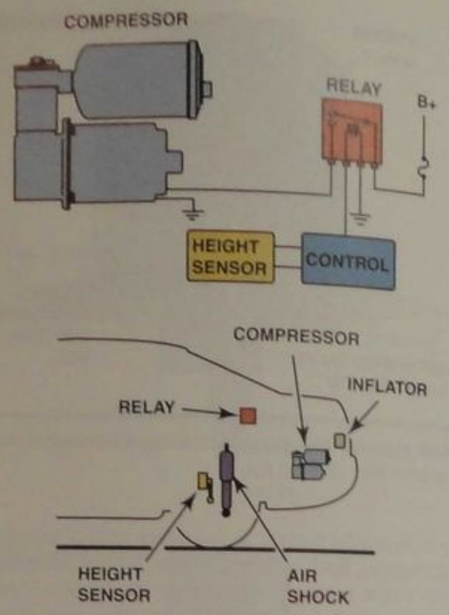


Figure 88–24 A typical schematic showing the air suspension compressor assembly and sensor.

indicates whether any doors are open. The on/off switch disables the air spring system to avoid unexpected movement while towing or servicing the vehicle.

CAUTION: Failure to turn off the system will cause the air springs to be vented when the vehicle is hoisted. This will cause the vehicle to drop almost to the ground when the vehicle is lowered. This can cause damage to the air springs and/or to the vehicle.

The ECM receives information from the height sensors indicating that the trim height is too high or too low, and it energizes the actuators to add or bleed air from the air springs. The system actuators can still operate for up to an hour after the ignition is switched off.

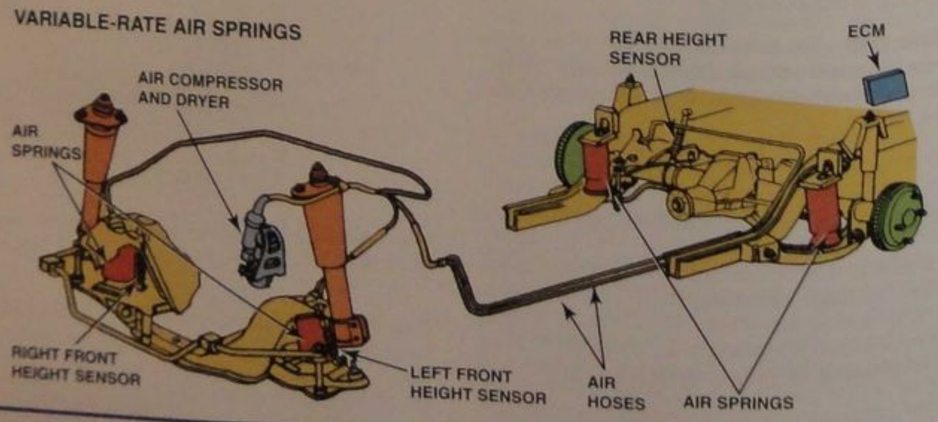


Figure 88–25 The typical variable-rate air spring system uses three height sensors, two in the front and one in the rear, to monitor trim height and to provide input signals to the ECM.

Any time the ignition is switched to the "run" position, the ECM raises the vehicle, if necessary, within the first 45 seconds. If trim height is too high and the vehicle must be lowered, the ECM always doing so for 45 seconds after the ignition is switched on.

An air compressor with a regenerative dryer provides the air charge required to inflate the air springs on the air suspension system, and a vent solenoid is used to relieve air pressure and deflate the springs. See Figure 88–26.

By energizing the compressor relay, the ECM directs current to turn on the compressor motor when trim height needs to be raised. The ECM command to lower the vehicle is an electrical signal that opens the vent solenoid to bleed air pressure out of the system. See Figure 88–27.

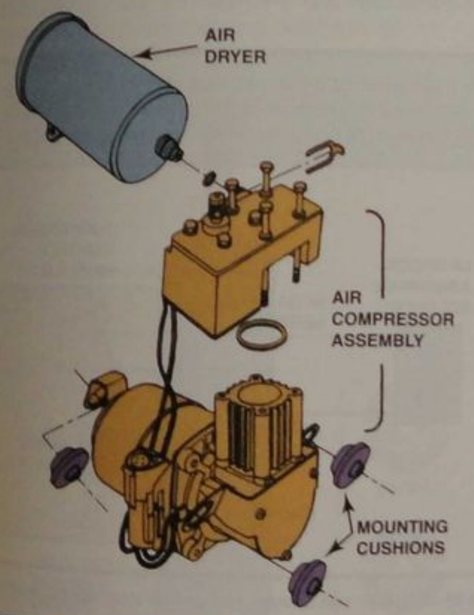


Figure 88–26 The air spring compressor assembly is usually mounted on rubber cushions to help isolate it from the body of the vehicle. All of the air entering or leaving the air springs flows through the regenerative air dryer.



Figure 88–27 A solenoid valve at the top of each spring regulates airflow into and out of the air spring.

General Motors Computer Command Ride The General Motors Computer Command Ride (CCR) system controls ride firmness by automatically controlling an actuator in each of the four struts to increase ride firmness as speed increases.

The three damping modes are:

- Comfort
- Normal
- Sport

Damping mode selection is controlled by the CCR control module according to vehicle speed conditions, driver select switch position, and any error conditions that may exist.

In the **perform ride mode,** the system will place the damping level in the firm mode regardless of vehicle speed.

In the **touring ride mode,** the damping level depends on vehicle speed. See Figure 88–28.

Real-Time Dampening and Road-Sensing Suspension Real-time dampening (RTD) independently controls a solenoid in each of the four shock absorbers in order to control the vehicle ride characteristics and is capable of making changes within milliseconds (0.001 second).

TECH TIP ✓ **Check the RPO Code**

Whenever working on the suspension system check the **RPO (regular production option)** code for the type of suspension used. For example, the F55 RPO may be called by a different name depending on the make and model of vehicle. Also, service procedures will be different on the same vehicle depending on whether it is equipped with an F45 or an F55 system.

Road-sensing suspension (RSS), along with ALC, controls damping forces in the front struts and rear shock absorbers in response to various road and driving conditions.

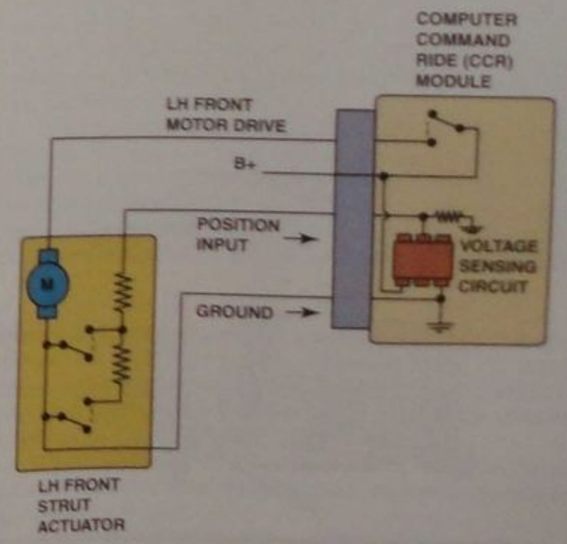


Figure 88–28 Schematic showing Computer Command Ride (CCR) system.

RTD and RSS incorporate the following components:

- An electronic suspension control module,
- Front and rear suspension position sensors,
- Bi-state dampers
- A ride select switch, and
- An air compressor is used on some models.

See Figures 88–29 and 88–30.

Bi-State and Tri-State Dampers The bi-state damper is also known as a **solenoid controlled damper.** Bi-state dampers are found on the RTD, RSS, and SR systems. Each of the suspension dampers used in these systems have an integral solenoid. The solenoid valve provides various amounts of damping by directing hydraulic damping fluid in the suspension shock absorber or strut. See Figure 88–31.

The General Motors version of ESC is called the vehicle stability enhancement system (VSES) and includes an additional level of vehicle control to the EBCM. VSES is also known as **Stabilitrak.**

The purpose of the vehicle stability enhancement system along with the antilock brake system (ABS) is to provide vehicle stability enhancement during oversteer or understeer conditions.

The pulse-width modulation (PWM) voltage signal from the suspension control module controls the amount of current flow through each of the damper solenoids. With a low PWM signal de-energized, more hydraulic damping fluid is allowed to bypass the main suspension damper passage, resulting in a softer damping mode.

As the PWM signal increases, or is energized, the damping mode becomes more firm. See Figure 88–32.

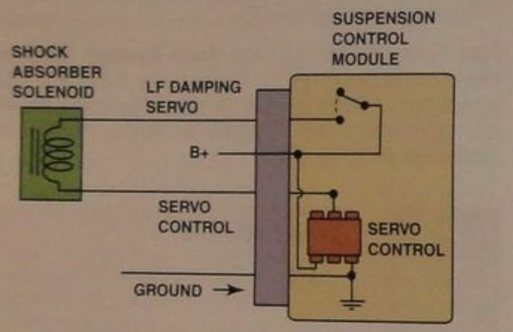
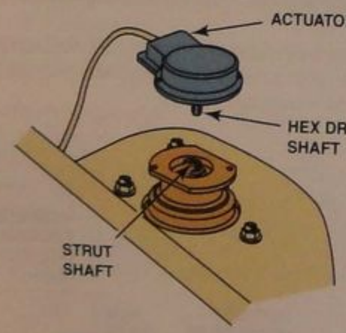


Figure 88–29 Schematic showing the shock control used in the RSS system.



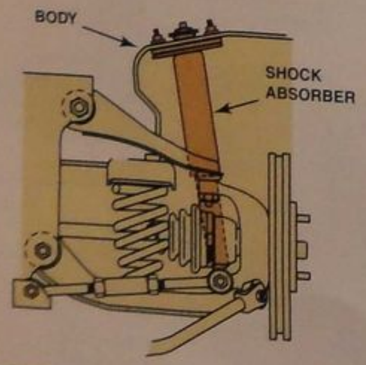


Figure 88–30 Bi-state dampers (shocks) use a solenoid to control fluid flow in the unit to control compression and rebound actions.

NOTE: If the suspension module does not control the shock absorber solenoid, a full soft damping mode results. In some system malfunctions, the module may command one or all of the damper solenoids to a full soft damping.

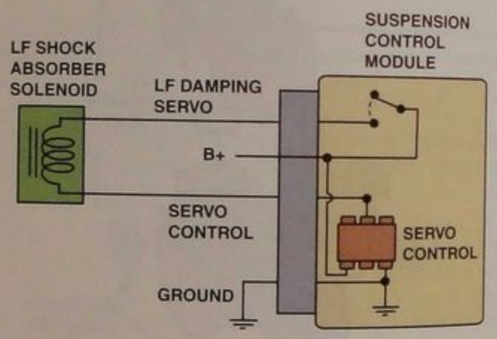


Figure 88–31 Solenoid valve controlled shock absorber circuit showing the left front (LF) shock as an example.

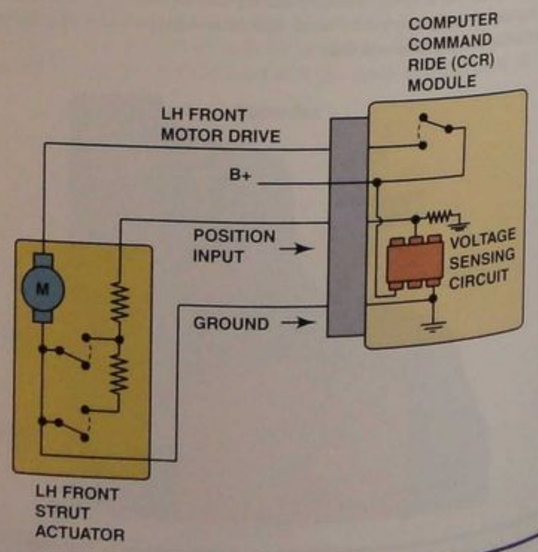


Figure 88–32 A typical CCR module schematic.

The main difference between a tri-state damper and a bi-state damper is that the tri-state damper uses an electrical actuator, whereas the bi-state damper is solenoid controlled.

The three damping modes include:

- Comfort
- Normal
- Sport

A tri-state damper has an integral electrical strut actuator that rotates a selector valve to change the flow of hydraulic damping fluid. See Figure 88–33.

The CCR module controls the operation of the strut actuators to provide the three damping modes.

The strut position input provides feedback to the CCR module. The strut position input is compared to the commanded actuator position to monitor system operation. See Figure 88–34.

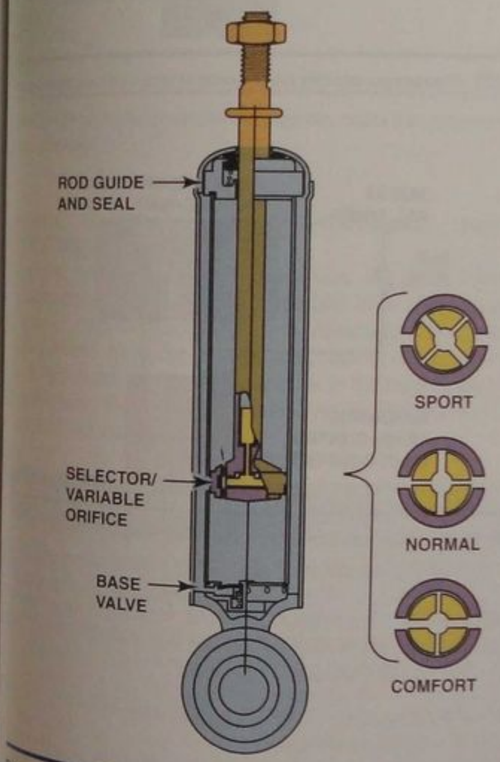


Figure 88–33 The three dampening modes of a CCR shock absorber.

AUTOMATIC LEVEL CONTROL (ALC)

Vehicles that have an air inflator system as part of the ALC system also have an air inflator switch. The air inflator switch is an input to the ALC and AS system. The inflator switch is used to control the air inflator system operation and provides a signal to the ALC or AS module to initiate compressor activation.

With the ignition on, the driver can turn the system to ON. The switch will command the compressor to run for up to 10 minutes, allowing time to inflate a tire or other items requiring air.

NOTE: There are no DTCs associated with compressor assembly.

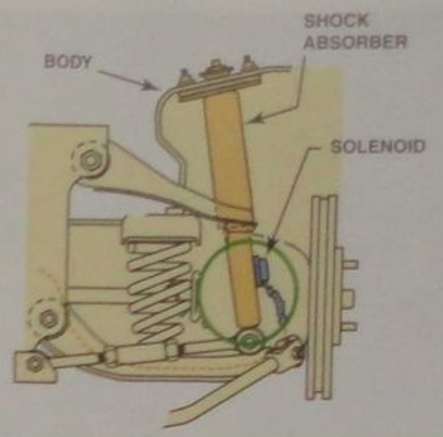


Figure 88–34 Integral shock solenoid.

FREQUENTLY ASKED QUESTION ???

What Are Self-Leveling Shocks?

A German company, ZF Sachs, supplies a self-leveling shock absorber to several vehicle manufacturers, such as Chrysler for use on the rear of minivans, plus BMW, Saab, and Volvo. The self-leveling shocks are entirely self-contained and do not require the use of height sensors or an external air pump. See Figure 88–35.

The shock looks like a conventional shock absorber but contains the following components:

- Two reservoirs in the outer tube
- An oil reservoir (low-pressure reservoir)
- A high-pressure chamber

Inside the piston rod is the pump chamber containing an inlet and an outlet valve. When a load is placed in the rear of the vehicle, it compresses the suspension and the shock absorber. When the vehicle starts to move, the internal pump is activated by the movement of the body. Extension of the piston rod causes oil to be drawn through the inlet valve into the pump. When the shock compresses, the oil is forced through the outlet valve into the high-pressure chamber. The pressure in the oil reserve decreases as the pressure in the high-pressure chamber increases. The increasing pressure is applied to the piston rod, which raises the height of the vehicle.

When the vehicle's normal height is reached, no oil is drawn into the chamber. Because the shock is mechanical, the vehicle needs to be moving before the pump starts to work. It requires about 2 miles of driving for the shock to reach the normal ride height. The vehicle also needs to be driven about 2 miles after a load has been removed from the vehicle for it to return to normal ride height.

Inflator or Compressor Relay The suspension control module energizes the relay to activate the compressor motor. This adjusts the rear trim height as needed. The suspension control module controls the compressor relay for normal operation or for the accessory air inflator.

To avoid compressor overheating, the timer within the suspension control module limits the compressor run time to 10 minutes. See Figure 88–36.

On RTD or RSS systems with a compressor, the scan tool may display DTCs associated with compressor relay operation. On some vehicle applications, the scan tool will display data relating to relay



Figure 88–35 A typical ZF Sachs self-leveling shock, as used on the rear of a Chrysler minivan.

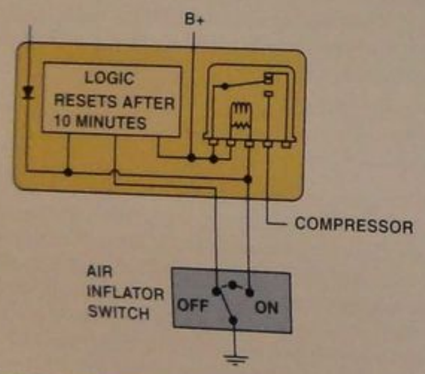


Figure 88–36 Schematic of the ALC system.

operation and can be used to command the relay to verify proper operation.

Compressor The compressor is a positive-displacement air pump and can generate up to 150 lbs. of pressure per square inch (PSI). The compressor is found on the ALC, AS, RTD, and RSS systems. A 12-volt permanent magnet motor drives the compressor. The compressor supplies compressed air to the rear air shock absorbers or struts to raise the vehicle. See Figure 88–37.

Air Dryer Within the compressor is an air dryer. The air dryer is responsible for removing moisture from the compressor system. Improper air dryer operation can cause a premature failure in the system if an air line restriction occurs due to excessive moisture build-up. A dryer on the output side of the compressor contains silica gel **desiccant**, which removes moisture from the discharge air before it travels through the nylon air hoses to the air chamber of the rear shocks.

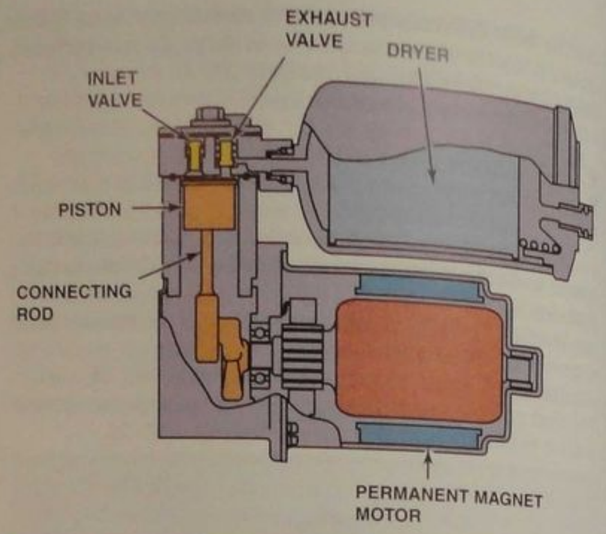


Figure 88–37 Air compressor assembly can be located at various locations depending on the vehicle.

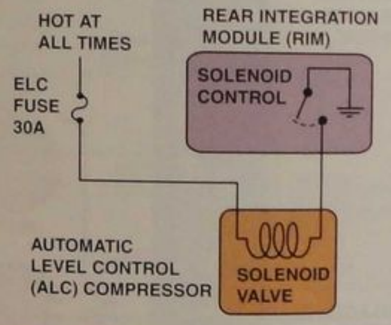


Figure 88–38 The exhaust solenoid is controlled by the rear integration module (RIM).

Exhaust Solenoid The exhaust solenoid, which is located on the compressor, relieves pressure in the system. The ground-side switched exhaust solenoid has three main functions:

1. It releases compressed air from the shock absorbers or air springs to lower the vehicle body.
2. It relieves compressor head pressure. By exhausting air, it protects compressor start-up from high head pressure, which can possibly cause fuse failure.
3. The solenoid acts as a pressure relief valve, which limits overall system pressure.

The special functions on many scan tools can be used to command the solenoid and to verify its operation. See Figures 88–38 and 88–39.

MAGNETO-RHEOLOGICAL (MR) SUSPENSION

MR fluid shocks use a working fluid inside the shock that can change viscosity rapidly depending on electric current sent to an electromagnetic coil in each device. The fluid is called **magneto-rheological (MR)** and is used in monotube-type shock absorbers. This type of shock and suspension system is called the **magneto-rheological real-time damping (MRRTD)** or **chassis continuously variable real-time dampening magneto-rheological suspension (CCVRTMR).**

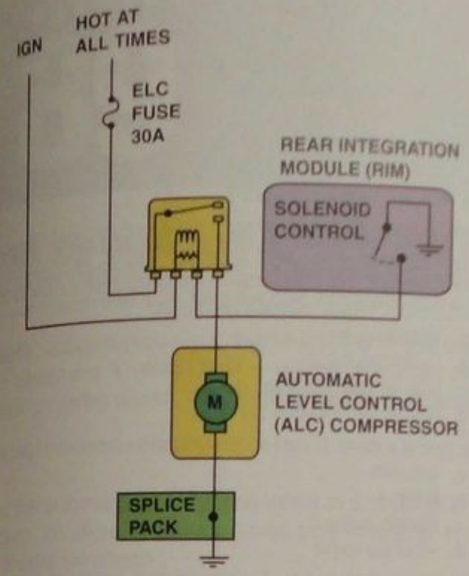


Figure 88–39 Schematic showing the rear integration module (RIM) and how it controls the ALC compressor.

Under normal operating conditions, the fluid flows easily through orifices in the shock and provides little dampening. When a large or high-frequency bump is detected, a small electrical current is sent from the chassis controller to an electromagnetic coil in each shock and the iron particles in the fluid respond within 3 milliseconds (ms), aligning themselves in fiberlike strands. See Figures 88–40 and 88–41.

FREQUENTLY ASKED QUESTION ???

Can Computer-Controlled Shock Absorbers and Struts Be Replaced with Conventional Units?

Maybe. If the vehicle was manufactured with or without electronic or variable shock absorbers, it may be possible to replace the originals with the standard replacement units. The electrical connector must be disconnected, and this may cause the control system to store a diagnostic trouble code (DTC) and/or turn on a suspension fault warning light on the dash. Some service technicians have used a resistor equal in resistance value of the solenoid or motor across the terminals of the wiring connector to keep the controller from setting a DTC. All repairs to a suspension system should be done to restore the vehicle to like-new condition, so care should be exercised if replacing electronic shocks with nonelectronic versions.

This causes the MR fluid to become thick like peanut butter and increases the firmness of the shock. This type of shock absorber is used to control squat during acceleration and brake dive as well as to reduce body roll during cornering by the chassis controller. See Figure 88–42.

SUMMARY

1. General Motors uses seven types of electronic suspension under many different names.



Figure 88–40 Vehicles that use magneto-rheological shock absorbers have a sensor located near each wheel, as shown on this C6 Corvette.



Figure 88–41 The controller for the magneto-rheological suspension system on a C6 Corvette is located behind the right front wheel.

2. Suspension height sensors and steering wheel (handwheel) position sensors are used in many systems.
3. A vehicle speed sensor signal is used to control the suspension at various speeds.
4. Many electronic suspension systems use a lateral accelerometer sensor, which signals the suspension computer when the vehicle is rapidly accelerating, braking, or cornering.
5. Solenoids and motors are used to control the suspension movement by moving valves in the shock absorbers or air springs.
6. An air pump and air shocks are used to raise the rear of the vehicle to compensate for a heavy load.

REVIEW QUESTIONS

1. What type of sensor is usually used on electronically controlled suspensions to sense the height of the vehicle?
2. Why is the vehicle speed sensor used as input for many electronic suspension systems?
3. What is a lateral accelerometer sensor and why is it used?
4. Why does the output side of the suspension air compressor contain a desiccant?



Figure 88–42 A cutaway of a magneto-rheological shock absorber as displayed at the Corvette Museum in Bowling Green, Kentucky.

CHAPTER QUIZ

1. What type of sensor is used as a height sensor on vehicles equipped with an electronically controlled suspension?
   a. Hall-effect
   b. Photo cell
   c. Potentiometer
   d. All of the above
2. Which sensors do most vehicles use if equipped with electronic suspension?
   a. Height sensors
   b. Steering wheel position sensors
   c. Lateral accelerometer sensors
   d. All of the above
3. A lateral acceleration sensor is used to provide the suspension control module with feedback regarding _____ force.
   a. Cornering
   b. Acceleration
   c. Braking
   d. All of the above
4. A steering wheel position sensor is being discussed. Technician A says that the sensor is used to determine the direction the steering wheel is turned. Technician B says that the sensor detects how fast the steering wheel is turned. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that an electronic control module used in the suspension system is the same as that used for engine control. Technician B says that most electronically controlled suspension systems use a separate electronic control module. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. What type of actuator is used on electronically controlled suspensions?
   a. Solenoid
   b. Relay
   c. Electric motor
   d. All of the above
7. Why is the typical rear load-leveling system connected to the ignition circuit?
   a. To keep the system active for a given time after the ignition is switched off
   b. To prevent the system from working unless the ignition key is on
   c. To keep the compressor from running for an extended period of time
   d. All of the above
8. Which sensor can be tested by unbolting the sensor and with the ignition on, engine off (KOEO), looking at the scan tool data?
   a. "G" sensor
   b. Wheel speed sensor
   c. Vehicle speed sensor
   d. Suspension sensor
9. The *firm* setting is usually selected by the electronic suspension control module whenever which of the following occurs?
   a. High speed
   b. Rapid braking
   c. Rapid acceleration
   d. All of the above
10. Which of the following is the *least likely* sensor to cause an electronic suspension fault?
    a. Yaw sensor
    b. Throttle position (TP) sensor
    c. Steering wheel position sensor
    d. Vehicle speed sensor

CHAPTER 89 Steering Columns and Gears

OBJECTIVES: After studying Chapter 89, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "A" (Steering System Diagnosis and Repair). • Discuss steering columns and intermediate shafts. • Explain how a recirculating ball-nut and worm gear steering gear system works. • Describe how a rack-and-pinion steering gear works.

KEY TERMS: collapsible column • flexible coupling • gear lash • inflator module • kickback • lock plate • overcenter adjustment • pinion torque • pitman arm • pitman shaft • preload • rack and pinion • rack support • sector gear • sector shaft • steering shaft • stub shaft • telescoping steering column • tilt steering column • universal joint • variable ratio • worm gear

When the driver turns the steering wheel in a circle, or in a rotary motion, the steering linkage moves side to side, or in a lateral motion, to steer the wheels.

STEERING WHEELS

The steering wheel, which consists of a rigid rim and a number of spokes connecting the rim to a center hub, attaches to the top of the steering shaft at its center. Most steering wheel hubs have internal splines that fit over external splines on the steering shaft. A bolt or nut at the center of the hub secures the wheel to the shaft. The steering wheel may also contain controls for the cruise control and audio controls, as well as the driver's airbag.

Horn Operation The horn circuit is in a series circuit in which electricity has one path that it can follow when the circuit is complete. A normally open switch in an electrical circuit is inside the horn button. When the driver pushes the horn button, the contacts on the switch close, allowing electrical current through the circuit to operate the horn. See Figure 89–1. A relay circuit is a more common method of wiring the horn. In a relay, closing a switch in a low-current series circuit triggers the high-current circuit that powers the horn.

Airbags An airbag is a device made of nylon cloth that is covered with neoprene. The airbag is folded and stored in the front center of the steering wheel. In a front-end collision, the airbag inflates in a fraction of a second to provide a cushion between the driver and the steering wheel and dashboard. See Figure 89–2. The part of the steering wheel where the airbag is stored is called the **inflator module.** The module also contains an igniter, a canister of flammable gas, and a number of sodium azide pellets. The sodium azide pellets burn quickly, and rapidly release nitrogen gas while they burn. The nitrogen gas fills the airbag. As it inflates, the airbag tears open the module cover and spreads out across the steering wheel, windshield, and dashboard. The entire process, from sensor reaction to full airbag deployment, takes 30 to 65 milliseconds. Within a second of inflating, the bag deflates partially as the nitrogen gas escapes through exhaust vents in the side of the airbag. Once deployed, an airbag cannot be reused.

The module fits in front of the nut that secures the steering wheel to the steering shaft. Bolts at the back of the steering wheel fasten the airbag module to the steering wheel. Electrical current is provided to the airbag through the spiral cable, which is also known as a coil. The spiral cable connects to the airbag module with two wire leads. The spiral cable is a tightly coiled metal strip that allows steering wheel rotation while maintaining electrical continuity. See Figure 89–3.

CAUTION: Whenever working on the steering column, consult service information for the recommended airbag disabling procedure.

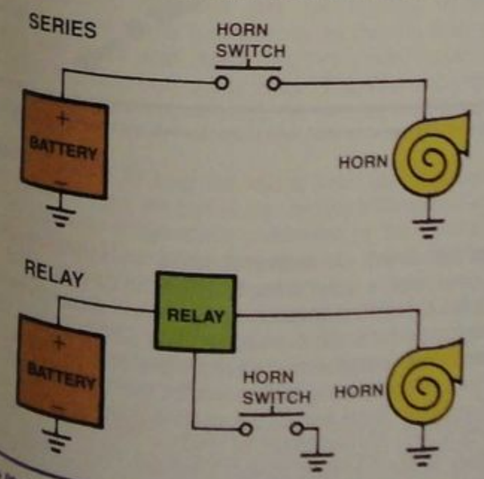


Figure 89–1 The horn button is a normally open (NO) switch. When the button is depressed, the switch closes, which allows electrical current to flow from the battery to sound the horn. Most horn circuits use a relay to conduct the horn current.

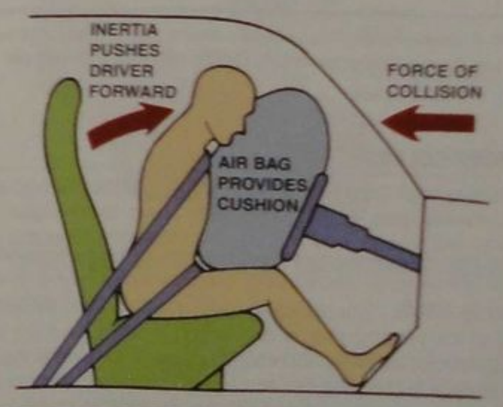


Figure 89–2 The airbag inflates at the same time the driver moves toward the steering wheel during a front-end collision and supplements the protection of the safety belt.

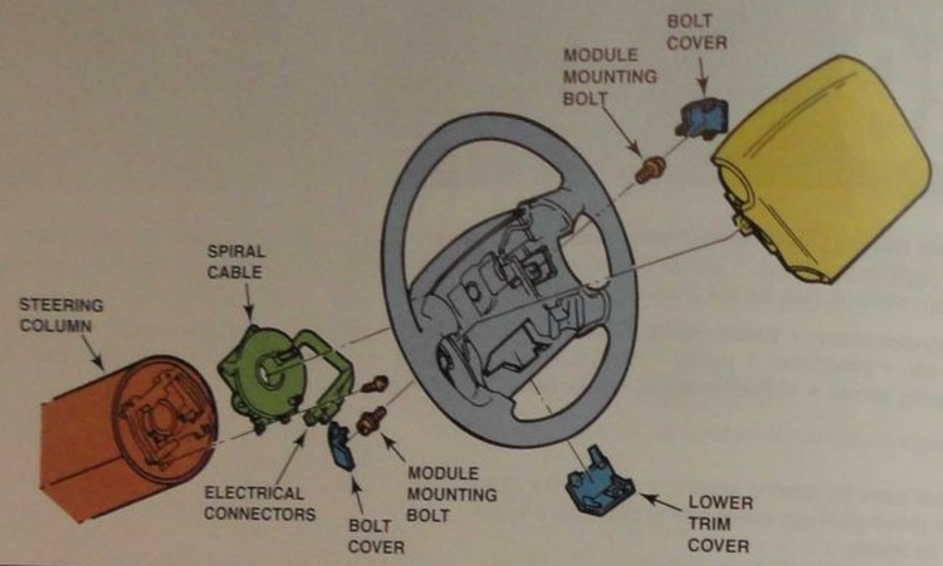


Figure 89–3 The airbag module attaches to the steering wheel and is removed as an assembly to service the steering wheel and column.

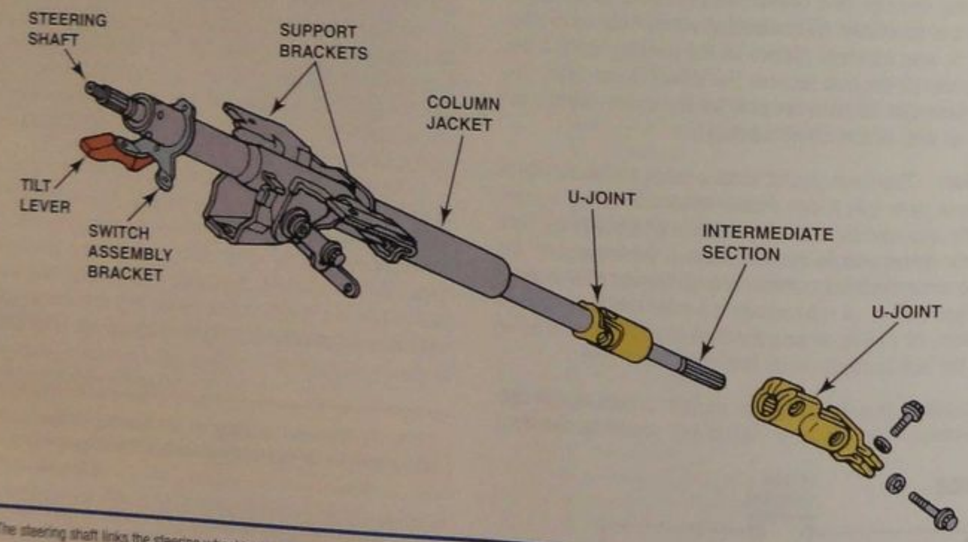


Figure 89–4 The steering shaft links the steering wheel to the steering gear while the column jacket, which surrounds part of the shaft, holds support brackets and switches. This steering shaft has a small intermediate section between the main section and the steering gear.

STEERING COLUMNS

The steering shaft transmits rotary motion from the steering wheel to the steering gear, while the column jacket that encases it attaches to the vehicle body and offers a stationary mounting point for a number of switches and mechanisms. See Figure 89–4.

Steering Shaft The **steering shaft** extends from the steering wheel to the steering gear. A bolt or nut secures the shaft to the steering wheel, and a flexible coupling joins it to the steering gear input shaft. The coupling can be a simple rubber or fabric insert, a universal joint (U-joint), or a pot joint. In addition to allowing a directional change of the shaft, a pot joint permits a limited amount of plunging motion. See Figure 89–5.

Universal Joint A **universal joint,** or U-joint, consists of two yokes with a steel crosspiece joining them together. See Figure 89–6. Universal joints allow changes in the angle between two rotating shafts. In a steering shaft, U-joints allow rotary motion transfer between the steering wheel and the steering gear even though the steering shaft meets the steering gear input shaft at an angle. On some models the steering shaft itself is assembled in sections that are connected by U-joints. This permits the steering shaft to bend around obstacles between the steering wheel and the steering gear.

Flexible Coupling A **flexible coupling** is a simple device made of rubber, or rubber reinforced with fabric, that is placed between two shafts to allow for a change in angle between them. See Figure 89–7. The rubber in a steering shaft flexible coupling absorbs vibrations and helps keep the steering wheel from shaking. A fail-safe connection between the steering shaft and the steering gear input shaft keeps the two shafts linked should the rubber coupling wear out or break. This allows the driver to maintain steering control, although the steering feels loose when this happens.

Column Cover To keep the wiring from the jacket-mounted switches out of sight, the part of the steering column that extends into the passenger compartment is shrouded by the column cover. See Figure 89–8. The column cover is usually at least two separate pieces, top and bottom. A knee bolster that mounts under the steering column is a safety feature designed to keep the driver from sliding forward during a collision. Knee bolsters are part of the passive restraint system required to meet U.S. federal safety standards on certain vehicles.

Collapsible Column Federal law requires that all vehicles sold in the United States have steering columns and shafts that collapse, **collapsible columns,** during a head-on collision to absorb some of the energy of the crash and lessen the danger of injury to the driver. See Figure 89–9. One early method used a section of the steering column constructed out of mesh, which would collapse easily during a crash. Another method is to use a two-piece column. One section of the column has a smaller diameter so that it fits inside the other and rides on a roller bearing. During a collision, the smaller section slides down into the larger one to collapse like a telescope.

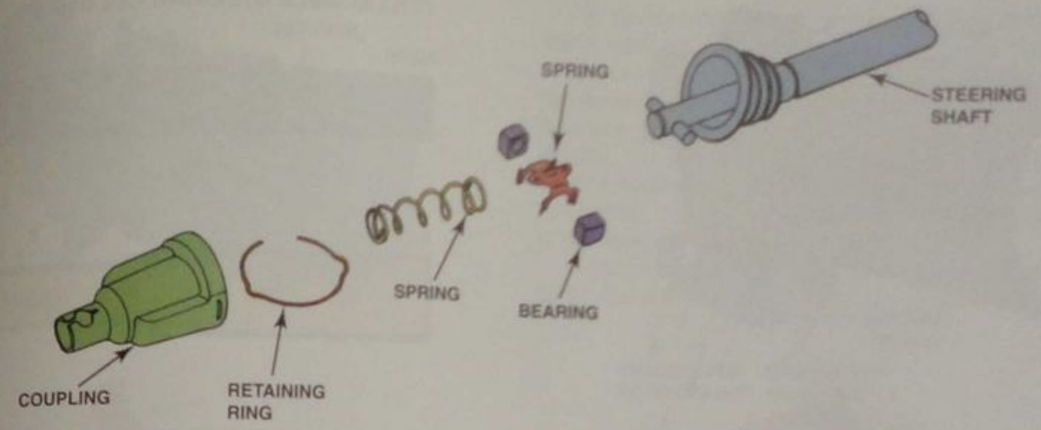


Figure 89–5 A pot joint is a flexible coupling used to join two shafts that allow plunging motion.

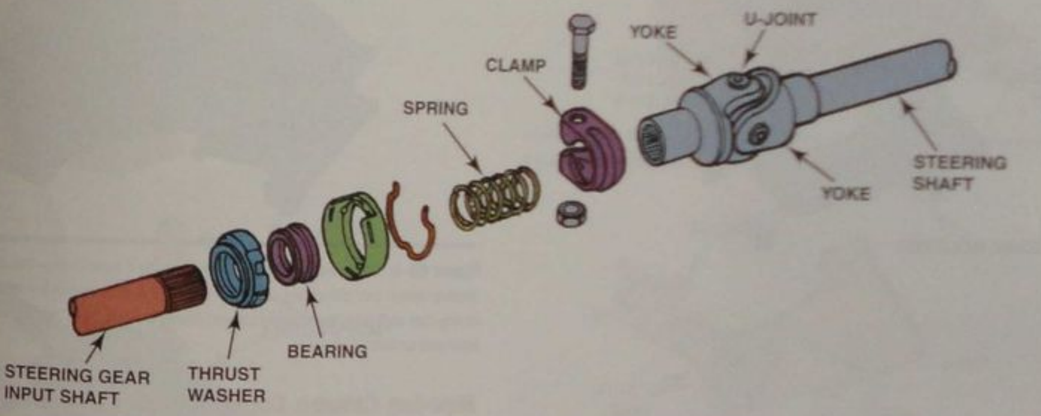


Figure 89–6 A typical intermediate steering shaft assembly showing a U-joint and related components.

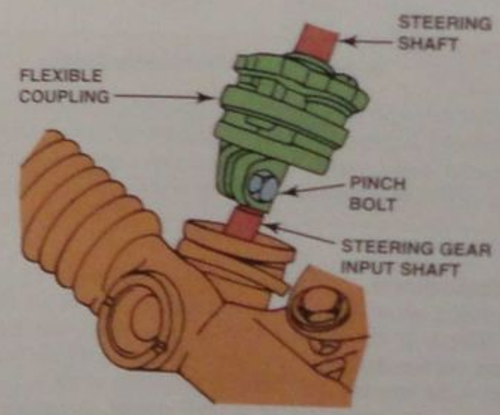


Figure 89–7 A flexible coupling is used to isolate road noise and vibration from the steering shaft.



Figure 89–8 Steering column covers are often part of the interior trim.

TECH TIP ✓ **Do Not Pound on the Steering Column**

Always use a steering wheel puller and/or the special tools recommended by the vehicle manufacturer when servicing the steering column. If a hammer is used on the steering shaft in an attempt to remove a steering wheel, the shaft could collapse, requiring the replacement of the entire steering column assembly.

Tilt Mechanisms Many steering columns have tilt mechanisms, which allow the driver to adjust the angle of the steering wheel relative to the steering column. In a typical **tilt steering column,** the steering shaft has a short section at the top joined to the rest of the steering shaft either by a U-joint or gears. Most tilt mechanisms are some sort of ratchet device that enables the driver to lift the steering wheel and the top section of the shaft and place them in the desired position. See Figure 89–10. Usually, spring tension locks the steering wheel in place on the ratchet, and a release lever compresses the spring to allow tilt adjustment.

Telescoping Steering Columns Some steering columns are designed to **telescope,** which means that the top of the steering shaft and jacket can be pulled out toward the driver or pushed in toward the dashboard, and then locked into the new position.

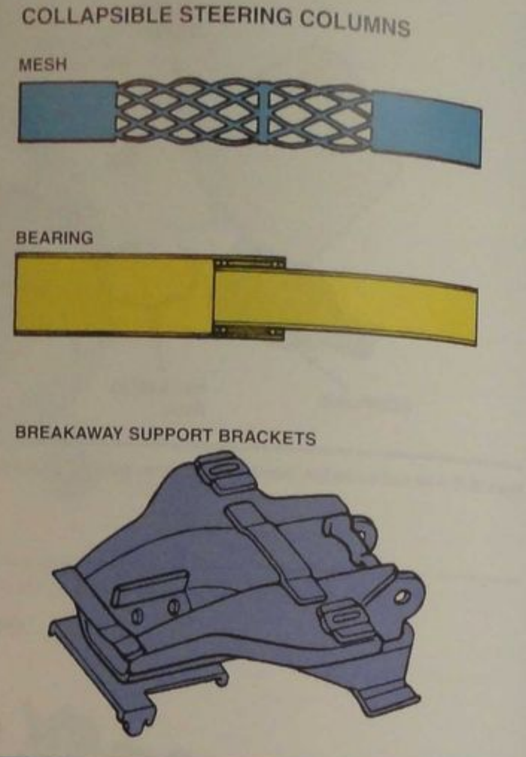


Figure 89–9 Collapsible steering columns include a mesh design that crushes easily, a bearing design that allows one section of the column to slide into the other, and a breakaway device that separates the steering column from the body of the vehicle in the event of a front-end collision.

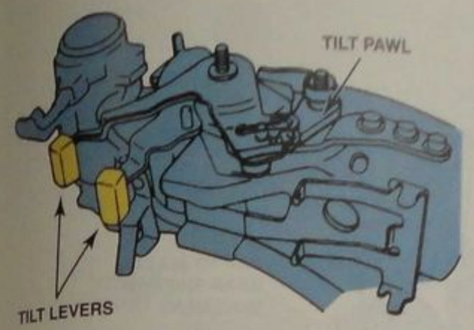
Steering Column Construction The steering shaft is at the center of the steering column. See Figures 89–11 and 89–12. The top end of the steering shaft splines to the center of the steering wheel, and a large nut fastens the steering wheel to the shaft. The lock housing, which contains the ignition lock cylinder, encases the top part of the steering shaft. The steering column jacket covers the shaft under the ignition lock housing, and the gear selector lever housing fits over a portion of the column jacket.

A U-joint connects the lower end of the steering shaft to a small intermediate shaft, often called a **stub shaft.** Because this steering column includes a gear selector lever, the lower end of the column also incorporates an attachment point that connects the shift tube to the gear shift rod. The intermediate shaft extends through a hole in the floor where it is coupled to the steering gear input shaft by a U-joint.

A toe plate bolts to the floor of the passenger compartment to cover the shaft opening and to protect the interior from noise, drafts, and dirt. See Figure 89–13. The toe plate has a tube for the intermediate shaft, and a seal and silencer fit on top of the tube.

Two sections at the upper end of the steering column house the column-mounted controls. See Figure 89–14. The lock housing, seated on top of the column jacket, is the topmost piece and contains the turn signal lever, hazard light control, and ignition lock. The gear selector lever and its housing are just below the lock housing, and the housing encases the top of the steering column jacket.

The lock housing contains the ignition lock cylinder, several electrical switches, and a steering shaft bearing. Some of the switches have driver-operated controls on the outside of the lock housing.



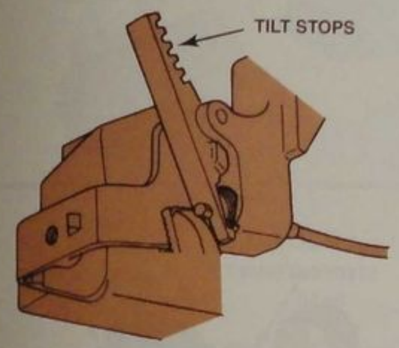




Figure 89–10 Tilt mechanisms vary by design and vehicle manufacturer, although most use a ratchet to position the top portion of the steering column.

A multifunction switch operates the turn signals, the windshield wiper and washer switch, and the dimmer switch.

Most steering shafts ride on at least two bearings, one near the top and one near the bottom of the shaft, to allow the shaft to rotate freely without affecting other parts of the steering column. See Figure 89–15. A snap ring at the center of the bearing housing rests in a groove on the steering shaft to secure the bearing, and an O-ring on the steering shaft keeps lubricant in the bearing.

Underneath the bearing and housing is a **lock plate** and coil spring that lock the steering shaft into position when the driver

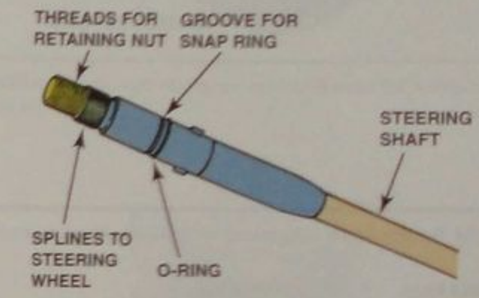


Figure 89–12 The steering shaft splines onto the steering wheel.

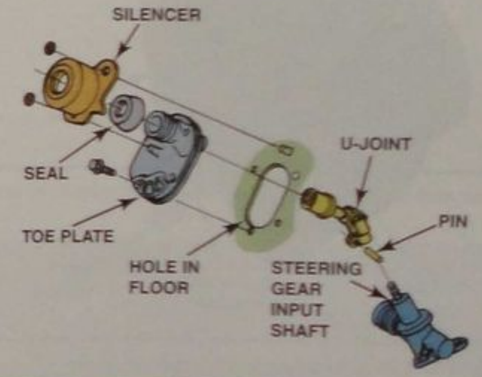


Figure 89–13 The toe plate seals the hole from the steering shaft and helps seal out noise and moisture.

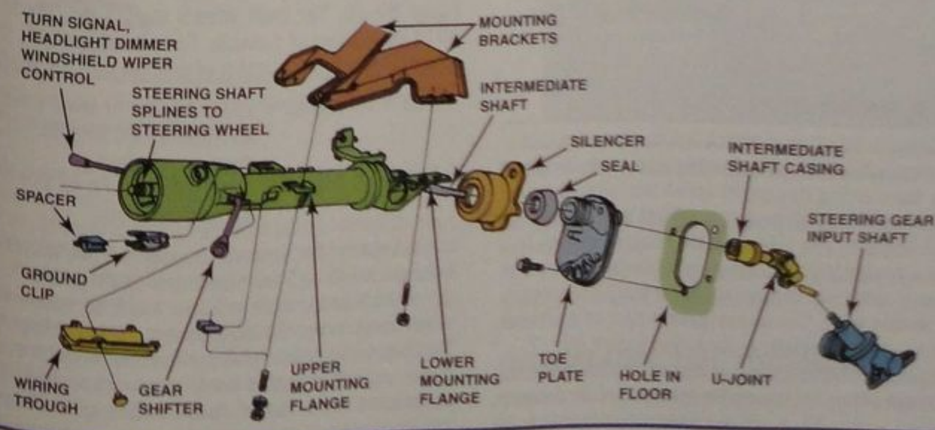


Figure 89–11 Typical steering column showing all of the components from the steering wheel to the steering gear.

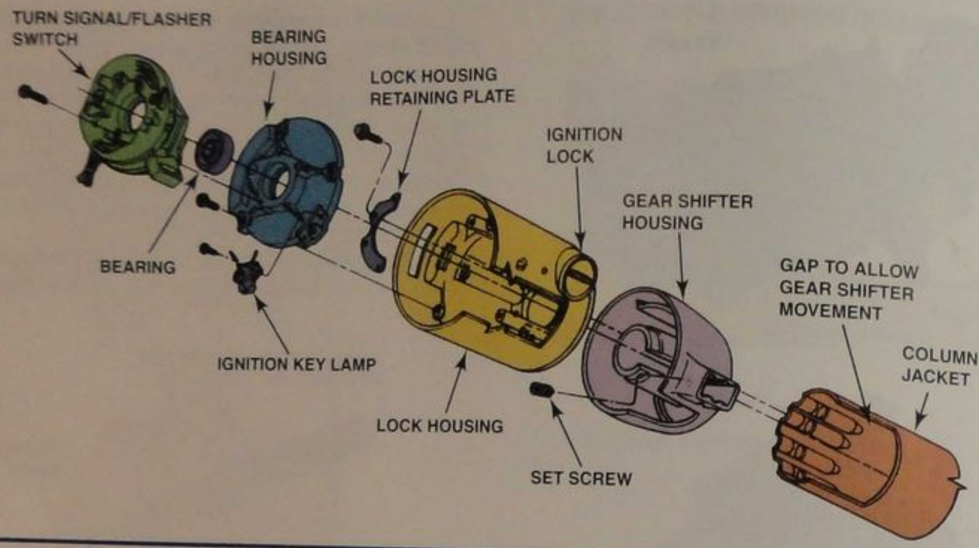


Figure 89–14 The upper section of the steering column includes the lock housing and switches.

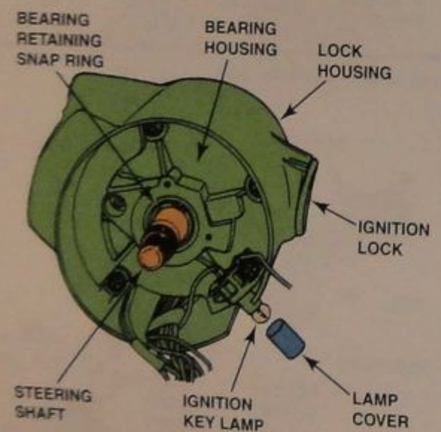


Figure 89–15 The upper section of the steering column contains the steering shaft bearing.

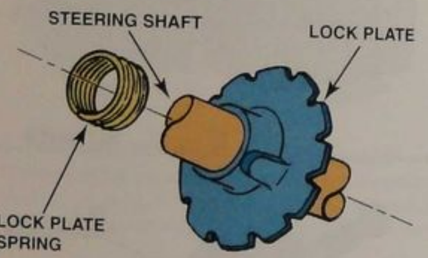


Figure 89–16 The lock plate engages an ignition lock pawl to keep the steering wheel in one position when the ignition is off.

removes the ignition key. See Figure 89–16. The ignition lock cylinder, which is under the lock plate, moves a bellcrank that in turn operates a spring and lever assembly linked to the ignition switch actuating rod.

CONVENTIONAL STEERING GEARS

All steering gears have an input gear, which transmits rotary movement from the steering wheel into the steering gear, and an output gear, which causes the steering linkage to move laterally. The rotation of the steering wheel is transferred to the front wheels through a steering gear and linkage. The intermediate shaft is splined to a **worm gear** inside a conventional steering gear. Around the worm gear is a nut with gear teeth that meshes with the teeth on a section of a gear called a **sector gear.** The sector gear is part of a **pitman shaft,** also known as a **sector shaft,** as shown in Figure 89–17.

Ball, roller, or needle bearings support the sector shaft and the worm gear shaft, depending on the make and model of the gear assembly.

As the steering wheel is turned, the movement is transmitted through the steering gear to an arm attached to the bottom end of the pitman shaft. This arm is called the **pitman arm.** Whenever the steering wheel is turned, the pitman arm moves.

Steering Gear Ratio When the steering wheel is turned, the front wheels turn on their steering axis. If the steering wheel is rotated 20 degrees and results in the front wheels rotating 1 degree, then the steering gear ratio is 20:1 (read as "20 to 1"). See Figure 89–18. The front wheels usually are able to rotate through 60 to 80 degrees of rotation. The steering wheel, therefore, has to rotate 20 times the number of degrees that the wheels move.

20 × 60 degrees = 1,200 degrees, or about three full revolutions (360 degrees = 1 full turn) of the steering wheel

20 × 80 degrees = 1,600 degrees, or over four revolutions of the steering wheel

A vehicle that turns three complete revolutions from full left to full right is said to have three turns "lock to lock."

A high ratio, such as 22 to 1 (22:1), means that the steering wheel must be rotated 22 degrees to move the front wheels 1 degree. This high ratio means that the steering wheel is easier to turn than a steering wheel with a lower ratio such as 14:1. The 14:1 ratio is considered to be "faster" than the 22:1 ratio. This fast ratio allows the front wheels to be turned with less movement of the steering

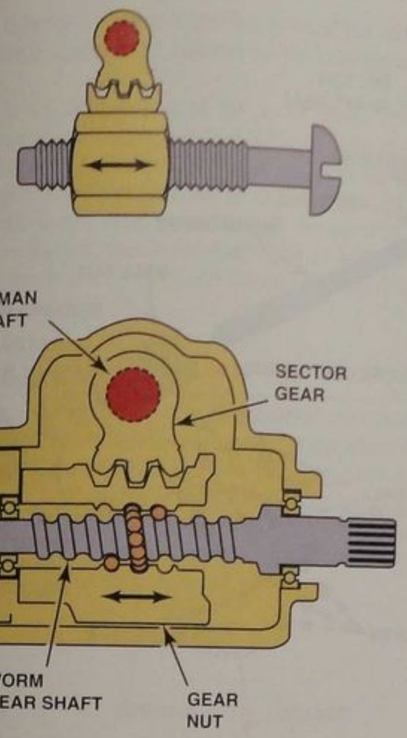


Figure 89–17 As the steering wheel is turned, the nut moves up or down on the threads, shown using a bolt to represent the worm gear and the nut representing the gear nut that meshes with the teeth of the sector gear.

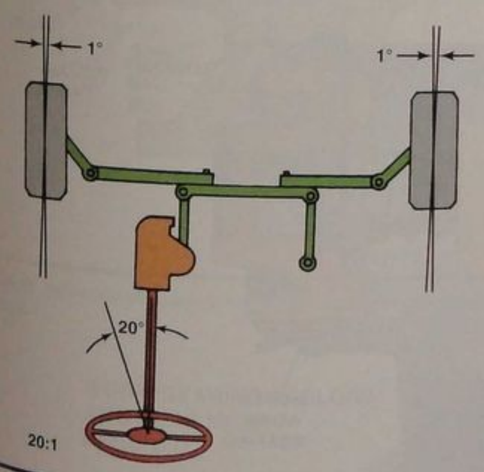


Figure 89–18 Steering gear ratio is the ratio between the number of degrees the steering wheel is rotated to the number of degrees the front wheel turns.

wheel, yet more force may be required to turn the wheel. This is considered by some to be more "sporty."

Most steering gears and some rack-and-pinion steering gears feature a **variable ratio.** This feature causes the steering ratio to decrease as the steering wheel is turned from the on-center position. The high on-center ratio (such as 16:1) provides good steering feel at highway speeds while the reduced off-center ratio (13:1) provides fewer steering wheel turns during turning and parking. The ratio is accomplished by changing the length of the gear teeth on the sector gear. See Figure 89–19 for an example of the teeth of a constant-ratio sector gear.



Figure 89–19 Constant-ratio steering gear sector shaft. Notice that all three gear teeth are the same size.



Figure 89–20 Variable-ratio steering gear sector shaft. Notice the larger center gear tooth.



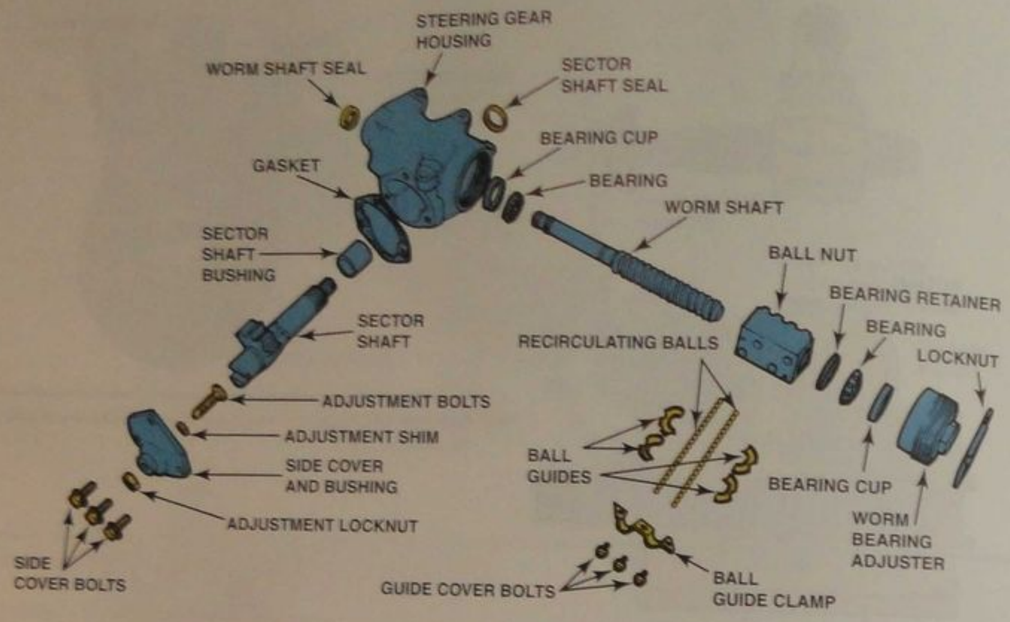
Figure 89–21 The sector gear meshes with the gear teeth on the ball nut.

See Figure 89–20 for an example of the teeth on a variable-ratio sector gear.

The sector gear meshes with the ball nut inside the steering gear, as shown in Figure 89–21.

RECIRCULATING BALL STEERING GEAR

A recirculating ball steering gear is the most commonly used conventional steering gear. See Figure 89–22.



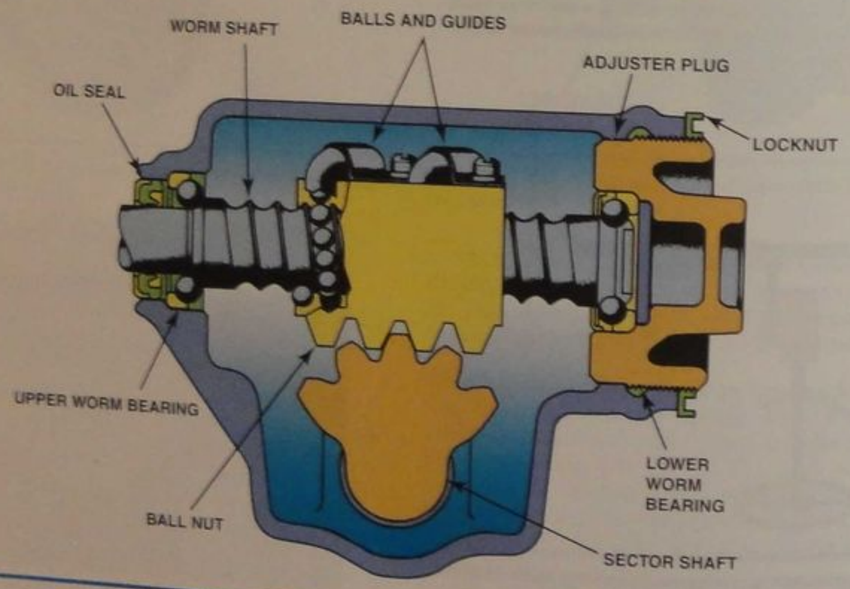


Figure 89–22 A typical manual recirculating ball steering gear.

The end of the steering gear input shaft, or worm shaft, splines to the steering shaft U-joint and provides rotary input to the steering gear. An oil seal prevents fluid leakage where the input shaft enters the steering gear housing. At the top and the bottom of the worm gear are the upper and lower thrust bearings. The upper bearing cup seats in the housing, and the lower bearing cup seats in the adjuster plug. The thrust bearings reduce friction between the worm gear and the steering gear housing and control worm endplay.

The adjuster plug at the lower end of the worm gear holds the worm gear, shaft, and bearings inside the steering gear housing.

The ball nut, which has internal grooves that match the worm gear thread, fits over the worm gear. Steel balls roll through the tunnels formed by the ball nut grooves and the worm gear thread. Crescent-shaped ball-return guides link the ends of the ball-nut tunnels together, so the balls continuously circulate through the ball nut and worm gear, into the ball-return guides, and back again. A clamp secured by screws holds the return guides in place on one side of the ball nut. Gear teeth mesh with the teeth of the sector gear machined into the outside of the ball nut on the side opposite the ball-return guides.

The sector gear is an integral part of the sector shaft, which runs through the center of the sector gear, and forms the axis of the gear. One end of the sector shaft extends out of the steering gear housing and splines to the pitman arm. An oil seal prevents lubricant leakage where the sector shaft goes through the opening in the housing. To reduce friction, the sector shaft rides on two bushings. One bushing fits inside the housing and the other is part of the housing side cover. See Figure 89–23.

STEERING GEAR ADJUSTMENTS

For the steering gear to operate efficiently, the internal parts must be positioned correctly in relation to the housing and each other. As parts wear, clearances inside the housing and between parts increase, causing looseness and excessive play. The acceptable clearance between any two mechanical parts is called their tolerance. Insufficient tolerance causes binding between parts, increasing steering effort. Excessive tolerance causes delayed reaction to steering input and too much steering wheel freeplay.

Worm bearing preload, also referred to as worm endplay, is a measurement of how much force is required to turn the steering gear input shaft against the force, or **preload,** that the thrust bearings apply to the worm gear and shaft. Worm endplay, which is the distance the worm gear can move end-to-end between the thrust bearings, is directly related to preload. The higher the force the bearings push against the worm gear, the less endplay there is, and the more force it takes to turn the input shaft and worm gear. Worm bearing preload is adjusted by one of two methods: turning an adjustment nut or screw or installing selectively sized shims. Either adjustment method increases or decreases the worm endplay.

Worm endplay is a linear measurement, made in fractions of inches or millimeters, of how far the worm gear and shaft can slide axially. See Figure 89–24. Worm bearing preload is a measurement of how much force it takes to overcome bearing pressure in order to turn the input shaft. Preload is a torque, or turning force, measurement made in inch-pounds or Newton-meters. Because endplay and preload are related, one measurement affects the other. When measuring and adjusting the worm bearing preload, a technician measures preload and adjusts endplay. The endplay is correct when the preload measurement is correct. See Figures 89–25 and 89–26.

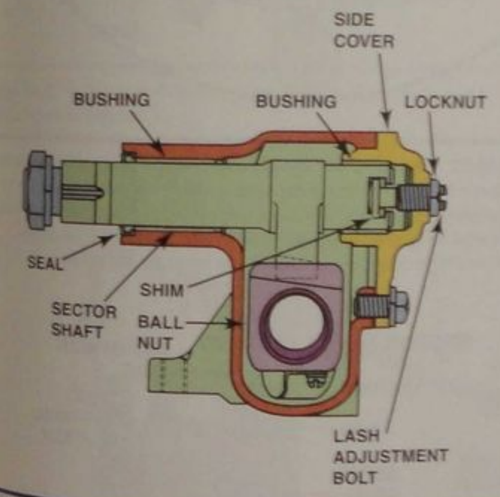


Figure 89–23 The sector shaft is supported by bushings, one in the housing and one in the side cover.

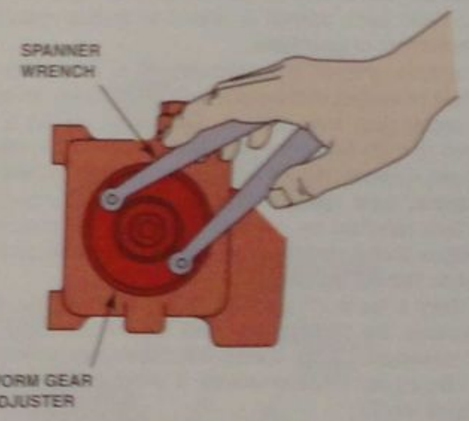


Figure 89–25 The first step to adjust worm gear freeplay is to bottom the worm gear nut, using a spanner wrench designed to fit into the two holes in the nut labeled 2.

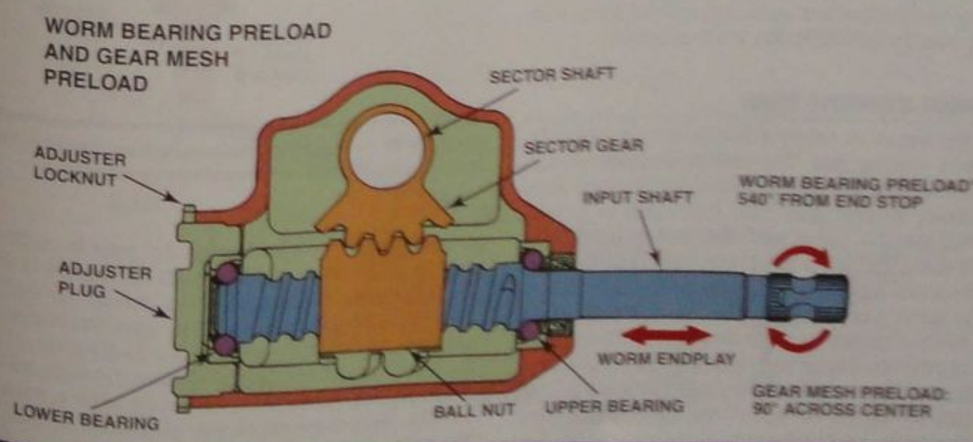


Figure 89–24 Worm bearing preload is a turning force measured in in.-lb or N-M, and worm endplay is axial movement measured in fractions of an inch or millimeters.

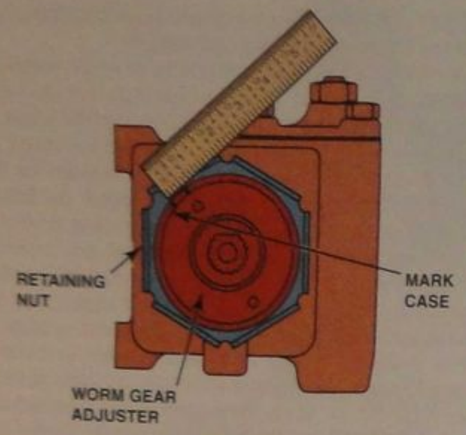


Figure 89–26 After the worm gear nut has been tightened, measure 1/2 inch (13 mm) and mark the case. Using the spanner wrench, rotate the worm gear nut counterclockwise 1/2 inch, align the marks, and then tighten the retaining the nut. This procedure gives the proper worm gear endplay.

Gear mesh preload is a measurement of how closely the teeth of the ball-nut gear and sector gear, or the worm gear and roller, fit together. Gear mesh preload is related to another measurement, called sector lash or **gear lash.**

Gear mesh preload is a measurement of how much turning force must be applied to the input shaft to overcome the resistance of the sector gear and move it. Gear mesh preload is usually measured in a 90-degree turn across the center of the input shaft movement. General Motors calls this adjustment the **overcenter adjustment.** Gear mesh preload (overcenter adjustment) determines how sensitive the steering gear is to small steering wheel movements during straight-ahead driving. Insufficient preload contributes to steering wander.

If there is too much gear lash, the steering becomes unresponsive because the steering gear does not transmit small steering wheel movements to the linkage. Insufficient lash makes the gears bind, offering too much resistance to steering wheel movement. See Figure 89–27.

Sector shaft endplay is a measurement of how much room the sector shaft has to slide axially. See Figure 89–28. If provision is made to measure sector shaft endplay, the measurement is taken in fractions of inches or millimeters. Some steering gears provide an external adjusting method, but it is more common for sector shaft endplay to be adjusted by internal shims, if it is adjustable.

RACK-AND-PINION STEERING GEAR

The term "rack and pinion" is simply a description of the basic design of this type of steering gear. The **rack-and-pinion** steering gear is widely used because it is light in weight and takes less space than a conventional steering gear. The input gear of a rack-and-pinion steering gear is a pinion gear that receives rotary input from the steering shaft. The rack is a rod with gear teeth machined into one side. The pinion gear teeth mesh with the teeth on the rack so that when the pinion gear turns, it pushes the rack from side to side. See Figure 89–29. The rack connects directly to the tie rod in the steering linkage to move the linkage back and forth in a straight line.

The steering gear input shaft is splined to the steering shaft U-joint. See Figure 89–30. At the end of the steering gear input shaft, which extends into the rack housing, is the pinion gear. Two ball bearings reduce friction between the shaft and the steering

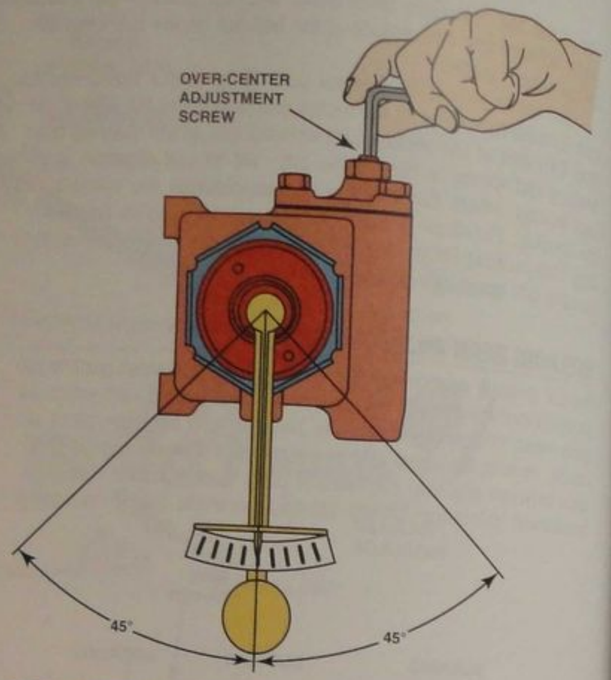


Figure 89–27 Performing an overcenter adjustment requires the use of a beam-type inch-lb torque wrench. After the worm bearing preload procedure has been completed, use the torque wrench to measure the rotating torque, which should be 6 to 15 lb-in. If the rotating torque is within the specified range, adjust the overcenter adjustment screw until you achieve 6 to 10 lb-in. more rotating torque and then tighten the retaining nut.

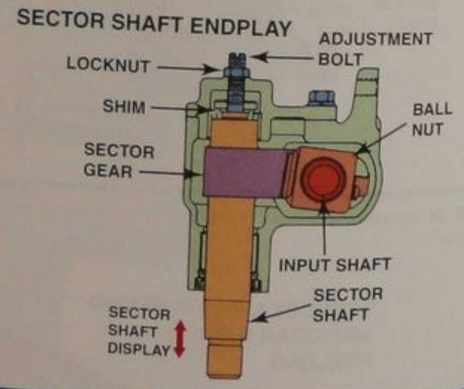


Figure 89–28 Sector shaft endplay is the measurement of how far the sector shaft can move axially and is measured in fractions of an inch or millimeters.

gear housing. The upper bearing is a press-fit on the input shaft, and the lower bearing installs inside the housing at the bottom of the pinion gear. A cover, which fits around the shaft and threads into the housing, seats on top of the upper ball bearing to preload it and close the top of the steering gear housing. An oil seal between the top cover and the input shaft keeps lubricant from leaking out of the housing. A lock nut holds the top cover in position.

The teeth of the pinion gear mesh with the teeth of the rack. The teeth are at one end of the rack and the pinion is offset at one side of the housing.

The rack is encased in the long, tubular steering gear housing with a mounting flange on the pinion end. Rubber bushings fit into the mounting flange bolt holes to absorb vibration and isolate the assembly from the frame.

A spring-loaded **rack support** and related hardware install through a hole at the back of the steering gear housing to position the rack. See Figure 89–31. The face of the rack support curves to match the back of the rack, which rests on it and slides back and forth across it. A spring behind the rack support cushions the rack from vibration and shocks. While the rack support provides a sliding surface to reduce friction at the pinion end of the rack, the

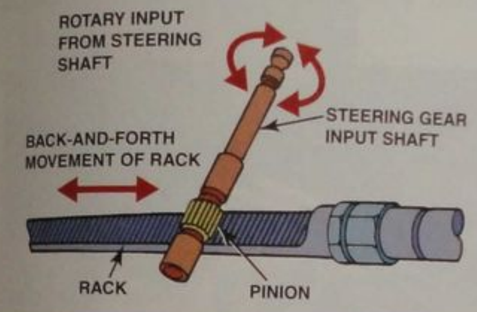


Figure 89–29 Rack-and-pinion steering gear operation is simple, direct, and the rack is in a straight line to the front wheels.

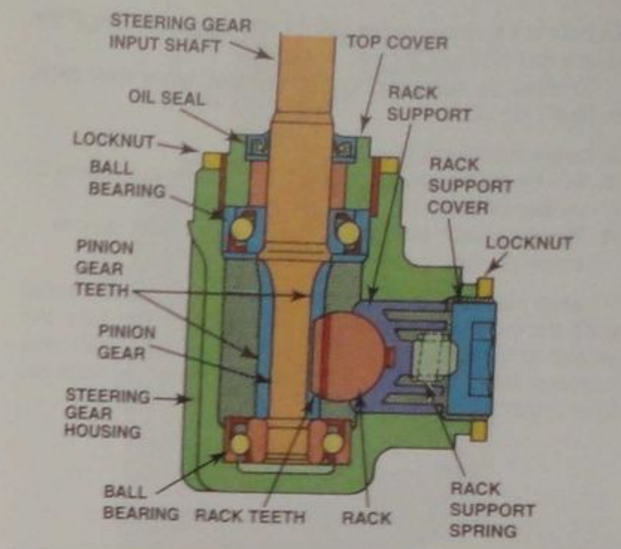


Figure 89–31 The spring-loaded rack support positions the rack to keep it from rubbing against the housing and establishes the pinion torque.

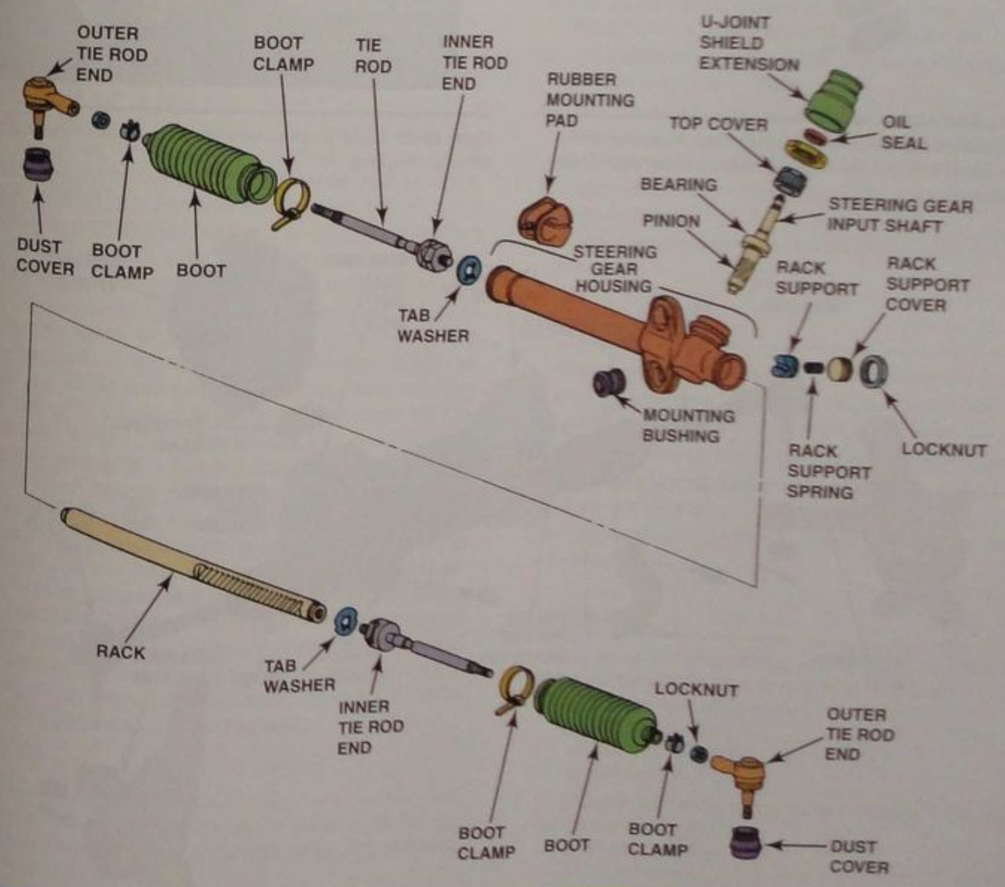


Figure 89–30 A typical manual rack-and-pinion steering gear used in a small front-wheel-drive vehicle.

rack rides in a bushing pressed into the steering gear housing at the opposite end to reduce friction.

To adjust the rack-and-pinion gear preload, follow these steps. See Figure 89–32:

1. Loosen the adjuster plug lock nut.
2. Turn the adjuster plug clockwise until the adjuster plug bottoms in the gear assembly.
3. Turn the adjuster plug back 50 degrees to 70 degrees (approximately one flat).

Most rack-and-pinion units use a small metal tube running along the outside of the housing to connect the two boots and transfer air from one to the other. See Figure 89–33. If there were no means for air displacement between the boots, they might collapse as they expanded or explode as they compressed.

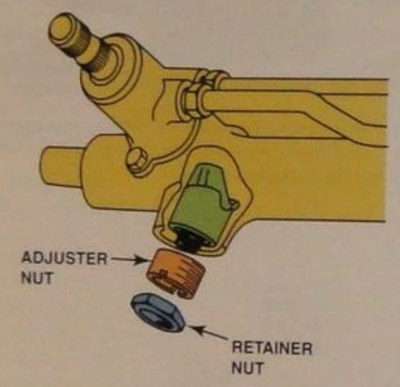


Figure 89–32 To adjust the rack-and-pinion gear preload, loosen the retaining nut and tighten the adjuster nut until it bottoms. Then loosen 60 degrees (one "flat" of the six-sided retainer). Tighten retaining nut.

Internal threads on each end of the rack allow attachment of the externally threaded tie rods.

A rubber boot at each side of the steering gear housing covers the end of the rack and the inner tie rod end to prevent dirt, water, and other contaminants from entering the assembly. Band clamps fasten the ends of the boots to the housing and tie rods. The tie rods move back and forth with the rack and connect it to the wheels through the steering linkage.

The housing generally bolts to either a flange on the firewall or to the subframe or engine cradle. See Figure 89–34. The mounting points have rubber cushions to isolate the steering gear from shock and vibration. If the driver can feel vibration and road shocks



Figure 89–33 A small air tube is used to transfer air between the boots as they extend and compress during turns.

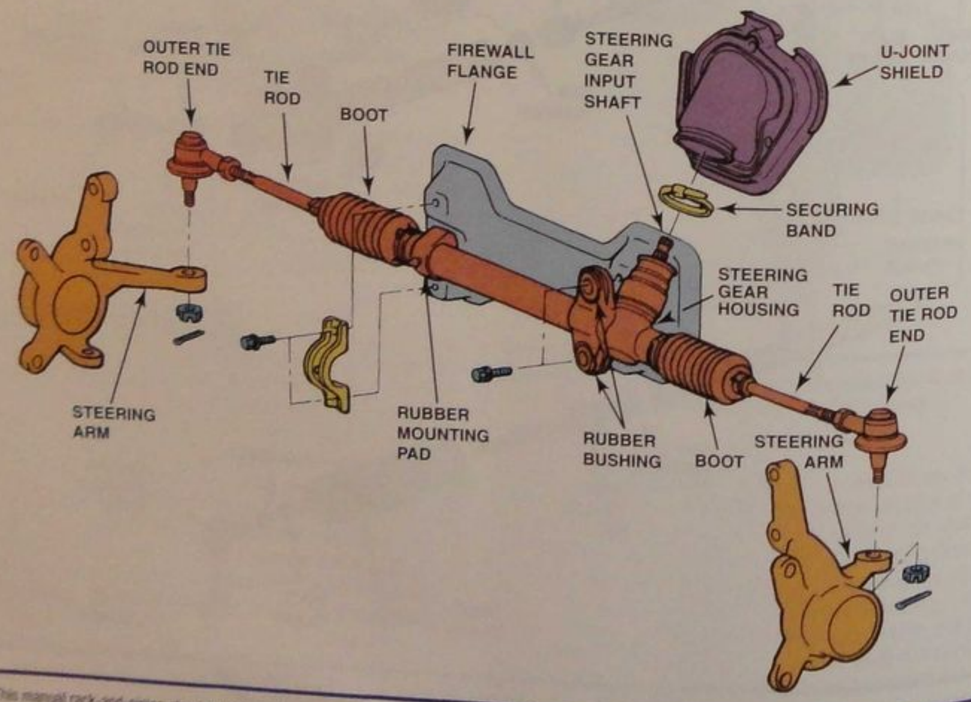


Figure 89–34 This manual rack-and-pinion steering gear mounts to the bulkhead (firewall), whereas others mount to the engine cradle or frame of the vehicle.

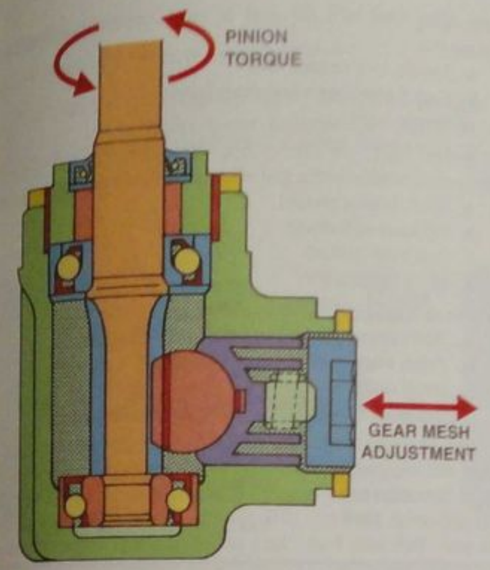


Figure 89–35 Pinion torque is a turning torque force measured in inch-pounds or Newton-meters. Tightening the rack support against the rack increases the pinion torque.

through the steering wheel, the condition is called **kickback.** Some kickback is inevitable with a rack-and-pinion steering gear.

RACK-AND-PINION ADJUSTMENTS

Some rack-and-pinion steering gears can be adjusted. **Pinion torque** is a measurement of how much turning force is needed at the input shaft for the pinion to overcome the resistance of the rack and move it. See Figure 89–35. The measurement gives an indication of how closely meshed the pinion teeth and the rack teeth are. Like gear mesh preload in a standard steering gear, pinion torque indicates steering system responsiveness. The adjustment method is to thread the rack support cover farther into the steering gear housing to reduce gear lash, or thread it out to increase gear lash. Manufacturers specify an acceptable range of pinion torque in inch-pounds or Newton-meters. Because the middle teeth on the rack wear before the teeth at either end, pinion torque should be checked across the whole stroke of the rack. Otherwise, reducing gear lash to a very close tolerance in the middle may cause binding as the pinion travels toward the end of the rack.

Pinion bearing preload in a rack-and-pinion steering gear is the same concept as worm bearing preload in a standard steering gear. That is, it is a measurement of how much force is required to turn the steering gear input shaft against the force, or preload, that the bearings apply to the pinion gear and shaft. See Figure 89–36. To provide adjustable pinion bearing preload, there may be a threaded adjustment mechanism or selectively sized shims that install behind a shim cover.

To set pinion bearing preload, the rack may need to be removed or loosened to prevent false readings caused by the resistance of the gears. Therefore, pinion bearing preload, when adjustable, must be set before pinion torque is measured and adjusted.

SUMMARY

1. Most horn circuits use a relay. The horn button or contact on the steering wheel completes the control circuit of the relay, which then completes the power circuit to the horn(s).
2. The driver's side airbag uses a clockspring spiral cable in the steering column electronically connecting the airbag inflator module.

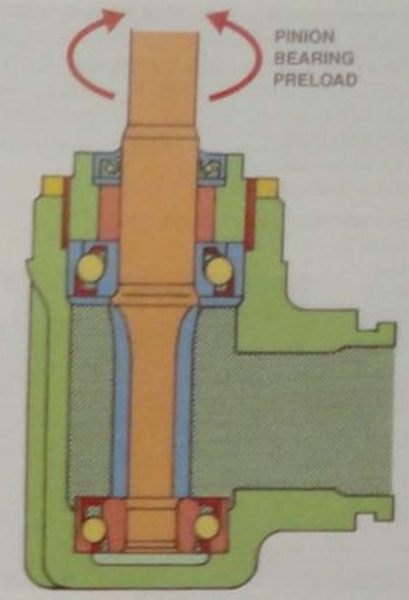


Figure 89–36 Pinion bearing preload is a measurement of the turning force required to overcome the resistance of the pinion shaft bearings.

3. The steering column, which connects the steering wheel to the steering gear, includes the steering shaft universal joint and flexible coupling.
4. Conventional steering gears consist of an input gear and output gear, also called the sector gear.
5. Steering gear ratio is the number of degrees the steering wheel is rotated compared to the number of degrees the front wheels are rotated. Most steering gears provide a ratio of between 14:1 and 22:1.
6. A recirculating-ball-type steering gear is the most commonly used conventional steering gear.
7. A rack-and-pinion steering gear ties the two tie rods together in a straight line.

REVIEW QUESTIONS

1. What components are included in a typical steering column assembly?
2. When the driver turns the steering wheel, how is the motion transferred to the front wheels through a conventional steering gear?
3. Why are recirculating balls used in the recirculating ball steering gear?
4. What steering gear adjustments are possible on a conventional recirculating-ball-type steering gear?
5. What steering gear adjustments are possible on a typical rack-and-pinion steering gear?

CHAPTER QUIZ

1. The circuit to the airbag inflation module is connected from the steering column to the steering wheel through what component?
   a. Slip ring and carbon brushes
   b. Clockspring (coil)
   c. Magnetic field sensor
   d. Hall-effect switch
2. Which part in the steering column allows for changes in the angle between the upper and lower shafts?
   a. Flexible coupling
   b. Column cover
   c. Universal joint
   d. Collapsible section

3. Technician A says that the ignition switch is located where the key is inserted. Technician B says that the ignition switch is controlled by the ignition lock cylinder through a lever and actuating rod. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

4. The pitman shaft is also called the _____.
   a. Sector
   b. Input
   c. Worm
   d. Spline

5. The driver rotates the steering wheel one-half of one revolution (180 degrees) on a vehicle equipped with a steering gear with a 20:1 gear ratio. How many degrees will the front wheels be rotated?
   a. 9 degrees
   b. 0.1 degree
   c. 90 degrees
   d. 11.1 degrees

6. What causes a variable-ratio steering gear to be able to change the ratio as the steering wheel is turned?
   a. Using two or three different sector gears depending on design
   b. Using a variable-length pitman arm
   c. Changing the number of teeth on the worm gear
   d. Changing the length of the teeth on the sector gear

7. Recirculating steel balls are used in most conventional steering gears because they _____.
   a. Provide for a variable ratio
   b. Keep the steering wheel centered
   c. Reduce friction
   d. Help provide feedback to the driver regarding the road surface

8. Which conventional steering gear adjustment should be the first performed?
   a. Worm bearing preload
   b. Tolerance adjustment
   c. Gear mesh preload
   d. Sector shaft endplay

9. The two rack-and-pinion steering gear adjustments include _____.
   a. Worm bearing preload and tolerance adjustment
   b. Pinion bearing preload and rack support
   c. Sector shaft and stub shaft preload
   d. Stub shaft endplay and sector shaft preload

10. A driver of a vehicle equipped with a rack-and-pinion steering gear complains that the steering wheel jerks whenever the vehicle is being driven into a curbed driveway approach at an angle. Technician A says that the rack-and-pinion gears may have too little clearance between the teeth of the gears. Technician B says that a lack of lubrication of the rack-and-pinion is the most likely cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 90

Steering Linkage and Service

OBJECTIVES: After studying Chapter 90, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "A" (Steering System Diagnosis and Service). • Identify steering linkage components. • Describe how the movement of the steering wheel causes the front wheels to turn. • Describe how to perform a dry park test to determine the condition of steering system components. • Perform an under-the-vehicle inspection of the steering system components. • List the service procedures for under-the-vehicle steering system service. • Explain how to replace steering linkage parts.

KEY TERMS: articulation test • ball socket assembly • center link • center take-off rack • cross-steer linkage • dry park test • front steer • grease fitting • opposite-phase steering • parallelogram linkage • pitman arm • RBS • rear steer • same-phase steering • steering dampener • steering stops • SWPS • tie rods • zerk fitting

The proper operation of the steering system is critical to the safe operation of any vehicle. Always follow the service procedures specified by the vehicle manufacturer.

STEERING LINKAGE

The steering linkage relays steering forces from the steering gear to the front wheels. Most conventional steering linkages use the **parallelogram** type design. A parallelogram is a geometric box shape where opposite sides are parallel and equal distance. A parallelogram-type linkage uses four **tie rods,** two inner and two outer (left and right), a **center link** (between the tie rods), and an idler arm on the passenger side and a **pitman arm** attached to the steering gear output shaft (pitman shaft). See Figure 90–1.

As the steering wheel is rotated, the pitman arm is moved. The pitman arm attaches to a center link. At either end of the center link are inboard (inner) tie rods, adjusting sleeves, and outboard (outer) tie rods connected to the steering arm, which moves the front wheels. The passenger side of all these parts is supported and held horizontal by an idler arm that is bolted to the frame. The center link may be known by several names, including the following:

Center link
Connecting link
Connecting rod
Relay rod
Intermediate rod
Drag link (usually a truck term only)

Other types of steering linkages often used on light trucks and vans include the **cross-steer linkage.** See Figure 90–2 for a comparison of parallelogram and cross-steer-type steering linkage arrangements.

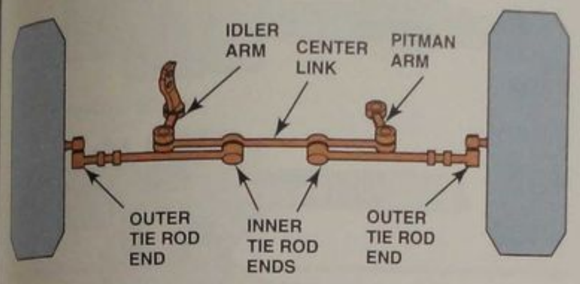


Figure 90–1 Steering movement is transferred from the pitman arm that is splined to the sector shaft (pitman shaft), through the center link and tie rods, to the steering knuckle at each front wheel. The idler arm supports the passenger side of the center link and keeps the steering linkage level with the road.

NOTE: Many light trucks, vans, and some luxury cars use a steering dampener attached to the linkage. A **steering dampener** is similar to a shock absorber, and it absorbs and dampens sudden motions in the steering linkage. See Figure 90–3.



Figure 90–3 Typical steering dampener used on a Hummer H2.

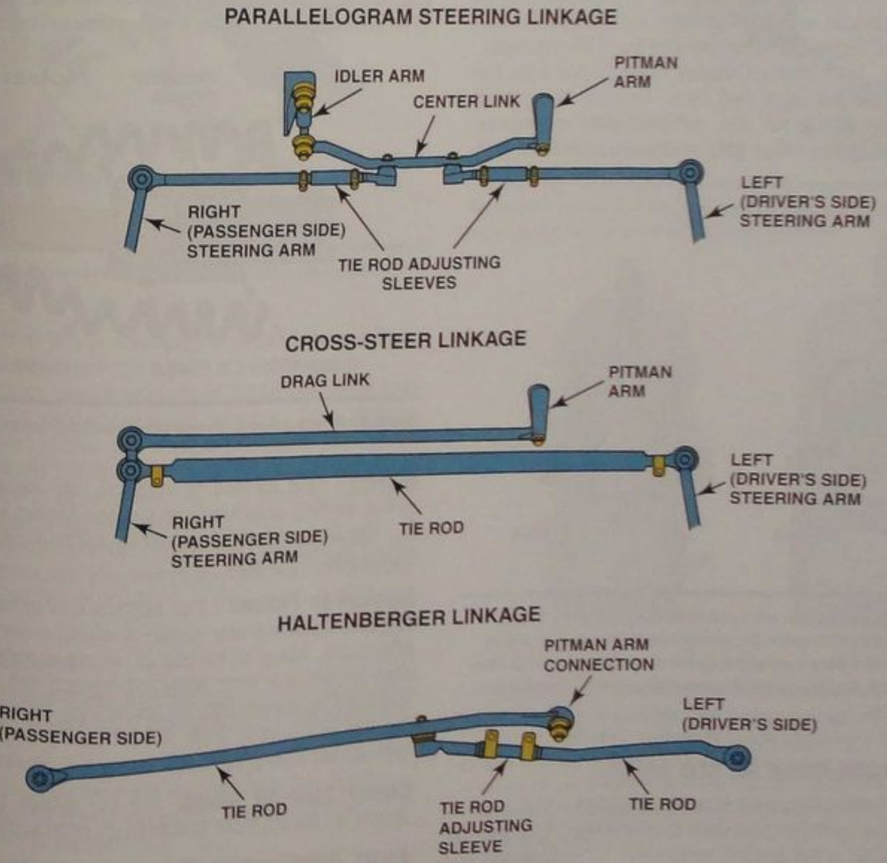


Figure 90–2 The most common type of steering is the parallelogram. The cross-steer and Haltenberger linkage designs are used on some trucks and vans.

Connections between all steering component parts are constructed of small ball-and-socket joints. These joints allow side-to-side movement to provide steering of both front wheels, and allow the joints to move up and down, which is required for normal suspension travel.

It is important that all of these joints be lubricated with chassis grease through a **grease fitting,** also called a **zerk fitting,** at least every six months or per the vehicle manufacturer's specifications.

Some vehicles come equipped with sealed joints and do not require periodic servicing. Some vehicles come from the factory with plugs that need to be removed and replaced with grease fittings and then lubricated.

FREQUENTLY ASKED QUESTION ???

Why Is a Grease Fitting Sometimes Called a Zerk Fitting?

In 1922 the zerk fitting was developed by Oscar U. Zerk, an employee of the Alemite Corporation, a manufacturer of pressure lubrication equipment. A zerk or grease fitting is also known as an *Alemite fitting.*

Tie Rod Ends Tie rod ends connect the steering linkage to the steering knuckles and to other steering linkage components. Conventional tie rod ends use a hardened steel ball stud assembled into a hardened steel and thermoplastic bearing. An internal preload spring limits the ball stud endplay and helps compensate for ball-and-socket wear. See Figure 90–4 for two designs of tie rod ends.

For many years, Ford Motor Company used tie rod ends that included a rubber-bonded steel ball stud. Because there is no sliding friction inside the tie rod end, no lubrication was needed. This type of tie rod end is called **RBS (rubber-bonded socket).** See Figure 90–5.

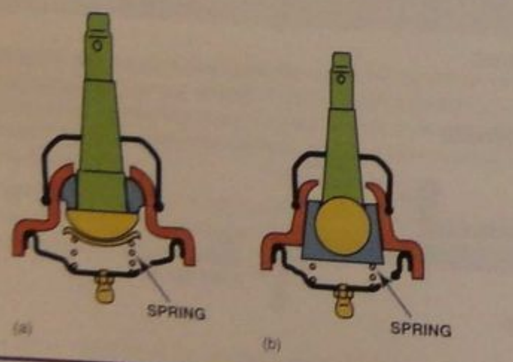


Figure 90–4 (a) A dual bearing design with a preload spring. The use of two bearing surfaces allows for one surface for rotation (for steering) and another surface for pivoting (to allow for suspension up-and-down movement). (b) The nylon wedge bearing type allows for extended lube intervals. Wear is automatically compensated for by the tapered design and spring-loaded bearing.

RACK-AND-PINION INNER TIE ROD ENDS

Inner tie rod end assemblies used on rack-and-pinion steering units require special consideration and often special tools. The inner tie rod end is also called a **ball socket assembly.**

The inner tie rod assemblies are attached to the end of the steering rack by one of several methods. See Figure 90–6.

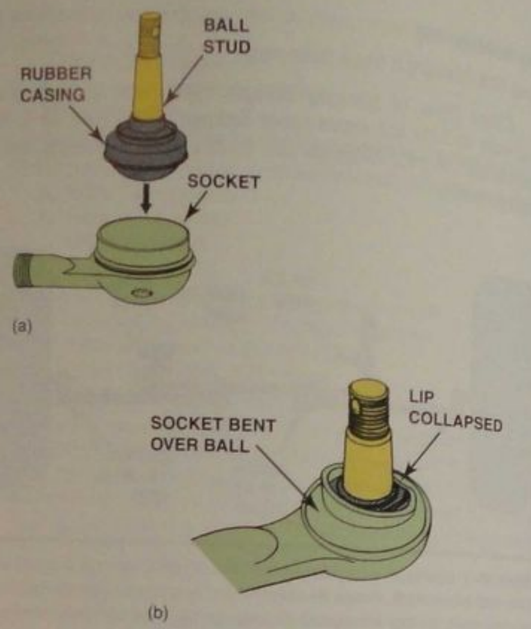


Figure 90–5 (a) A rubber-bonded socket is constructed of a rubber casing surrounding the ball stud, which is then inserted into the socket of the tie rod end. The hole in the socket allows air to escape as the ball stud is installed and there is not a place for a grease fitting. (b) The socket is crimped over the ball so that part of the socket lip retains the stud.

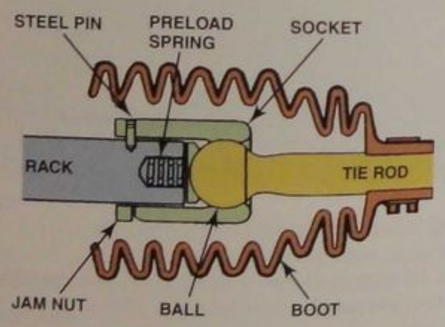


Figure 90–6 Rack-and-pinion steering systems use a ball-and-socket-type inner tie rod end.

Staked This method is common on Saginaw-style rack-and-pinion steering units found on General Motors vehicles.

The flange around the outer tie rod must be restaked to the flat on the end of the rack.

Riveted or Pinned This method is commonly found on Ford vehicles. Some roll pins require a special puller, or the pin can be drilled out. Many styles use an aluminum rivet. A special, very deep socket or a large open-end wrench can usually be used to shear the aluminum rivet by unscrewing the socket assembly from the end of the rack while the rack-and-pinion unit is still in the vehicle. See Figure 90–7.

Center Take-Off Racks For the **center take-off racks,** use bolts to secure the inner tie rods to the rack, as shown in Figure 90–8.

Front Steer versus Rear Steer **Front steer,** also called *forward steer,* is the term used to describe a vehicle that has the steering gear in front of the front wheel centerline. Having the steering gear located in this position improves handling and directional stability, especially when the vehicle is heavily loaded.

Front-steer vehicles usually produce an understeer effect that makes the vehicle feel very stable while cornering. If the steering gear linkage is located behind the wheels, it is called **rear steer** and the cornering forces are imposed on the steering in the direction of the turn. This is an oversteer effect. It tends to make the steering easier and makes the vehicle feel less stable.

Most front-wheel-drive vehicles are rear steering, with the rack-and-pinion steering unit attached to the bulkhead or subframe behind the engine. See Figure 90–9.

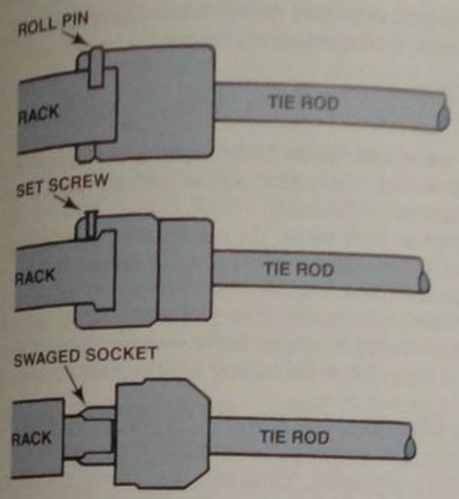


Figure 90–7 A variety of methods are used to secure the inner tie rod end socket assembly to the end of the rack.

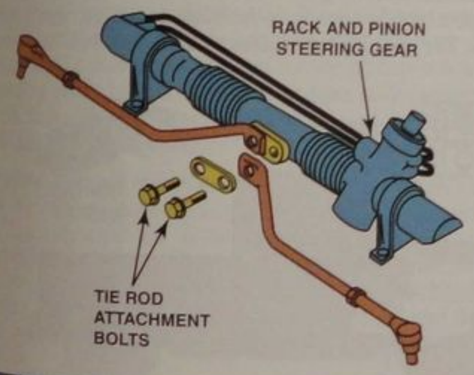


Figure 90–8 Exploded view of a center-take-off-style rack-and-pinion steering gear assembly.

FOUR-WHEEL STEERING

Some vehicles were equipped with a system that steers all four wheels. Two terms are commonly used when discussing four-wheel steering:

1. **Same-phase steering.** Same-phase steering means that the front and rear wheels are steered in the same direction. Same-phase steering improves steering response, especially during rapid-lane-change-type maneuvers.
2. **Opposite-phase steering.** Also called *negative-phase mode,* opposite-phase steering is when the front wheels and rear wheels are steered in the opposite direction. See Figure 90–10.



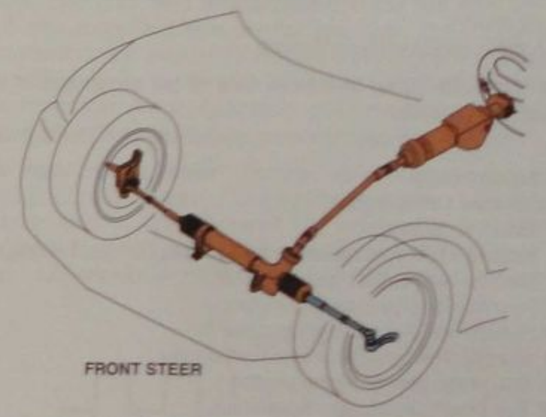


Figure 90–9 In a rear-steer vehicle, the steering linkage is behind the centerline of the front wheels, whereas the linkage is in front on a front-steer vehicle.

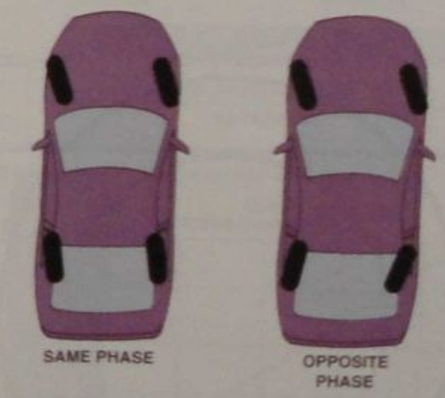


Figure 90–10 Opposite-phase four-wheel steer is usually used only at low vehicle speed to help in parking maneuvers. Sample-phase steering helps at higher speeds and may not be noticeable by the average driver.

Opposite-phase steering will quickly change the vehicle's direction, but may cause a feeling of oversteering.

Opposite-phase steering is best at low speeds; same-phase steering is best for higher-speed handling and lane-change maneuvers.

Quadrasteer Quadrasteer™ is a four-wheel steering system that dramatically enhances low-speed maneuverability, high-speed stability, and towing capability. See Figure 90–11.

The system is an electrically powered rear wheel steering system comprised of the following components:

- A steerable, solid rear axle
- A heavy-duty wiring harness and fuse
- A programmable control module
- A power relay in the control module
- A rack-and-pinion-style steering actuator mounted on the rear differential cover
- An electric motor assembly on top of the rear steering actuator
- Three Hall-effect switches in the motor assembly
- A shorting relay in the motor assembly
- A rear wheel position sensor located under a cover on the bottom of the actuator, below the motor assembly
- A steering wheel position sensor located at the base of the steering column
- A mode select switch on the dash

See Figure 90–12 for an overall view of the components of the Quadrasteer system.

The rear wheel steering control module has the following inputs:

- Battery voltage
- Switched battery voltage
- Class 2 serial data
- Steering wheel position sensor analog signal, via class 2 message from the body control module (BCM)
- Steering wheel position sensor phase A
- Steering wheel position sensor phase B
- Steering wheel position sensor marker pulse
- Rear wheel position sensor position 1
- Rear wheel position sensor position 2
- Rear wheel steering motor Hall sensor A
- Rear wheel steering motor Hall sensor B
- Rear wheel steering motor Hall sensor C
- Vehicle speed signal from the instrument panel cluster (IPC)
- Rear wheel steering mode switch signal

See Figure 90–13.

The system operates in three principal modes, as follows:

- **Two-wheel steer mode.** Normal steering operation—the rear wheels are held in a centered position and rear wheel steering is disabled while in this mode.
- **Four-wheel steer mode.** The four-wheel steering mode provides three principal phases of steering: negative phase, neutral phase, and positive phase. Negative phase occurs at low speeds and the rear wheels turn opposite of the front wheels. In the neutral phase, the rear wheels are centered and do not turn. Positive phase occurs at higher speeds and the rear wheels turn in the same direction as the front wheels.
- **Four-wheel steer tow mode.** The four-wheel steer tow mode provides more positive-phase steering than the normal four-wheel steering at high speed. During low-speed driving, the four-wheel steer tow mode provides similar negative-phase steering as it does in the normal four-wheel steering mode.

Rear Wheel Steering Control Module The rear wheel steering control module controls all functions of the rear wheel steering system. The module has a dedicated power feed line from an underhood fuse holder, via a 125-amp mega fuse. The module is located in the rear of the vehicle on the underbody. The module uses the inputs listed earlier to determine when and how far to turn the rear wheels. The module uses the Hall switches in the motor assembly, a shorting relay, and a motor control relay to monitor and control the direction and speed of the motor. The module also controls the duty cycle of the phase leads to the motor. The motor control relay is part of the rear wheel steering control module and is not serviceable.

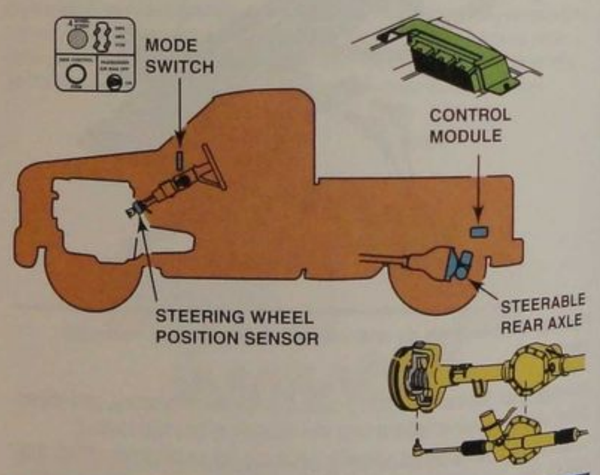


Figure 90–12 The Quadrasteer system includes many components that all work together.

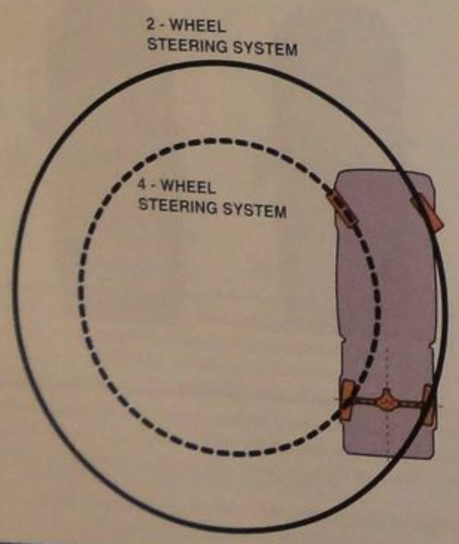


Figure 90–11 Being equipped with four-wheel steer allows a truck to make shorter turns than would otherwise be possible.

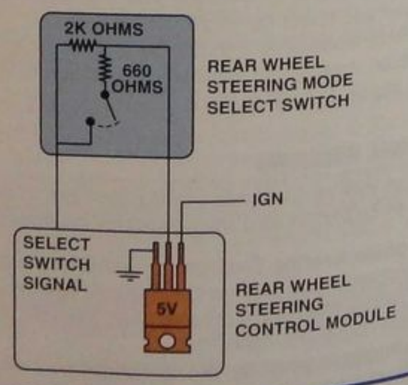


Figure 90–13 Rear steer select switch schematic.

The control module allows the vehicle rear wheels to turn a maximum of 12 degrees left or right. When the vehicle is operated in reverse, the maximum rear wheel steering angle is 5 degrees left or right. When the vehicle is sitting still in the test mode, the system will move a maximum of 5 degrees left or right.

Rear Wheel Steering Mode Switch The mode switch located in the instrument panel allows the driver the option of selecting two-wheel steering, four-wheel steering, or four-wheel steering tow modes of operation. The mode switch has indicators that show which mode the rear wheel steering system is in. When all indicators are lit the rear wheel steering control module has lost its memory settings and the scan tool must be used to recalibrate the rear wheel steering control module. During a mode change, the indicator for the selected mode will flash until the mode change is complete. The rear wheel steering control module will wait for the steering wheel to pass the center position before entering the selected mode. The indicators on the mode switch are LEDs; the switch is also back lit. See Figure 90–14.

Rear Wheel Steering Motor Assembly The rear wheel steering motor assembly is a three-phase, six-pole, brushless DC motor. The motor assembly is located on the top of the rear steering actuator, and transmits its power through a planetary gearset inside the actuator. There are three Hall switches inside the assembly: Hall A, Hall B, and Hall C. The rear wheel steering control modules uses the Hall switch inputs to monitor the position, speed, and direction of the motor.

Steering Wheel Position Sensor The **steering wheel position sensor (SWPS)** provides one analog signal and three digital signals. The digital signals—Phase A, Phase B, and marker pulse—are direct inputs to the rear wheel steering control module. The analog signal is input to the body control module (BCM) and is sent via a class 2 message to the rear wheel steering control module. Battery voltage is supplied to the sensor from the cruise fuse to operate the digital portion of the sensor. A 12-volt reference is provided by the rear wheel steering control module to the Phase A, Phase B, and marker pulse circuits of the SWPS. The module monitors each circuit as it is either remains high or is pulled low by the SWPS. The scan tool displays the Phase A and Phase B data parameters as either high or low when the steering wheel is being rotated. Each change from high to low, or low to high, represents 1 degree of steering wheel rotation. When observing with the scan tool, the parameters for Phase A and Phase B will not always display the same value at the same time. The marker pulse is a digital pulse signal that is displayed as high by the scan tool with the steering wheel angle between +10 degrees and −10 degrees. At greater than 10 degrees steering wheel angle in either direction, the marker pulse data will be displayed as low. The BCM provides the 5-volt reference and low reference for the analog portion of the SWPS. The BCM reads the SWPS analog signal in voltage, which is typically 2.5 volts with the steering wheel on center. The voltage ranges from 0.25 volts at approximately one full turn left to 4.75 volts at approximately one full turn right. The voltage will then remain at that level for the remainder of steering wheel travel. This voltage can be monitored in BCM data display on a scan tool. The sensor may also be utilized by other optional systems. See Figures 90–15 through 90–18.

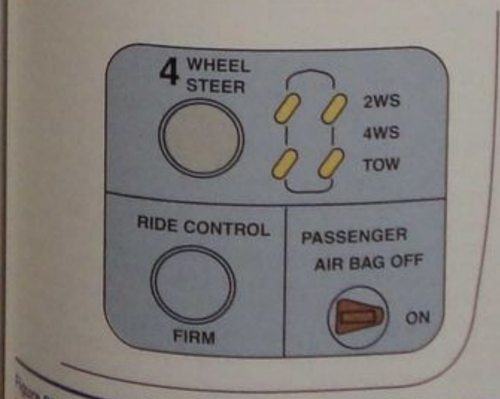


Figure 90–14 The dash-mounted select switch showing the three positions for the four-wheel steer system.

Rear Wheel Position Sensor The rear wheel position sensor has two signal circuits: position 1 and position 2. Position 1 is a linear measurement of voltage per degree. The voltage range for position 1 is from 0.25 to 4.75 volts, and the angular measurement range is from −620 degrees to +620 degrees. At 0.25 volts the steering

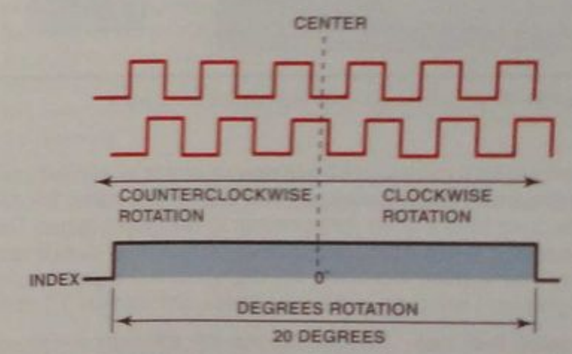


Figure 90–15 The output of the handwheel sensor digital signal.

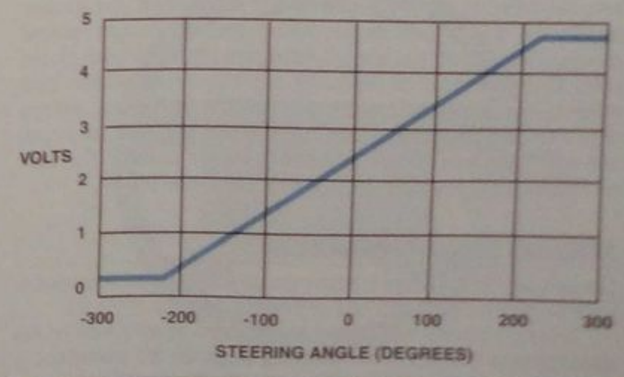


Figure 90–16 Handwheel analog signal.

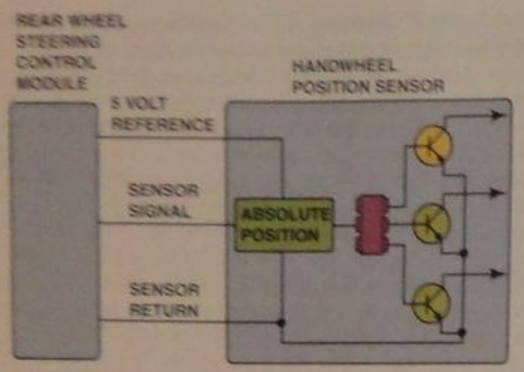


Figure 90–17 Handwheel position sensor analog signal to control module.

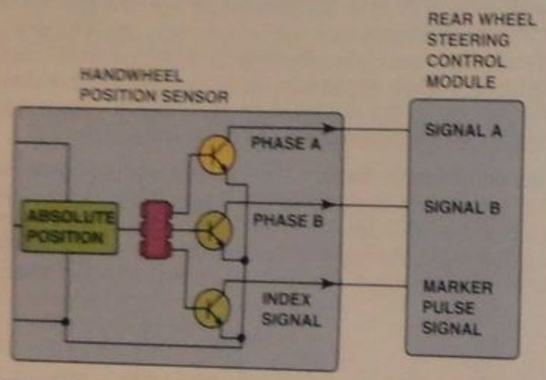


Figure 90–18 Handwheel position sensor digital signal to control module.

wheel has been rotated −600 degrees past center. At 4.75 volts the steering wheel has been rotated +600 degrees past center. The position 2 circuit is a linear measurement of voltage per degree. The voltage for position 2 increases or decreases from 0.25 to 4.75 volts every 180 degrees. When the steering wheel is 0 degrees center, the position 1 and position 2 output signals each measure 2.5 volts.

Steerable Rear Axle The steerable rear axle has a rack-and-pinion-style actuator mounted to the differential cover, specially designed axle shafts, and movable hub and bearing assemblies mounted by upper and lower ball joints. The actuator housing is part of the differential cover. In the event of a system malfunction, the actuator returns the rear wheels to the center position through internal springs. The actuator has specially designed inner and outer tie rod ends. There are inner tie rod boots to prevent contaminants from entering the actuator. The actuator has the rear wheel steering motor assembly attached to the upper housing. There are shields and a skid plate on the rear axle to protect the actuator. There are no internal adjustments to the actuator. See Figure 90–19.

STEERING LINKAGE LUBRICATION

Keeping all joints equipped with a grease fitting properly greased is necessary for long life and ease of steering. See Figure 90–20.

During a chassis lubrication, do not forget to put grease on the steering stop, if so equipped. **Steering stops** are the projections or built-up areas on the control arms of the front suspension designed to limit the steering movement at full lock. See Figure 90–21.



Figure 90–19 A Quadrasteer system showing all of the components. The motor used to power the rear steering rack can draw close to 60 amperes during a hard turn and can be monitored using a Tech 2.



Figure 90–20 Greasing a tie rod end. Some joints do not have a hole for excessive grease to escape, and excessive grease can destroy the seal.

FREQUENTLY ASKED QUESTION ???

What Is "Goofy Mode"?

Trucks that are equipped with the Quadrasteer system have a three-position switch on the dash:

1. 2WS
2. 4WS
3. Tow

The Quadrasteer module then determines the right amount of rear steer and in which direction based on vehicle speed and steering wheel angle. If trailer towing mode is selected and the truck is *not* towing a trailer, the computer will adjust the steering as if there is a trailer and will slightly delay the rear steering action when changing lanes and other maneuvers. As a result, when the steering wheel is turned the front wheels will of course turn in direct proportion to the input from the steering wheel; however, the rear wheels will be delayed in their action to allow the trailer to track properly. If, however, a trailer is not being towed, this delay feels "goofy" and could result in customer concerns about the proper operation of the Quadrasteer system. Be sure that the control switch is placed in the off or normal modes unless a trailer is in fact being towed.



Figure 90–21 Part of steering linkage lubrication is applying grease to the steering stops. If these stops are not lubricated, a grinding sound may be heard when the vehicle hits a bump when the wheels are turned all the way one direction or the other. This often occurs when driving into or out of a driveway that has a curb.

When the steering wheel is turned as far as it can go, the steering should *not* stop inside the steering gear! Forces exerted by the power steering system can do serious damage to the steering gear if absorbed by the steering gear rather than the steering stop.

NOTE: Many rack-and-pinion steering units are designed with a rack-travel-limit internal stop and do not use an external stop on the steering knuckle or control arm.

Most steering stops are designed so that the lower control arm hits a small section of the body or frame when the steering wheel is turned to the full "lock" position. Steering stops should be lubricated to prevent a loud grinding noise when turning while the vehicle is going over a bump. This noise is usually noticeable when turning into or out of a driveway.

DRY PARK TEST

Since many steering (and suspension) components do *not* have wear specifications for replacement purposes, it is extremely important that the beginning service technician work closely with an experienced veteran technician. While most technicians can determine when a steering component such as a tie rod end is definitely in need of replacement, marginally worn parts are often hard to find and can lead to handling problems. One of the most effective, yet easy to perform, steering component inspection methods is called the **dry park test.**

FREQUENTLY ASKED QUESTION ???

Why Do Only a Few Vehicles Use Grease Fittings?

Many years ago, all vehicles were equipped with grease fittings, while today very few vehicles are so equipped. The reasons for this, as given by engineers, include the following:

- It has been determined that the use of the wrong type of grease can cause more harm than good.
- If a grease fitting is used to allow grease to enter the suspension or steering joint, then water can also get inside the joint.
- Grease fittings are often ignored or the greasing of the joint is not performed by the service technician.
- Low-friction joints do not require routine service like the older metal-to-metal joints required.

Excessive play in the steering wheel can be caused by worn or damaged steering components. Looseness in the steering components usually causes freeplay in the steering wheel. Freeplay refers to the amount of movement of the steering wheel required to cause movement of the front wheels. The exact cause of freeplay in the steering should be determined if the freeplay exceeds 2 in. (5 cm) for parallelogram-type steering linkages, or 3/8 in. (1 cm) for rack-and-pinion steering. See Figure 90–22.

This simple test is performed with the vehicle on the ground or on a drive-on ramp-type hoist, moving the steering wheel back and forth *slightly* while an assistant feels for movement at each section of the steering system. The technician can start checking for any looseness in the steering linkage starting either at the outer tie rod ends and working toward the steering column, or from the steering column toward the outer tie rod ends. It is important to check each and every joint and component of the steering system, including the following:

1. The intermediate shaft and flexible coupling.
2. All steering linkage joints, including the inner tie rod end ball socket. See Figure 90–23.
3. Steering gear mounting and rack-and-pinion mounting bushings.

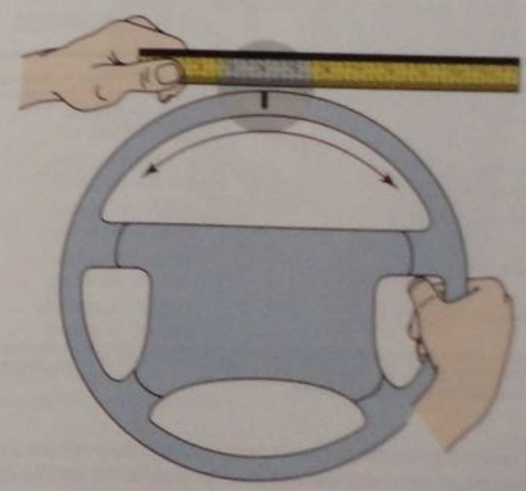


Figure 90–22 Checking for freeplay in the steering.

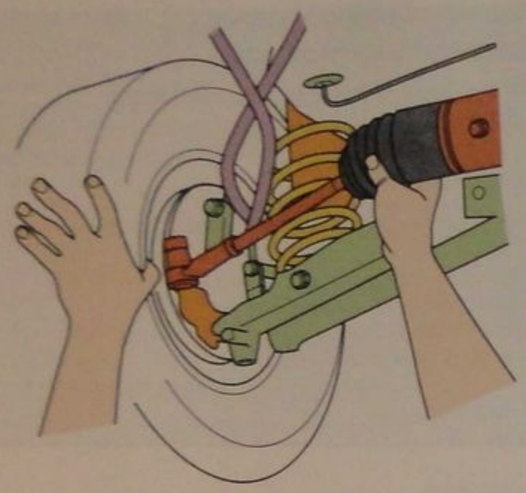


Figure 90–23 All joints should be felt during a dry park test. Even inner tie rod ends (ball socket assemblies) can be felt through the rubber bellows on many rack-and-pinion steering units.

TECH TIP ✓ **Jounce/Rebound Test**

All steering linkage should be level and "work" at the same angle as the suspension arms, as shown in Figure 90–24. A simple test to check these items is performed as follows:

1. Park on a hard, level surface with the wheels straight ahead and the steering wheel in the *unlocked* position.
2. Bounce (jounce) the vehicle up and down at the front bumper while watching the steering wheel.

The steering wheel should *not* move during this test. If the steering wheel moves while the vehicle is being bounced, look for a possible bent steering linkage, suspension arm, or steering rack. See Figure 90–25.

COMMON WEAR ITEMS

On a vehicle equipped with a conventional steering gear and parallelogram linkage, as shown in Figure 90–26, typical items that wear first, second, and so on include the following:

Steering Component	Estimated Mileage to Wear Out*
1. Idler arm	40,000–60,000 miles (60,000–100,000 km)
2. Outer tie rod ends (replaced in pairs only)	60,000–100,000 miles (100,000–160,000 km)
3. Inner tie rod ends	80,000–120,000 miles (130,000–190,000 km)
4. Center link	90,000–130,000 miles (140,000–180,000 km)
5. Pitman arm	100,000–150,000 miles (160,000–240,000 km)

*Mileage varies greatly due to different road conditions and levels of vehicle maintenance. This chart should be used as a guide only.

Note that there are overlapping mileage intervals for several components. Also note that the mileage interval for an idler arm is such that by the time other components are worn, the idler arm may need to be replaced a second time.



Figure 90–24 The steering and suspension arms must remain parallel to prevent the up-and-down motion of the suspension from causing the front wheels to turn inward or outward.

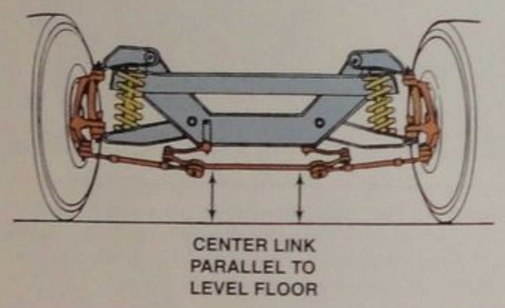


Figure 90–25 The steering linkage should be parallel to the ground.

For vehicles that use rack-and-pinion-type steering systems, the list is shorter because there are fewer steering components and the forces exerted on a rack-and-pinion system are in a straight line. The first to wear are usually outer tie rod ends (one or both) followed by the inner tie rod ball-and-socket joints, usually after 60,000 miles (100,000 km) or more. Intermediate shaft U-joints usually become worn and can cause steering looseness after 80,000 miles (130,000 km) or more.

NOTE: Experienced front-end technicians can often guess the mileage of a vehicle simply by careful inspection of the steering linkage. For example, if the idler arm is a replacement part and again needs to be replaced, and the outer tie rods also need replacement, then the vehicle probably has at least 60,000 miles and usually more! When inspecting a used vehicle for possible purchase, perform a careful steering system inspection. This is one area of the vehicle where it is difficult to hide long or hard service.

TECH TIP ✓ **Wear and Nonwear Center Links**

Some center links are equipped with ball-and-socket joints, which can wear. Other center links are manufactured with holes for ball joint studs only. See Figure 90–27. Generally, the center links that do not use joints are unlikely to need replacement unless a joint becomes loose and wears the tapered stud hole. Knowing which style of center link is used will help determine the most likely location to check for excessive steering linkage play.

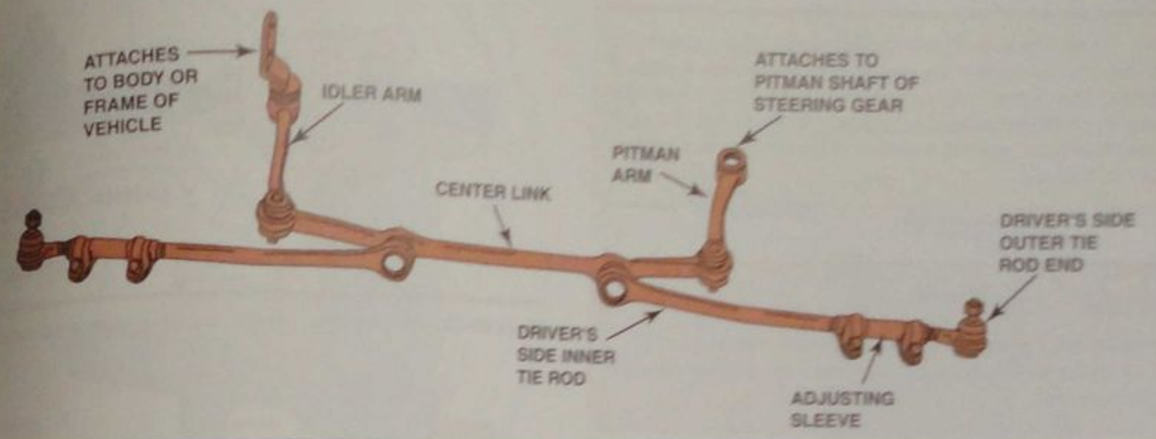


Figure 90–26 Typical parallelogram steering linkage. The center link can also be named the relay rod, drag link, or connecting link.

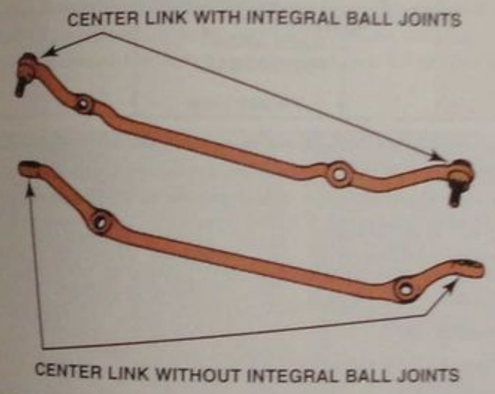


Figure 90–27 Some center links have ball joints while others have tapered socket holes to accept ball joints on the pitman arm, idler arm, and inner tie rod ends.

UNDER-VEHICLE INSPECTION

After checking the steering system components as part of a dry park test, hoist the vehicle and perform a thorough part-by-part inspection:

1. Inspect each part for damage due to an accident or bent parts due to the vehicle's hitting an object in the roadway.

CAUTION: Never straighten a bent steering linkage; always replace with new parts.

2. Idler arm inspection is performed by using *hand* force of 25 lb (110 N-m) up and down on the arm. If the *total* movement exceeds 1/4 in. (6 mm), the idler arm should be replaced. See Figure 90–28.
3. All other steering linkage should be tested *by hand* for any vertical or side-to-side looseness. Tie rod ends use ball-and-socket joints to allow for freedom of movement for suspension travel and to transmit steering forces to the front wheels. It is therefore normal for tie rods to rotate in their sockets when the tie rod sleeve is rocked. **Endplay in any tie rod should be zero.** Many tie rods are spring loaded to help keep the ball-and-socket joint free of play as the joint wears. Eventually, the preloaded spring cannot compensate for the wear, and endplay occurs in the joint. See Figures 90–29 and 90–30.

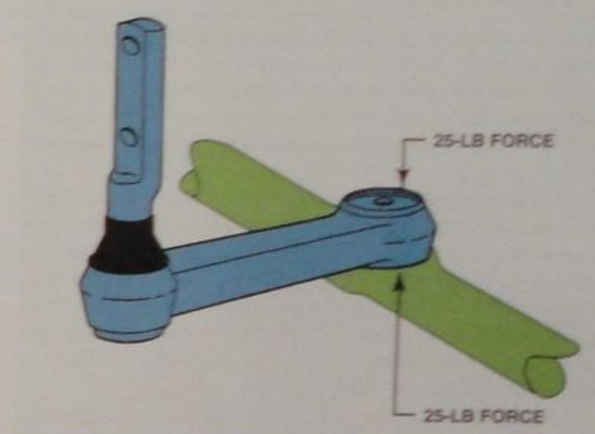


Figure 90–28 To check an idler arm, most vehicle manufacturers specify that 25 pounds of force be applied by hand up and down to the idler arm. The idler arm should be replaced if the total movement (up and down) exceeds 1/4 in. (6 mm).

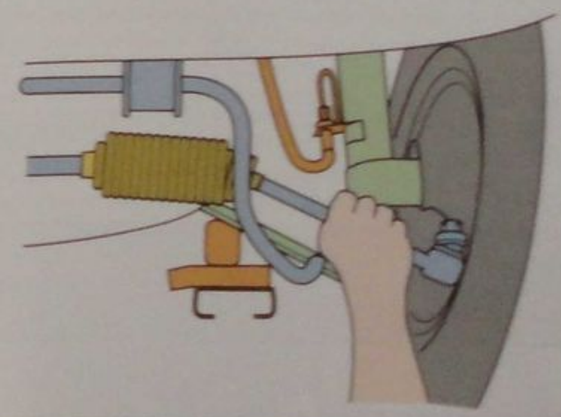


Figure 90–29 Steering system component(s) should be replaced if any noticeable looseness is detected when moved by hand.

4. All steering components should be tested with the wheels in the straight-ahead position. If the wheels are turned, some apparent looseness may be noticed due to the angle of the steering linkage.

CAUTION: Do not turn the front wheels of the vehicle while suspended on a lift to check for looseness in the steering linkage. The extra leverage of the wheel and tire assembly can cause a much greater force to be applied to the steering components than can be exerted by hand alone. This extra force may cause some apparent movement in good components that may not need replacement.

TECH TIP ✔ **The Killer Bs**

The "three Bs" that can cause steering and suspension problems are bent, broken, or binding components. Always inspect each part under the vehicle for each of the killer Bs.

REAL WORLD FIX **Bump Steer**

Bump steer, or *orbital steer*, is used to describe what happens when the steering linkage is not level: The front tires turn inward or outward as the wheels and suspension move up and down. (Automotive chassis engineers call it *roll steer*.) The vehicle's direction is changed *without moving the steering wheel* whenever the tires move up and down over bumps, dips in the pavement, or even over gentle rises!

This author experienced bump steer once and will never forget the horrible feeling of not having control of the vehicle. After replacing an idler arm and aligning the front wheels, everything was OK until about 40 mph (65 km/h); then the vehicle started darting from one lane of the freeway to another. Because there were no "bumps" as such, bump steer was not considered as a cause. Even when holding the steering wheel perfectly still and straight ahead, the vehicle would go left, then right. Did a tie rod break? It certainly felt exactly like that's what happened. I slowed down to below 30 mph and returned to the shop.

After several hours of checking everything, including the alignment, I discovered that the idler arm was not level with the pitman arm. This caused a pull on the steering linkage whenever the suspension moved up and down. As the suspension compressed, the steering linkage pulled inward on the tie rod on that side of the vehicle. As the wheel moved inward (toed in), it created a pull just as if the wheel were turned by the driver.

This is why all steering linkages must be parallel with the lower control. The reason for the bump steer was that the idler arm was bolted to the frame, which was slotted vertically. I didn't pay any attention to the location of the original idler arm and simply bolted the replacement to the frame. After raising the idler arm back up where it belonged (about 1/2 in. [13 mm]), the steering problem was corrected.

Other common causes of bump steer are worn or deteriorated rack mounting bushings, a noncentered steering linkage, or a bent steering linkage. If the steering components are not level, any bump or dip in the road will cause the vehicle to steer one direction or the other. See Figure 90–31.

Always check the steering system carefully whenever a customer complains about any "weird" handling problem.

STEERING LINKAGE REPLACEMENT

Parallelogram Type When replacing any steering system component, it is best to replace all defective and marginally good components at the same time. Use the following guidelines.

Parts that can be replaced *individually* include the following:

Idler arm

Center link

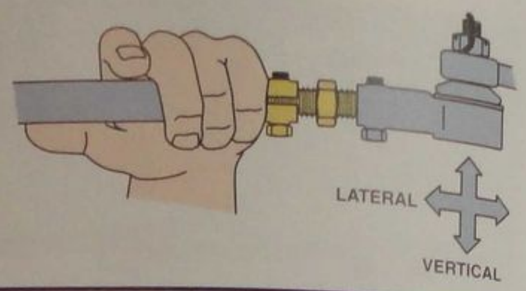


Figure 90–30 All joints should be checked by hand for any lateral or vertical play.

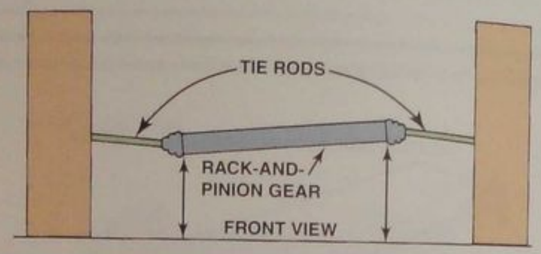


Figure 90–31 If a rack-and-pinion or any other steering linkage system is not level, the front tires will be moved inward and/or outward whenever the wheels of the vehicle move up or down.

Pitman arm

Intermediate shaft

Intermediate shaft U-joint

Parts that should be replaced in *pairs only* include the following:

Outer tie rod ends

Inner tie rod ends

Idler arm (if there are two on the same vehicle, such as GM's Astro van)

Replacing steering system components involves these steps:

Step #1 Hoist the vehicle safely with the wheels in the straight-ahead position. Remove the front wheels, if necessary, to gain access to the components.

Step #2 Loosen the retainer nut on tapered components, such as tie rod ends. Use a tie rod removal puller (also called a *taper breaker*), as shown in Figure 90–32, or use hammers to slightly deform the taper, as shown in Figure 90–33.

CAUTION: Vehicle manufacturers often warn not to use a tapered pickle-fork tool to separate tapered parts. The wedge tool can tear the grease seal and damage both the part being removed and the adjoining part.

Pitman arms require a larger puller to remove the pitman arm from the splines of the pitman shaft. See Figures 90–34 and 90–35.

Step #3 Replace the part using the hardware and fasteners supplied with the replacement part. *Do not reuse the precrimped torque prevailing nuts used at the factory as original equipment on many tie rod ends.*

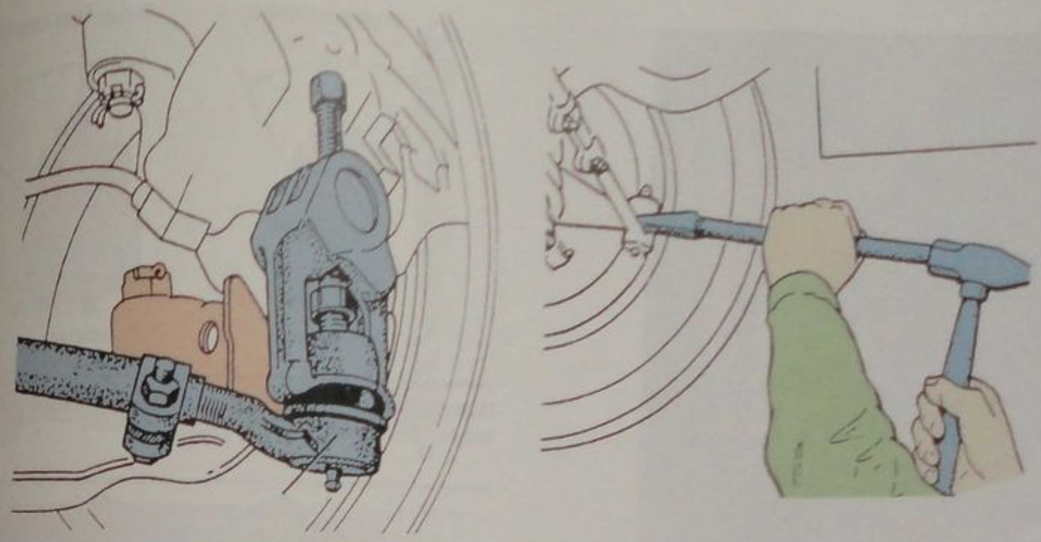


Figure 90–32 The preferred method for separating the tie rod end from the steering knuckle is to use a puller such as the one shown. A pickle-fork-type tool should only be used if the tie rod is not going to be replaced. A pickle-fork-type tool can damage or tear the rubber grease boot.

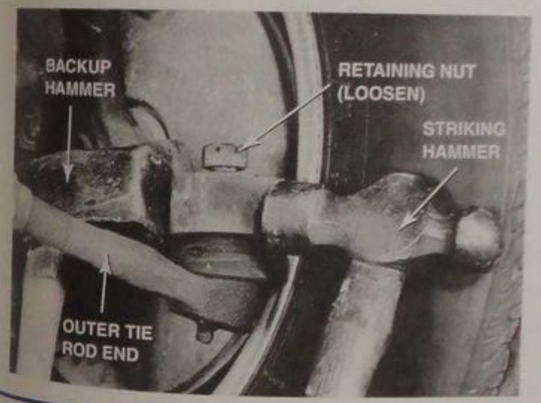


Figure 90–33 Two hammers being used to disconnect a tie rod end from the steering knuckle. One hammer is used as a backing for the second hammer. Notice that the attaching nut has been loosened, but not removed. This prevents the tie rod end from falling when the tapered connection is knocked loose.

CAUTION: Whenever tightening the nuts of tapered parts such as tie rods, *DO NOT* loosen after reaching the proper assembly torque to align the cotter key hole. If the cotter key does not fit, *tighten* the nut farther until the hole lines up for the cotter key. See Figure 90–36. Always use a new cotter key.

When replacing tie rod ends, use the adjusting sleeve to adjust the total length of the tie rod to the same position and length as the original. Measure the original length of the tie rods and assemble the replacement tie rod(s) to the same overall length. See Figure 90–37.

When positioning the tie rod end(s), check that the stud is centered in the socket, as shown in Figure 90–38. This permits maximum steering linkage movement without getting into a bind if the steering linkage is pivoted beyond the angle the tie rod end can move in the socket.

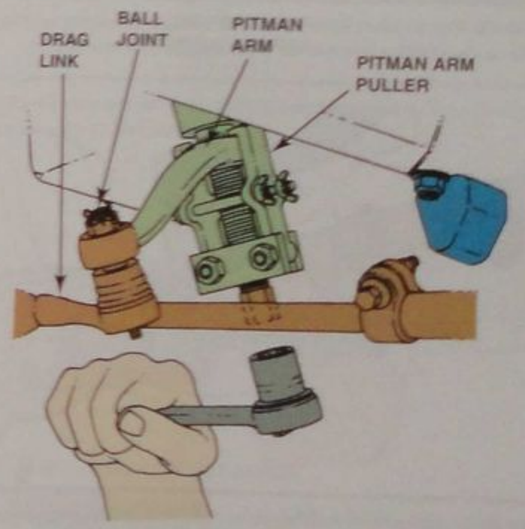


Figure 90–34 A pitman arm puller is used to remove the pitman arm from the pitman shaft.

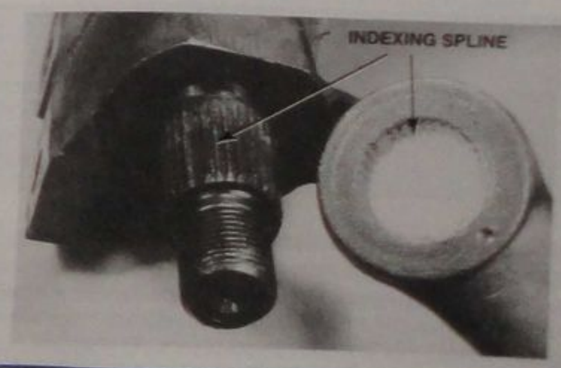


Figure 90–35 Pitman arm and pitman shaft indexing splines.

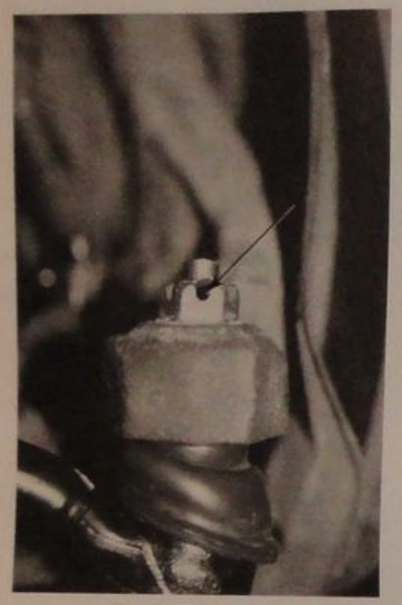


Figure 90–36 Align the hole in the tie rod end with the slot in the retaining nut. If the holes do not line up, always tighten the nut further (never loosen) until the hole lines up.



Figure 90–37 Replacement tie rods should be of the same overall length as the originals. Measure from the edge of the tie rod sleeve to the center of the grease fitting. When the new tie rod is threaded to this dimension, the toe setting will be close to the original.

NOTE: To ensure proper wheel alignment, install the adjusting sleeve with an equal number of threads showing at each end of the sleeve. Some manufacturers also specify a *minimum* of three threads showing at each end. If the sleeve itself is corroded or bent, it should be replaced along with either or both of the tie rod ends (inner and outer). See Figure 90–39.

Service of Ball Socket Assemblies Inner tie rod end assemblies used on rack-and-pinion steering units require special consideration and often special tools. The inner tie rod end, also called a ball socket assembly, should be replaced whenever there is any noticeable freeplay in the ball-and-socket joint. Another test of this joint is performed by disconnecting the outer tie rod end and measuring the effort required to move the tie rod in the socket, as shown in Figure 90–40. This is called the **articulation test.**

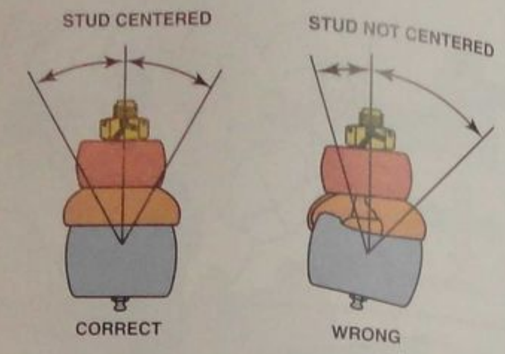


Figure 90–38 All tie rod ends should be installed so that the stud is in the center of its operating range, as shown.

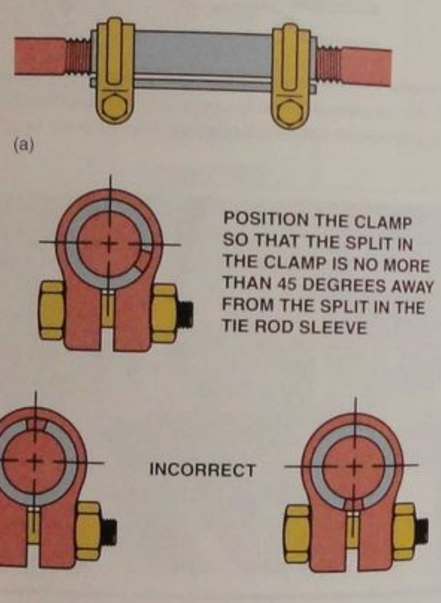


Figure 90–39 (a) Tie rod adjusting sleeve. (b) Be sure to position the clamp correctly on the sleeve.

NOTE: The articulation test is to be used on metal-to-metal ball socket assemblies. Low-friction joints (polished ball and plastic liner-type joints) may require less effort to move and still be serviceable.

The inner tie rod assemblies are attached to the end of the steering rack by one of several methods.

Removing a ball socket assembly usually requires the use of two wrenches or a special tool. See Figure 90–41.

The flange around the outer tie rod must be restaked to the flat shoulder on the end of the rack, as shown in Figure 90–42.

Always follow the instructions that come with the replacement part(s). See Figure 90–43.

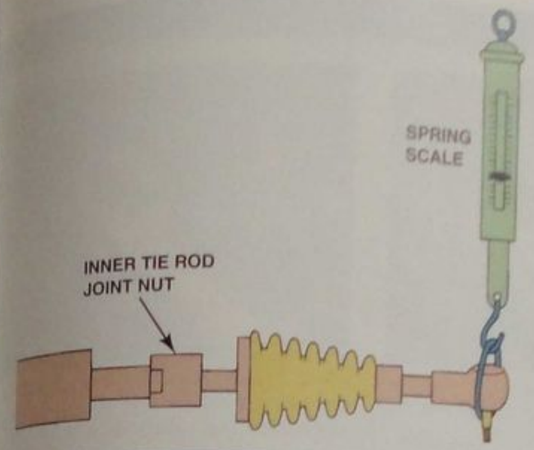


Figure 90–40 An articulation test uses a spring scale to measure the amount of force needed to move the tie rod in the ball socket assembly. Most manufacturers specify a minimum of 1 lb (4.4 N) of force and a maximum of 6 lb (26 N).

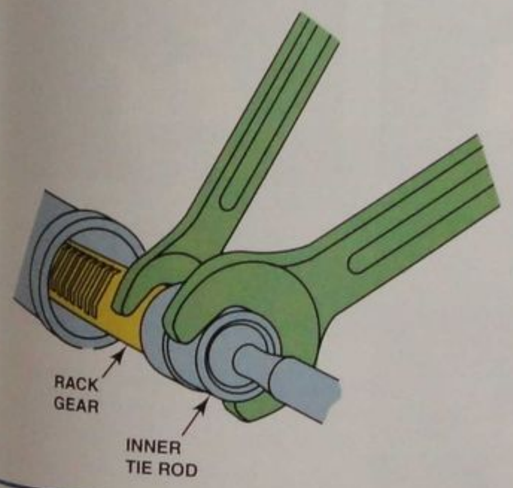


Figure 90–41 Removing a staked inner tie rod assembly requires two wrenches—one to hold the rack and the other to unscrew the joint from the end of the steering rack.

NOTE: When replacing a rack-and-pinion assembly, specify a long rack rather than a short rack. A short rack does not include the bellows (boots) or inner tie rod ends (ball socket assemblies). The labor and cost required to exchange or replace these parts usually make it easier and less expensive to replace the entire steering unit.

SUMMARY

1. The dry park test is a very important test to detect worn or damaged steering parts. With the vehicle on the ground, have an assistant move the steering wheel back and forth while the technician feels for any looseness in each steering system part.
2. The steering system must be level side-to-side to prevent unwanted bump steer. Bump steer is when the vehicle's direction is changed when traveling over bumps or dips in the road.
3. The idler arm usually is the first steering system component to wear out on a conventional parallelogram-type steering system. Following the idler arm in wear are the tie rods, center link, and then the pitman arm.
4. Steering components should be checked for wear using hand force only.
5. All steering components should be installed and tightened with the front wheels in the straight-ahead position.
6. Always use a tie rod remover/puller or a taper breaker when separating tapered components, such as tie rods.

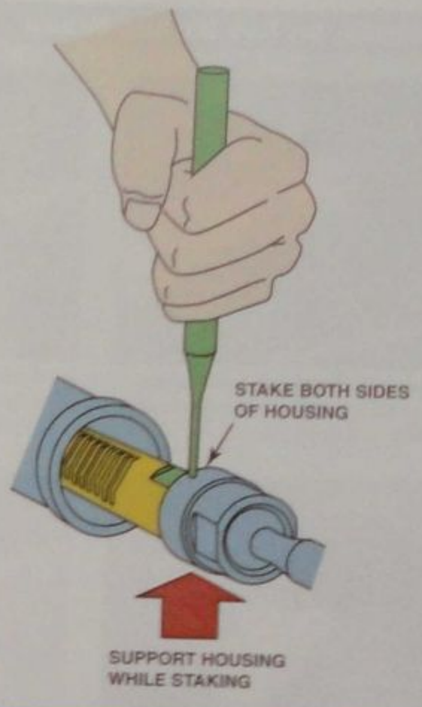


Figure 90–42 When the inner tie rod end is reassembled, both sides of the housing must be staked down onto the flat shoulder of the rack.

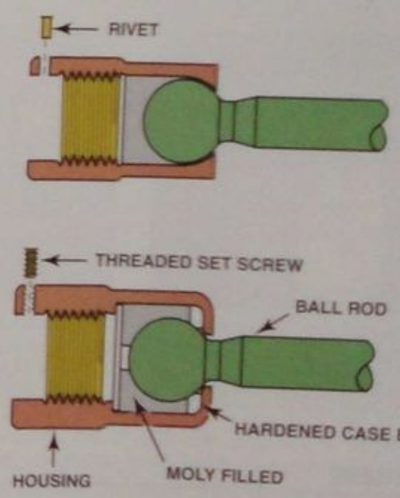


Figure 90–43 After replacing an inner tie rod end, the socket assembly should be secured with a rivet or set screw depending on the style of the replacement part.

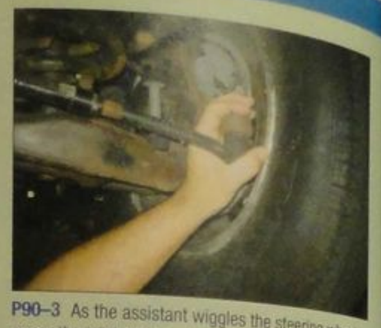
PHOTO SEQUENCE Dry Park Test Step-by-Step



P90–1 Drive the vehicle onto a drive-on-type hoist and have an assistant gently rotate the steering wheel back and forth about 2 inches (50 mm).



P90–2 Perform a visual inspection of the steering and suspension system, looking for damage from road debris or other faults.



P90–3 As the assistant wiggles the steering wheel, grasp the joint at the outer tie rod end on the driver's side to check for any movement.



P90–4 Next, check for any freeplay at the pitman arm.



P90–5 Check the joint between the left inner tie rod end and the center link for play.



P90–6 Move to the passenger side and check for any looseness at the joint between the center link and the right-side inner tie rod end.



P90–7 Check for looseness at the idler arm connector to the center link and the idler arm at the frame mount.



P90–8 Check for looseness at the passenger-side outer tie rod end. After the inspection, record the results on the work order.

REVIEW QUESTIONS

1. Describe how to perform a dry park test.
2. List the steering parts that should be replaced in pairs.
3. What test procedure can be used to check that the steering linkage is straight and level?
4. What is the difference between a wear and nonwear center link?

CHAPTER QUIZ

1. A "dry park" test to determine the condition of the steering components and joints should be performed with the vehicle _____.
   a. On level ground on a drive-on lift
   b. On turn plates that allow the front wheels to move
   c. On a frame contact lift with the wheels off the ground
   d. Lifted off the ground about 2 in. (5 cm)
2. Two technicians are discussing bump steer. Technician A says that an unlevel steering linkage can be its cause. Technician B says that if the steering wheel moves when the vehicle is bounced up and down, the steering linkage may be bent. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. A vehicle has an excessive amount of freeplay in the steering wheel and it is difficult to keep it traveling straight on a straight and level road. Which is the *least likely* cause?
   a. Worn tie rod ends
   b. Excessive play in the ball socket assemblies
   c. Worn idler arms
   d. Loose pitman arm retaining nut
4. How are the inner tie rods attached to the rack on a center-take-off-type rack-and-pinion steering gear?
   a. Staked
   b. Bolted
   c. Riveted
   d. Pinned
5. What is the *most likely* cause of bump steer?
   a. Worn outer tie rod ends
   b. A worn center link
   c. Worn or oil-soaked rack bushings
   d. A lack of proper lubrication of all ball-and-socket joints
6. How much endplay is usually acceptable in tie rod ends?
   a. Zero
   b. 0.0010 to 0.030 in.
   c. 0.030 to 0.050 in.
   d. 0.050 to 0.100 in.
7. Technician A says that outer tie rod ends should be replaced in pairs, even if only one is worn. Technician B says that inner tie rod ends should be replaced in pairs, even if only one is worn. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Which tool is *not* recommended to be used to separate tapered steering components because it can do harm?
   a. Taper breaker
   b. Pickle fork
   c. Tie rod removal puller
   d. Two hammers
9. Technician A says that torque prevailing nuts can be reused unless damaged. Technician B says that a new cotter key should always be used. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. New tie rods are being installed. Technician A says to tighten the retaining nuts to specification and then loosen, if needed, to align the cotter pin hole. Technician B says to tighten farther to align the cotter key hole. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 91

Power-Assisted Steering Operation and Service

OBJECTIVES: After studying Chapter 91, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "A" (Steering Systems Diagnosis and Repairs). • Discuss the components and operation of power steering pumps. • List the components of a typical power-recirculating-ball-nut steering gear system. • Describe the operation of a power rack-and-pinion steering system.

KEY TERMS: BPP • cold climate fluid • EHPS • EPS • EVO • flow control valve • force • integral reservoir • magnasteer • Pascal's law • poppet valve • pressure • pressure-relief valve • PSCM • PSP • remote reservoir • rotary control valve • self-park • SPS • SSS • TFE • VES

Power-assisted steering hydraulically boosts the mechanical steering gear operation so the driver can turn the steering wheel with less effort for the same response. Hydraulic power steering has been available since the 1950s, and many late-model systems are enhanced by electronic controls.

POWER STEERING HYDRAULIC SYSTEMS

Hydraulics is the study of liquids and their use to transmit force and motion. Hydraulic systems transmit force and motion through the use of fluid pressure. **Force** is a push or pull acting on an object and is usually measured in pounds or Newtons. **Pressure** is force applied to a specific area. Pressure is usually measured in force per unit of area, such as pounds per square inch (PSI), or kilopascals (kPa). One PSI is equal to 6.895 kPa.

The Pascal is a unit of measure named after the French scientist Blaise Pascal (1623–1662), who studied the behavior of fluids in closed systems. One of his discoveries, known as **Pascal's law,** was that pressure on a confined fluid is transmitted equally in all directions and acts with equal force on equal areas.

Hydraulic systems can transmit force and motion through liquids because, for all practical purposes, a liquid cannot be compressed. No matter how much pressure is placed on a liquid, its volume remains the same. This allows a liquid to transmit force much like a mechanical lever. See Figure 91–1.

The advantage of a liquid over a mechanical lever is that a liquid has volume but does not have a fixed shape. Because it assumes the shape of its container, a liquid can transfer force around obstacles or through pipes and passages of any shape. As explained by Pascal's Law, a liquid can also decrease or increase the force it transmits depending on the area of the output surface to which the force is applied. See Figure 91–2.

POWER STEERING PUMP AND RESERVOIR

The power steering pump draws fluid from the reservoir, pressurizes it, and delivers it to the power steering system. A power steering

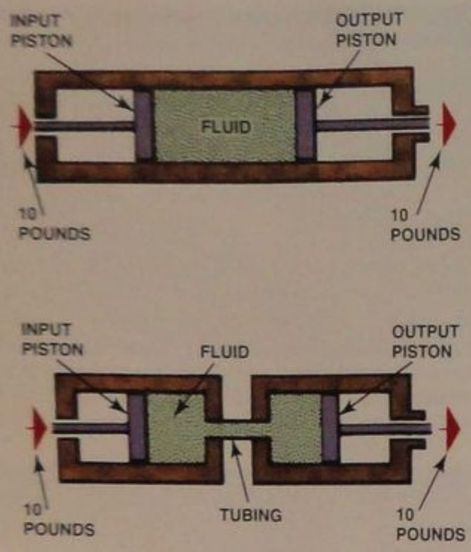


Figure 91–1 Hydraulic fluid transmits the same force whether it passes through a single chamber or two chambers connected by a narrow passage.

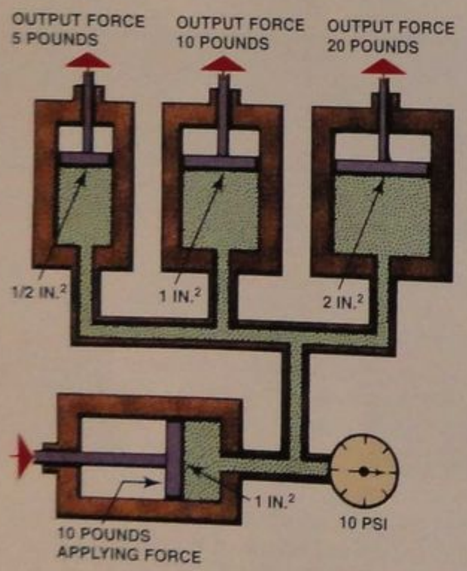


Figure 91–2 A fluid applies a force equal to the applied force on a surface that is equal in size to the applying surface. If the surface is half the size, then the fluid exerts half the force; if the surface is twice as large, the fluid exerts twice the force.

pump produces a high-pressure stream of fluid, typically in the 1,500-PSI (10,500 kPa) range. The fluid reservoir may be either integral to (built into) the pump or remotely mounted and connected to the pump by a hose. The power steering fluid reservoir is usually made of either plastic or stamped metal, and it includes the fluid filler neck, cap, and dipstick. It can be integral to or remote from the pump. An **integral reservoir** is part of the pump, and the pump itself operates submerged in power steering fluid. See Figure 91–3. Although once common, steering pumps with an integral reservoir have given way to those with a remote reservoir on many current-production vehicles. This is because the remote reservoir allows for

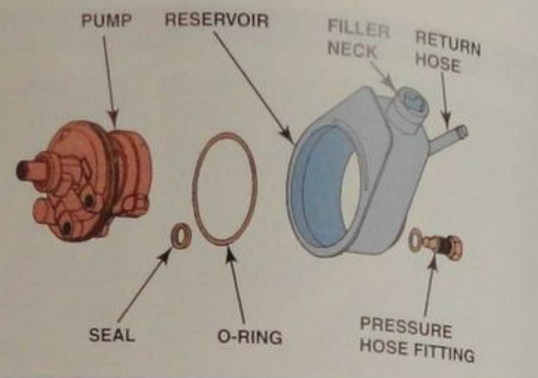


Figure 91–3 A typical integral power stering pump when the pump is mounted inside the reservoir.

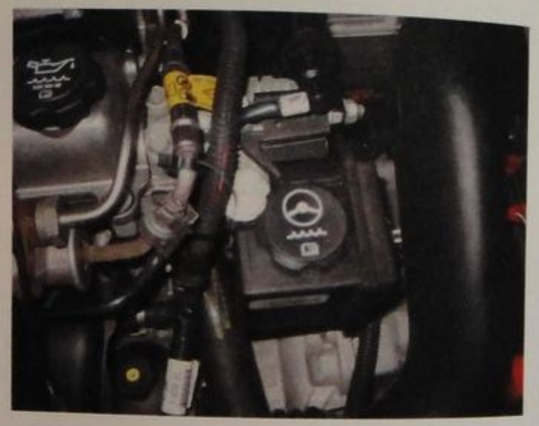


Figure 91–4 Typical remote reservoir.

a smaller, more compact pump assembly that is better suited to the cramped engine compartment of a modern vehicle.

A **remote reservoir** is a separate assembly from the pump and provides fluid to it through a suction hose. See Figure 91–4.

A typical power steering system requires only 2 to 3.5 lb (0.9 to 1.6 kg) of effort to turn the steering wheel.

Most power steering systems use an engine-driven hydraulic pump. Power steering hydraulic pumps are usually belt driven from the front crankshaft pulley of the engine, as shown in Figure 91–5.

The power steering pump delivers a constant flow of hydraulic fluid to the power steering gear or rack. A typical power steering pump requires less than 1/2 horsepower, which is less than 1% of engine power while driving straight ahead. Even while parking at low speed, the power steering requires only about 3 horsepower while providing high hydraulic pressures. Typical pressures generated by a power steering system include the following.

Straight ahead	less than 150 PSI (1,400 kPa)
Cornering	about 450 PSI (3,100 kPa)
Parking (maximum)	750–1400 PSI (5,200–10,000 kPa)

The power steering pump drive pulley is usually fitted to a chrome-plated shaft with a press fit. The shaft is applied to a rotor with vanes that rotate between a thrust plate and a pressure plate. See Figure 91–6.

Some power steering pumps are of the slipper or roller design instead of the vane type. When the engine starts, the drive belt

rotates the power steering pump pulley and the rotor assembly inside the power steering pump.

With a vane-type pump, centrifugal force and hydraulic pressure push the vanes of the rotor outward into contact with the pump ring. The shape of the pump ring causes a change in the volume of fluid between the vanes. As the volume increases, the pressure is decreased in the space between the vanes and draws in fluid from the pump reservoir. When the volume between the vanes decreases, the pressure is increased and flows out the pump discharge port. See Figures 91–7, 91–8, and 91–9.

The pressure outlet hose connects to a fitting that threads into the outlet port of the pump body. A modulator valve, commonly called a **flow control valve,** installs in the same bore as the hose fitting. See Figure 91–10.

The modulator valve is a spring-loaded pressure-relief device that bleeds off excess pressure to prevent system damage. When pump output is more than the power steering system requires, the excess pressure overcomes spring force and moves the valve down in its bore. This uncovers an orifice through which the fluid can flow back into the inlet passages. An orifice is a small opening that regulates fluid pressure and flow. It can be a restriction in a fluid line or a hole between two fluid chambers. This particular opening is called a *variable orifice* because the size of the opening varies with the amount of pressure applied to the valve. When fluid pressure is not high, spring force keeps the valve seated so that all of the pressurized fluid flows through the outlet port and into the pressure hose.

Because the engine drives the pump, the power steering pump places a load on the engine whenever the engine is running. Under certain conditions, such as when the steering wheel is turned to or near full stop for more than a few seconds, pressure builds in the system and the pump must work harder to keep up with the demand. As a result, the pump draws more power from the engine. If the engine is running at idle, the extra load can cause it to stall. A pressure switch, known as the **power steering pressure (PSP)** switch, transmits an electronic signal to the power train control module (PCM) when the pressure in the system is high enough to increase the load on the engine. In response to the PSP switch signal, the PCM increases the engine idle speed to prevent stalling.

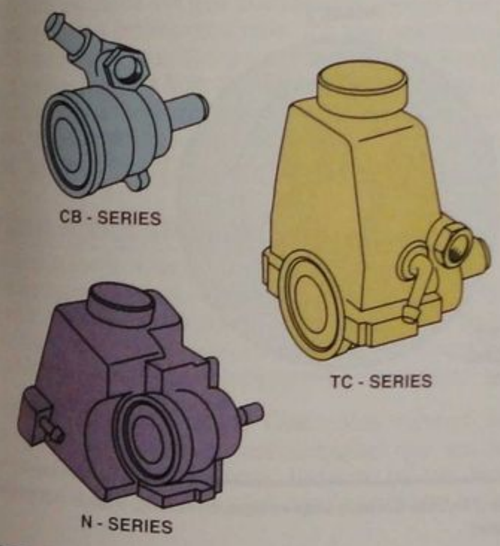


Figure 91–5 Typical integral power steering pump assemblies.

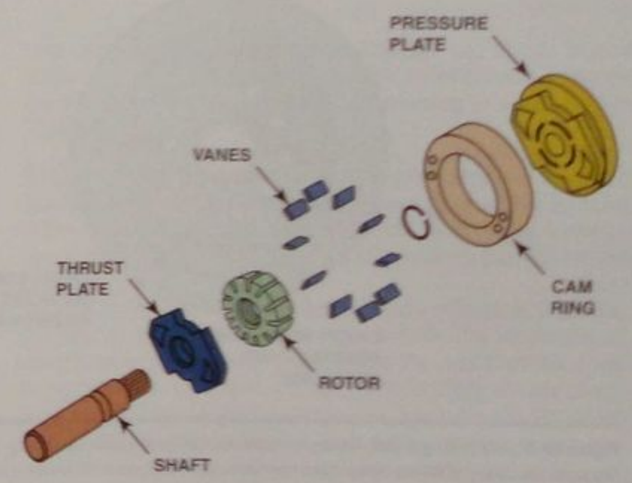


Figure 91–6 General Motors vane-type pump.

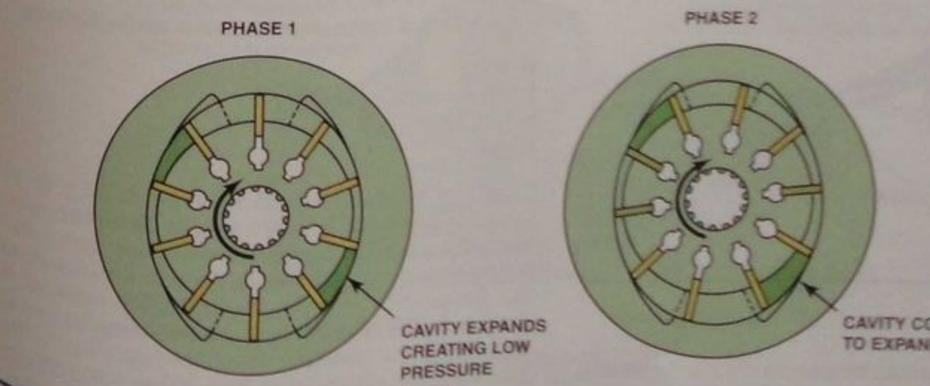


Figure 91–7 Vane pump operation. In phase 1, the rotor moves past the opposed suction ports, and the vanes move out to maintain contact with the ring. This creates a low-pressure area, drawing fluid into the cavities formed by the vanes. As the rotor continues to move during phase 2, the vanes follow the contour of the ring. The contour of the ring forms a larger cavity between the vanes. This increases the suction and draws more fluid into the pump.

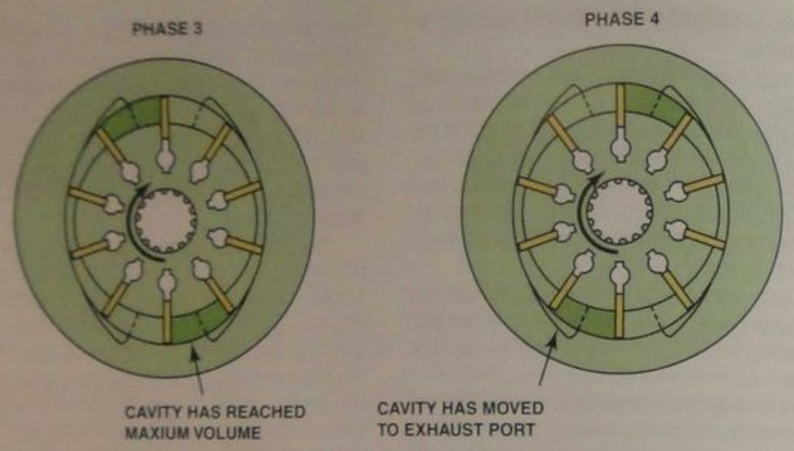


Figure 91–8 Vane pump operation—continued. At phase 3, the vanes are at the end of the intake port of the pump and the cavity has reached its maximum volume. In phase 4, the rotor moves into alignment with the opposed discharge ports.

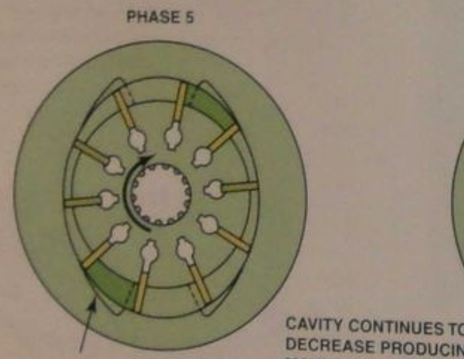


Figure 91–9 Vane pump operation—continued. As the rotor continues to move during phase 5, the volume of the cavity decreases, which increases the discharge pressure. At phase 6, the last phase, the contour of the ring results in the minimum cavity volume, and the discharge of fluid is completed.

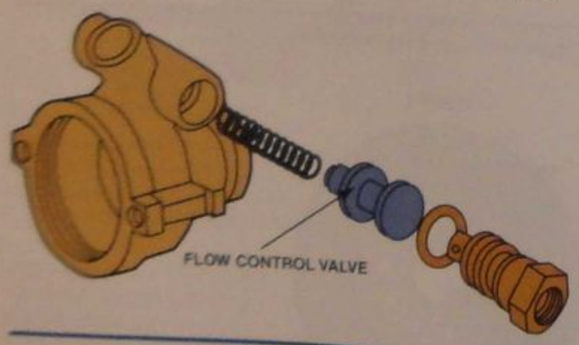


Figure 91–10 Flow control valve.

The pressure increases when the steering wheel is turned to its full stop in either direction. To handle the excess pressure, a pressure-relief passage runs from a point near the pressure hose fitting to the spring end of the modulator valve. Inside the passage is a **pressure-relief valve**. The spring end of the modulator valve forms a seat for the pressure-relief check ball. Under normal circumstances, the check ball remains seated.

The parts of the pressure-relief valve are the following:

- Spring
- Valve piston
- Check ball
- Seat

A shim installs on the check ball seat to adjust the pressure at which the check ball unseats to open the pressure-relief valve. Normally, the spring force holds the piston against the check ball to keep it in its seat. When pressure becomes excessive in the pressure-relief passage, the check ball raises off its seat to allow fluid to flow through the relief passage and out through an orifice in the modulator valve. See Figure 91–11. The pressure when this occurs varies from 750 to 1,400 PSI (5,200 to 10,000 kPa) depending on the calibration of the pressure-relief valve. When power steering systems are pushed to the limit, most will make a chattering or squealing noise until the pressure is reduced.

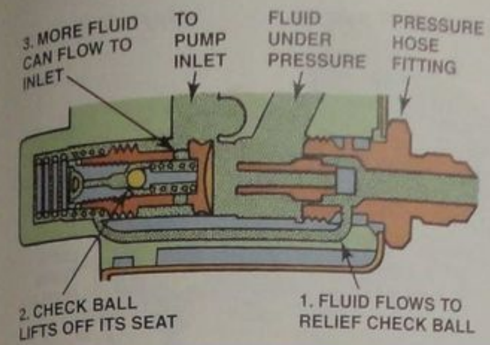


Figure 91–11 The pressure-relief check ball unseats, allowing fluid to flow back into the pump inlet if the pressure rises above a certain limit.

POWER STEERING HOSES

Because the power steering pump and the steering gear are not part of the same assembly, the system requires two hoses to connect the power steering pump and gear assembly. The pressure hose is connected to the flow control/relief valve. This hose supplies pressurized fluid to the steering gear. The second hose is called the return hose and it returns the fluid from the steering gear to the pump. Some vehicles will use a cooler in the return path to the pump. The cooler is used to reduce the temperature of the fluid before it enters the pump. See Figure 91–12.

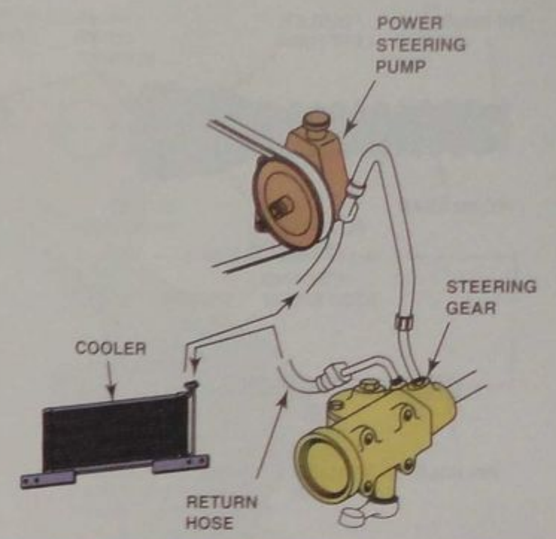


Figure 91–12 The power steering fluid cooler, if used, is located in the return hose.

INTEGRAL POWER STEERING

In an integral power steering system, the control valve and the power piston are incorporated into the steering gear construction. The control valve regulates the application of pressurized fluid against the power piston, and the power piston helps move the output member of the steering gear when pressure is applied to one side of it.

Integral Standard Steering Gear Most standard steering gears with power assist are the recirculating-ball type, and the ball nut functions as the power piston. Hydraulic pressure from the steering gear control valve is applied directly against the ball nut to help move it through the housing. The ball nut in this type of power steering gear is called the *power piston* because hydraulic pressure moves it as if it were a piston traveling in a cylinder. See Figure 91–13.

Rotary Control Valve A **rotary control valve** is a two-piece assembly that operates by rotating an inner valve within an outer valve. A steering gear with a rotary control valve is also a *torsion bar steering* gear, because a small torsion bar is used to control valve movement.

The rotary control valve consists of two cylindrical elements: the inner valve element and outer valve element. The inner valve element is secured to the steering gear input shaft and the torsion bar. In the valve, the inner element and the input shaft are one piece, and the torsion bar attaches to them. See Figure 91–14. The inner element assembly fits inside the outer valve element, and is also

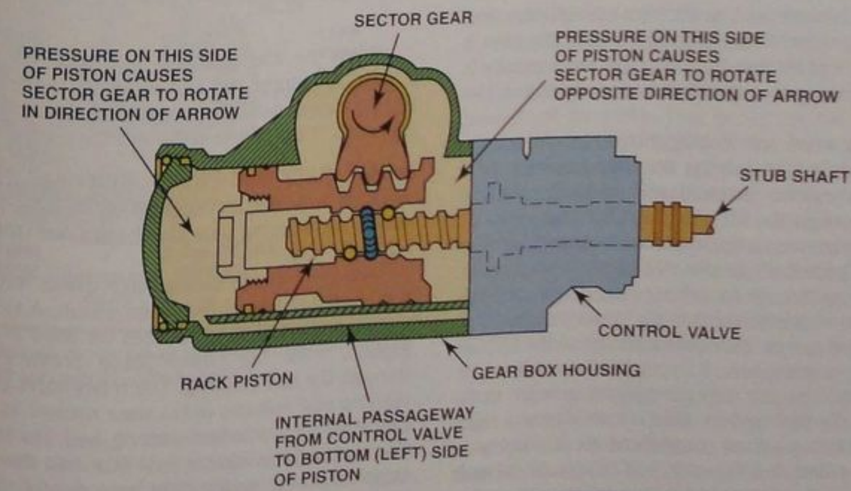


Figure 91–13 Forces acting on the rack piston of an integral power steering gear.

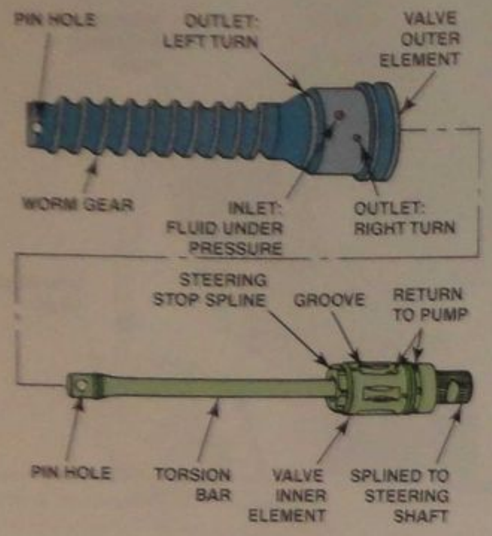


Figure 91–14 The rotary valve consists of inner and outer elements. The worm gear is part of the outer element and the torsion bar is part of the inner element. A pin attaches the worm gear to the bottom of the torsion bar to join the two elements together.

secured to the torsion bar by a pin. The outer valve element is also the steering worm gear. The torsion bar acts as a spring between the two elements to allow movement between them when the steering shaft turns. The spring force of the torsion bar tends to pull the elements back to their neutral positions when the steering wheel is released or returned to center. The strength of the torsion bar determines steering feel. A weak torsion bar moves easily and provides soft steering, while a strong bar resists movement and makes steering feel firm.

The facing surfaces of the inner and outer elements have grooves machined into them through which fluid can flow. Passages carry fluid from some of the inner-element grooves to the center of the element, where it travels through the return line to the pump reservoir. The outer element has three sets of fluid passages that connect the outside of the element to a groove at the inside. One set of passages carries fluid into the element from the pressure hose fitting, the second set carries fluid to and from the left-turn side of the power piston, and the third carries it to and from the right-turn side.

When the steering wheel is aimed straight ahead, the valve is in its neutral position. Fluid enters the valve and flows equally to both sides of the steering gear piston and to the return line. See Figure 91–15.

When the steering wheel and steering shaft turn to the left, the inner element twists on the torsion bar and repositions the valve ports. In this left-turn position, pressurized fluid flowing into the valve can only exit through the left-turn ports. See Figure 91–16. Meanwhile, the right-turn ports align with the return ports to bleed off residual pressure from the opposite side of the power piston. Pressurized fluid flowing through the left-turn ports is directed into the steering gear, where it applies force to the power piston and reduces the effort needed to turn the steering linkage to the left. See Figure 91–17. As the piston moves, it forces fluid out of the right-turn side, and that fluid returns through the control valve to the pump reservoir. Exactly the opposite flow occurs during a right-hand turn: The right-turn ports are opened and the left-turn ports exhaust to the return line. See Figure 91–18. Hydraulic pressure moves the piston up the housing bore during a right-hand turn. See Figure 91–19.

STRAIGHT-AHEAD

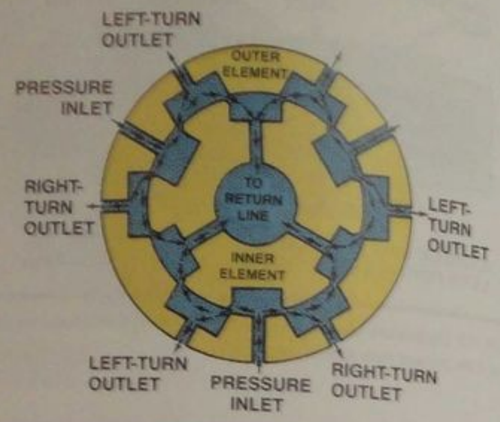


Figure 91–15 When the steering wheel is in the straight-ahead position, all of the ports in a rotary valve are open equally to the pressure and return circuits.

LEFT TURN

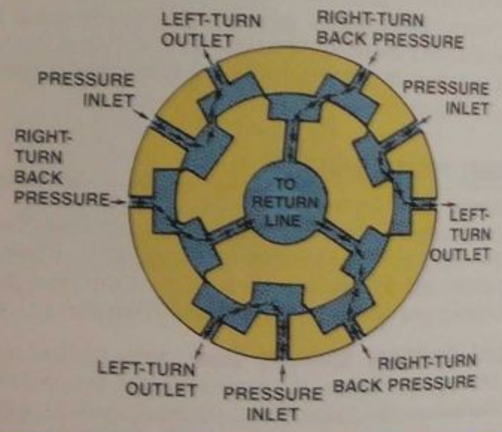


Figure 91–16 During a left turn, the inner element turns so that the left-turn circuits are open to pressure and the right-turn circuits are open to the return circuit.

When the steering wheel is released, the spring force of the torsion bar returns the two elements to their natural positions. Fluid pressure equalizes throughout the steering gear and recenters the piston in the middle of the steering gear.

Power Rack-and-Pinion Steering The rotary control valve on a power rack-and-pinion steering gear is located between the steering gear input shaft and the pinion gear. See Figure 91–20.

Fluid discharged by the valve travels through external steel lines to either side of the power piston. A steel air-transfer tube allows air displacement between the boots as they compress and expand, since the power piston prevents air from passing through the rack housing. The rotary valve in a rack-and-pinion steering unit operates in the same manner as the one previously described for a standard steering gear. During a left-hand turn, the control valve directs fluid flow into the left-turn steel line, which routes it to the right-hand side of the power piston in order to move the rack to the left. As this happens, fluid on the opposite side of the power piston is forced out through the

LEFT TURN

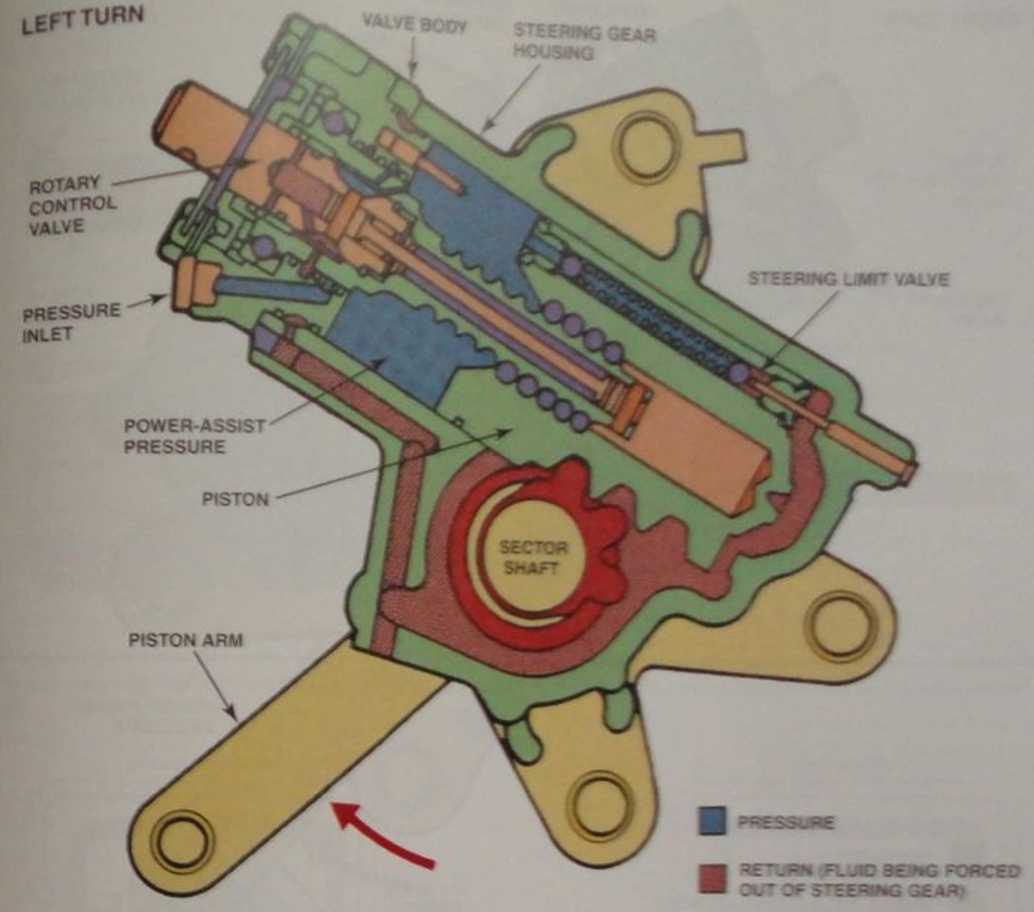


Figure 91–17 During a left turn, the high-pressure fluid helps push the piston along the worm gear, thereby reducing the steering effort from the driver.

RIGHT TURN

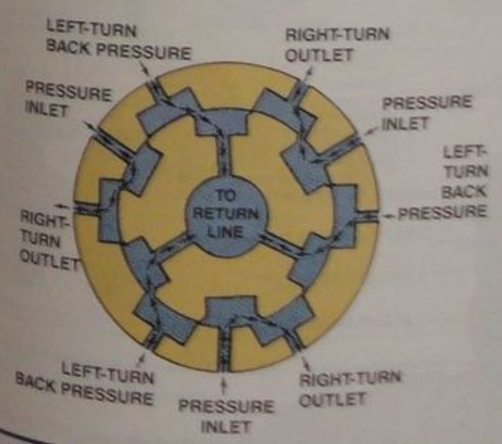


Figure 91–18 During a right turn, the inner element turns so that the right-turn outlets are open to pressure and the left-turn outlets are open to the return circuit.

right-turn steel line and back to the control valve, where it is exhausted to the return circuit. When the steering wheel is turned to the right, fluid flow is reversed so the power piston moves to the right and fluid in the left-turn chamber is exhausted to the return circuit. See Figure 91–21 on page 1153.

Flow Control Valve Operation When the power steering pump begins operation, the fluid from the output of the pump flows into the control valve. The fluid then flows through the orifice, where a pressure differential is formed. The pressure differential results in a higher pressure on the pump side than on the system side. The fluid from the orifice flows into the power steering system and through a passage on the backside of the control valve. See Figure 91–22 on page 1153.

The fluid on the backside of the control valve is used to assist the spring force acting on the valve. At this point, the combination of the spring force and hydraulic pressure is higher than the output pressure of the pump. This causes the control valve to block the passage to the pump intake. When the output pressure is higher than the spring force, the pressure behind the valve forces the control valve to move. The movement of the valve opens the passage to the intake side of the pump. This allows some of the fluid to flow into the passage. As the pump speed continues to increase, the valve moves more to compensate for the higher pressure and flow. The pressure and flow in the power steering system must remain in the correct range or the steering system components can be damaged. Failure of the control valve to regulate the pressure in the power steering system can result in excessive pressure and temperature. As long as fluid can flow through the system, the control valve can regulate the pressure. See Figure 91–23 on page 1153.

However, there are times during normal operation when the flow in the system will stop. Fluid flow can stop during parking maneuvers and when the steering wheel is turned to the extreme right and left positions.

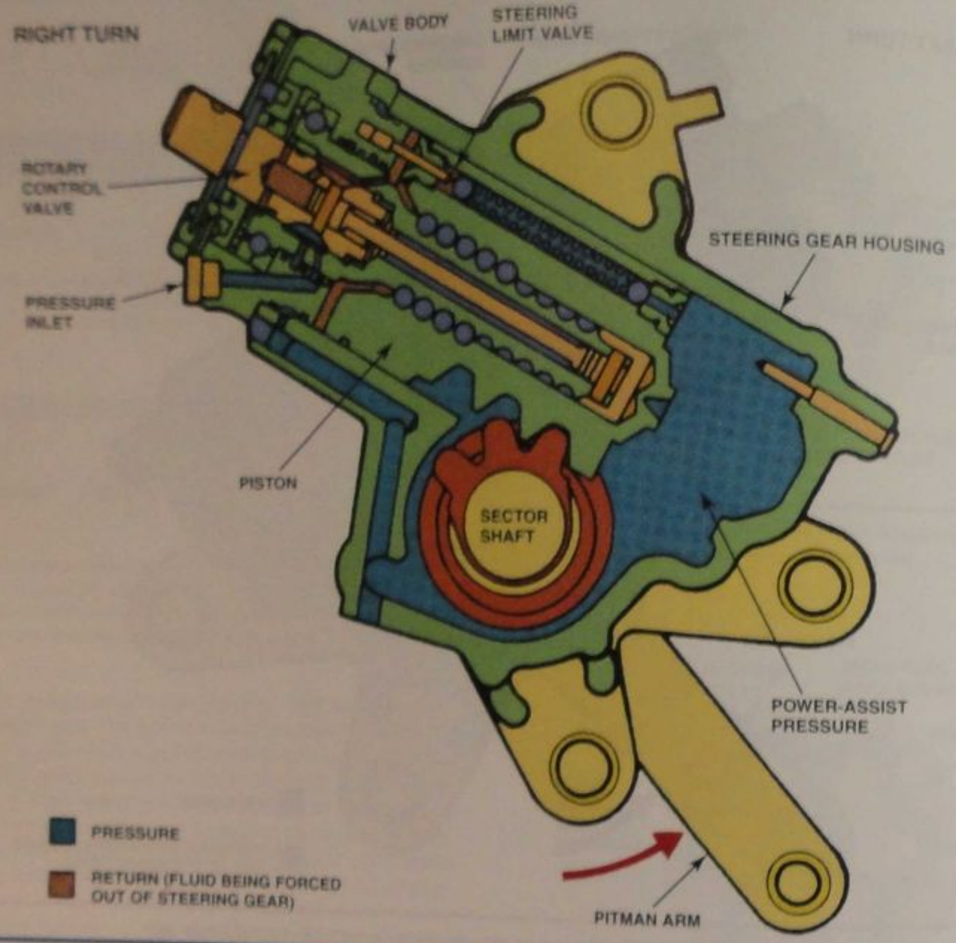


Figure 91–19 During a right turn, high-pressure fluid pushes the piston up the worm gear, moving the sector shaft and pitman arm to provide assist during a right turn.

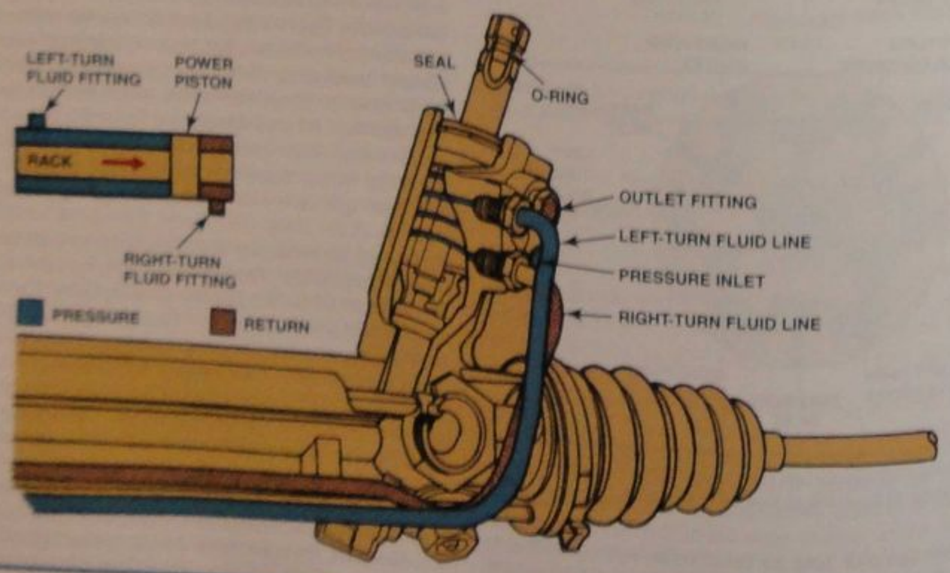


Figure 91–20 During a left turn, the control valve directs pressure into the left-turn fluid line and the rack moves left. (See inset.) Fluid pushed out of the right-turn fluid chamber travels back through the right-turn fluid line and control valve to the return circuit.

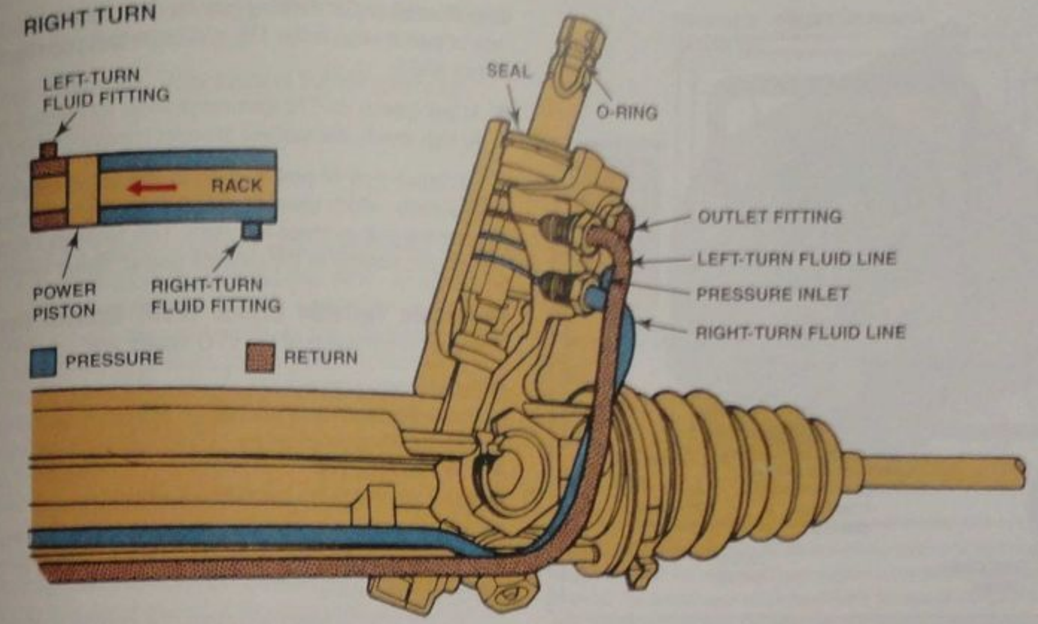


Figure 91–21 The control valve routes high-pressure fluid to the left-hand side of the power piston, which pushes the piston and assists in moving the rack toward the right when the steering wheel is turned right.

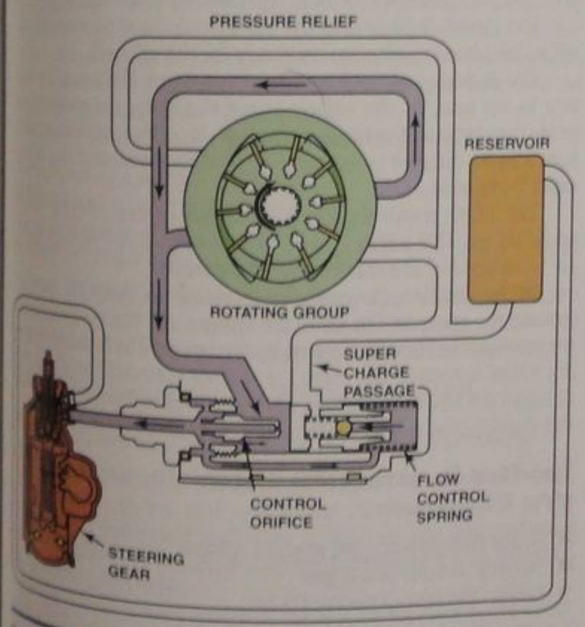


Figure 91–22 Low-speed flow control.

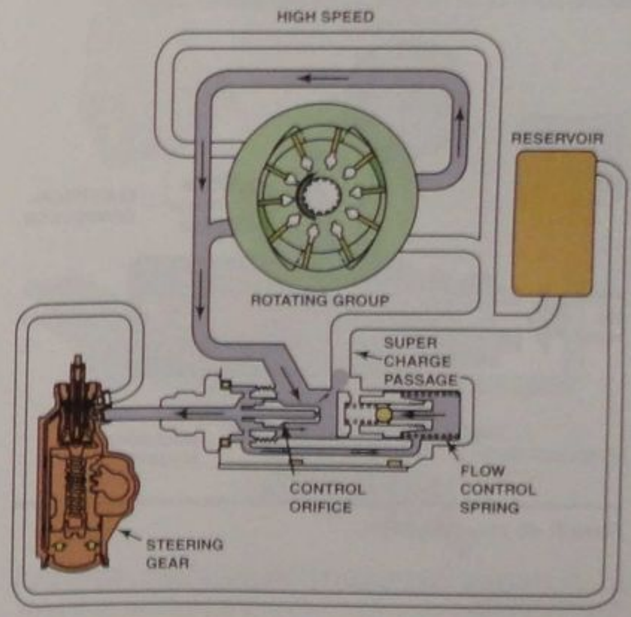


Figure 91–23 High-speed flow control operation.

When the fluid flow through the system stops, the pressure equalizes on both sides of the orifice. This creates equal pressure on both sides of the control valve. Because the backside of the valve has a spring, the combination of the hydraulic pressure and spring force moves the control valve to prevent flow into the pump intake passage. As the pump continues to operate, the pressure in the system builds. If the pressure is not relieved, the system can be damaged. To prevent this, the control valve has a check valve inside of it. At a specific pressure, the check valve opens to relieve the pressure on the backside of the control valve. This creates a pressure differential and allows the control valve to move. With the control valve moved, the high pressure is allowed into the pump intake passage. At this point, the check valve and control valve seat. See Figure 91–24.

VARIABLE-EFFORT STEERING

Variable-effort steering (VES) systems are designed to provide variable power-assisted steering. The amount of power assist increases at lower vehicle speeds to aid parking maneuvers and decreases at higher speeds for greater road feel.

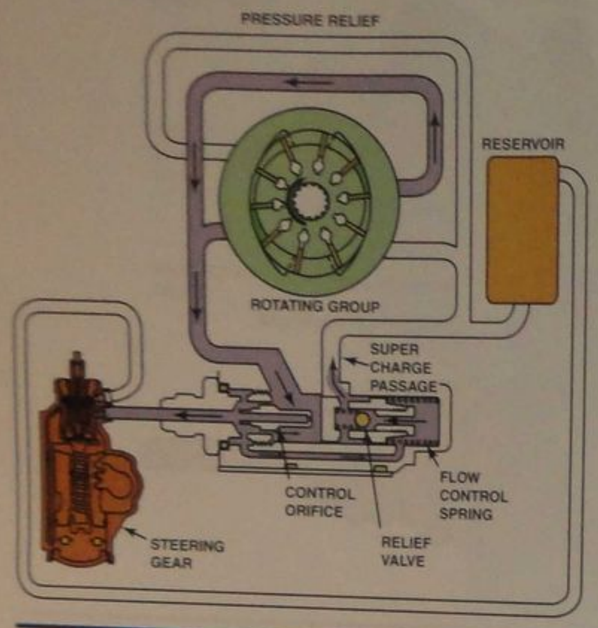


Figure 91–24 Pressure-relief mode. In this mode the steering gear has blocked the flow of fluid from the pump and the pressure rises, which unseats the pressure-relief valve. Now fluid flows back to the inlet through the pressure-relief orifice and passage.

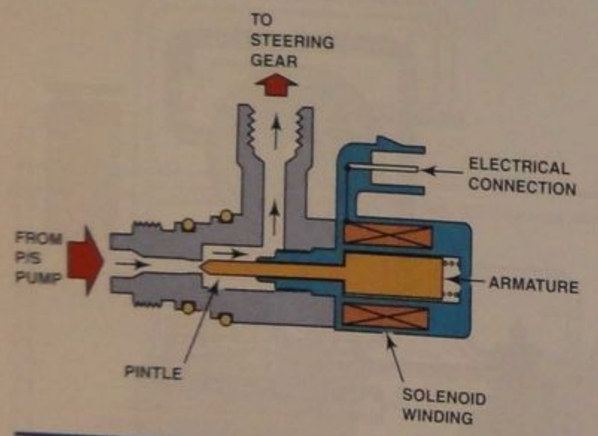


Figure 91–25 EVO actuator assembly.

As examples, General Motors uses four different variable-effort steering systems:

- **Electronic Variable Orifice (EVO)**
- **Two-Flow Electronic (TFE)**
- **Speed Sensitive Steering (SSS)**
- **Magnasteer**

The Electronic Variable Orifice (EVO) system provides a wide range of power-assisted steering based on the vehicle's operating conditions. See Figure 91–25.

The system uses vehicle speed and steering wheel speed to regulate the current to a solenoid that changes the orifice size of the flow control valve.

The size of the orifice controls the flow rate through the valve and the pressure in the hydraulic system. The desired amount is then directed to the steering gear for the power assist. The second type of power assist is the TFE system, which provides two rates of power assist:

- At low speeds, the TFE solenoid provides maximum power assist.
- At high speeds, the solenoid provides minimum power assist.

Another type of power assist is the Speed Sensitive Steering (SSS) system, which uses hydraulic pressure to resist movement in the steering gear as speed increases. This provides a firmer sense of control and stability in the steering gear at higher speeds.

Electronic Variable Orifice (EVO) System Components

The main components of the EVO system are:

- Vehicle speed sensor
- Power steering control module
- Steering wheel speed sensor
- Power steering gear
- Power steering pump and solenoid actuator

The actuator is a solenoid-operated pintle valve. Electrical current flow through the solenoid controls the position of the pintle in relation to the orifice.

As the vehicle speed increases, the control module provides a higher current flow and the solenoid positions the pintle to change the size of the orifice.

This increased speed results in a reduced amount of hydraulic flow and provides less hydraulic pressure to the steering gear.

The control module uses the signal from the vehicle speed sensor to calculate the required amperage for the solenoid.

The amperage has a direct effect on steering effort and the flow rate to the gear. As the vehicle speed increases, the solenoid extends the pintle and reduces the size of the orifice. Hydraulic pressure is being reduced as the vehicle speed increases and less power assist is available.

The other sensor for the EVO system is the steering wheel speed sensor. This sensor is used to determine if the vehicle operator is performing an evasive steering maneuver.

In this situation, the controller increases the hydraulic pressure to assist the operator. The faster the driver turns the steering wheel, the stronger the signal generated by the sensor. The faster the steering wheel is rotated, the more the solenoid retracts the pintle and enlarges the size of the orifice. This increases hydraulic pressure to the steering gear and provides more power assist for the operator.

Two-Flow Electronic (TFE) System

The main components of the TFE system are:

- Power steering pump and solenoid actuator
- Steering rack-and-pinion gear
- Power train control module (PCM)

The TFE actuator is a solenoid-operated pintle valve. The pintle valve only has two positions—maximum assist and reduced assist. When the solenoid is provided a ground from the chime module, the pintle extends out from the orifice and provides maximum assist. When the chime module opens the ground path, the pintle moves in to restrict the orifice and thus reduces steering assist.

The PCM provides the chime module with a vehicle speed signal. The logic circuits in the chime module determine when to energize the solenoid. The solenoid is energized whenever the vehicle speed is approximately 20 mph (32 km/h) or lower and the pintle is extended, causing the power steering pressure to increase. This provides maximum assist and the steering effort is low. When the vehicle speed is higher than 20 mph (32 km/h), the pintle is moved in and the steering pressure is low. This provides reduced assist and higher steering effort.

SSS System

The major components of the SSS system are:

- Power steering pump
- SSS actuator
- Steering gear
- Road sensing suspension control module

The actuator is a solenoid-operated valve that controls the flow of fluid into the chambers of the steering gear valve. As more fluid flows into the chamber, pressure is built against the four pistons that are located around the spool shaft. As the pistons are loaded and pushed against the spool shaft, steering effort is increased.

Unlike the EVO and TFE systems, the SSS system uses hydraulic pressure to resist movement in the steering gear. The amount of fluid allowed into the chambers is based on the electrical current flow through the solenoid.

The Road Sensing Suspension (RSS) control module, using the signal from the vehicle speed sensor, calculates the required amperage for the solenoid.

The amperage has a direct effect on steering effort and the hydraulic flow rate into the chambers of the spool shaft. As the vehicle's speed increases, more hydraulic pressure is built against the pistons and the steering effort is increased. The steering effort adjustment begins at a vehicle speed of 20 mph (32 km/h).

Magnasteer

The fourth type of VES steering system used by General Motors is the Magnasteer system. This system uses a variable bi-directional magnetic rotary actuator built into the steering rack. The bi-directional magnetic rotary actuator has no effect on the hydraulic operation of the steering rack.

The main components in the system include:

- Power steering pump
- Magnasteer actuator assembly
- Steering gear
- Electronic brake control module (EBCM)

The Magnasteer system uses a conventional rack-and-pinion steering gear and an engine-driven hydraulic pump to provide power assist. The Magnasteer actuator consists of the following:

- A permanent magnet attached to the rotary input shaft
- A pole-piece assembly attached to the pinion
- An electromagnetic coil mounted in the steering gear housing

Integrated with the pinion shaft is a spool valve that senses the level of torque in the shaft and applies hydraulic pressure to the steering rack whenever assistance is needed. The electromagnet acts in parallel with the input shaft from the steering wheel to open or close the spool valve.

The electromagnet generates variable torque, which can either increase or diminish the amount of steering torque that is needed to open the spool valve. See Figures 91–26 and 91–27.

To vary the amount of steering assist, the EBCM uses the signal from the wheel speed sensor to calculate the required amperage and direction of current flow to the Magnasteer actuator.

The amperage and direction of current flow have a direct effect on steering effort and the flow rate to the rack piston. When the vehicle is stationary, approximately 1.6 amps of current flow through the electromagnetic coil.

As the vehicle speed increases to approximately 45 mph, the current decreases to 0 amps. The EBCM then switches the direction of current flow. Current flow through the electromagnetic coil causes either a magnetic attraction or repelling in the Magnasteer actuator.

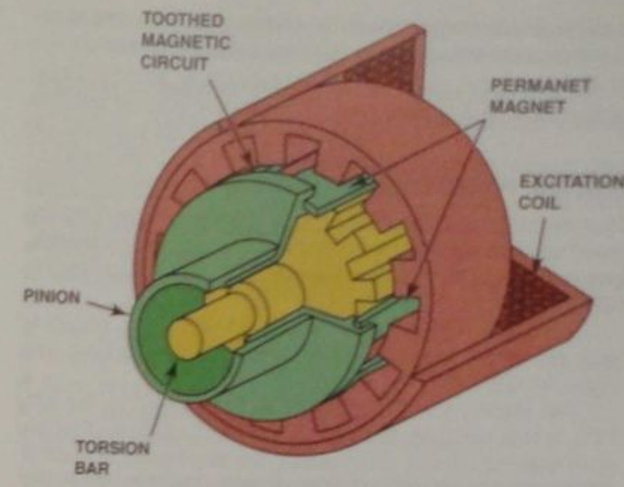


Figure 91–26 Integrated with the pinion shaft is a spool valve that senses the level of torque in the shaft and applies hydraulic pressure to the steering rack whenever assistance is needed. The electromagnet acts in parallel with the input shaft from the steering wheel to open or close the spool valve. The electromagnet generates variable torque, which can either increase or diminish the amount of steering torque that is needed to open the spool valve.

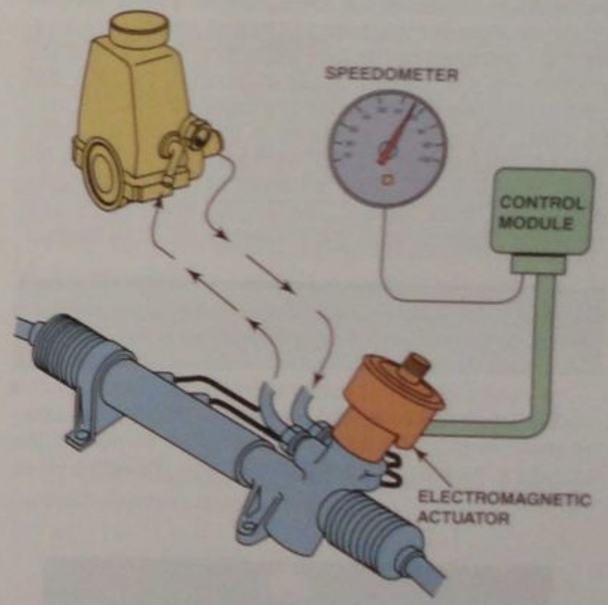


Figure 91–27 Magnasteer system.

At low vehicle speeds below 45 mph, the direction of current flow creates a magnetic field that opposes the permanent magnet. The repelling force of the magnetic field assists the spool valve in moving out of alignment with the valve body, and this increases the power assist.

With vehicle speeds below 45 mph, increased current provides increased steering assist. At vehicle speeds above 45 mph, the direction of current through the electromagnetic coil creates a magnetic field that attracts the permanent magnet.

- The magnet helps keep the spool valve aligned with the valve body, and this reduces the power assist and provides a greater road feel.

- As the vehicle speed increases, the amount of effort required to overcome the attracting force of the magnetic field increases.

With vehicle speeds above 45 mph, increased current flow provides decreased steering assist.

ELECTRIC POWER STEERING SYSTEM

Most electric power steering units use a DC electric motor. Some operate from 42 volts while others operate from 12 volts. The **electric power steering (EPS)** is also called electric power-assisted steering (EPAS).

The Toyota system on a Prius uses a DC motor, reduction gear, and torque sensor all mounted to the steering column. See Figure 91–28.

The electric power steering (EPS) is controlled by the EPS ECU, which calculates the amount of needed assist based on the input from the steering torque sensor. The steering torque sensor is a noncontact sensor that detects the movement and torque applied to the torsion bar. The torsion bar twists when the drive exerts torque to the steering wheel, and the more torque applied the further the bar will twist. This generates a higher-voltage signal to the EPS ECU. See Figure 91–29.

The steering shaft torque sensor and the steering wheel position sensor are not serviced separately from each other or from the steering column assembly. The steering column assembly does not include the power steering motor and module assembly. The detection ring 1 and detection ring 2 are mounted on the input shaft and detection ring 3 is mounted on the output shaft. The input shaft and the output shaft are connected by a torsion bar. When the steering wheel is turned, the difference in relative motion between detection rings 2 and 3 is sensed by the detection coil and it sends two signals to the EPS ECU. These two signals are called Torque Sensor Signal 1 and Torque Signal 2. The EPS ECU uses these signals to control the amount of assist, and also uses the signals for diagnosis.

NOTE: If the steering wheel, steering column, or steering gear is removed or replaced, the zero point of the torque sensors must be reset.

The Toyota Highlander and Lexus RX 400h use a different electric power steering unit due to the larger size of the vehicles. This unit uses a brushless DC on the steering rack. See Figures 91–30 and 91–31.

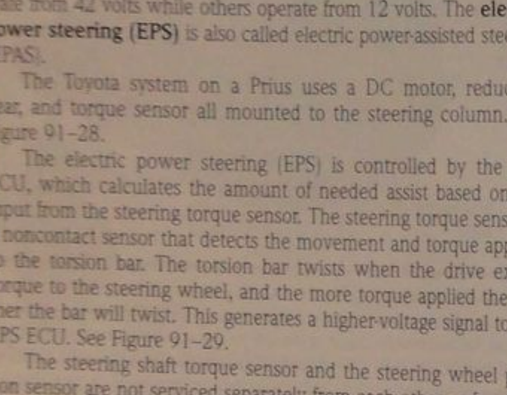


Figure 91–28 A Toyota Prius EPS assembly.

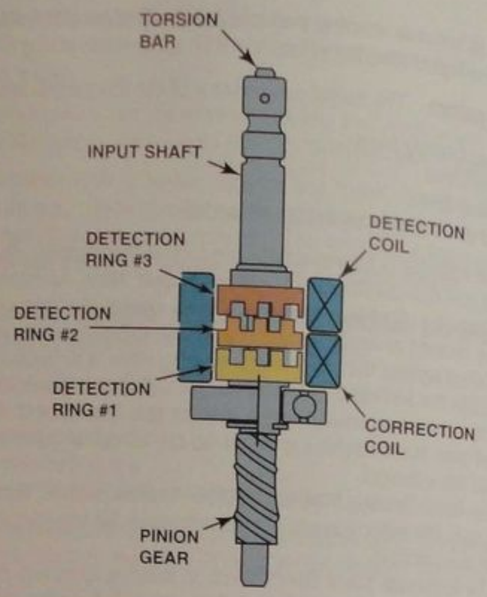


Figure 91–29 The torque sensor converts the torque the driver is exerting to the steering wheel into a voltage signal.

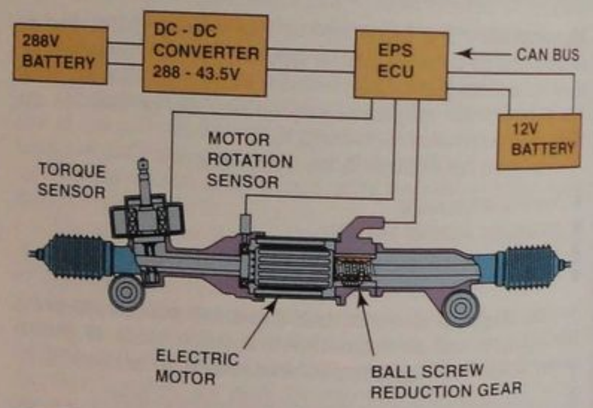


Figure 91–30 The electric power steering in Toyota/Lexus SUVs uses a brushless DC (labeled BLDC) motor around the rack of the unit and operates on 42 volts.



Figure 91–31 Photo of the electric power steering gear on a Lexus 400h taken from underneath the vehicle.

The Honda electric power steering uses an electric motor to provide steering assist and replaces the need for a hydraulic pump, hoses, and gear. A torque sensor is used to measure road resistance and the direction that the driver is turning the steering wheel. The torque sensor input and the vehicle speed are used by the EPS controller to supply the EPS motor with the specified current to help assist the steering effort. See Figure 91–32.

The motor turns the pinion shaft using a worm gear. The worm gear is engaged with the worm wheel so that the motor turns the pinion shaft directly when providing steering assist. The steering rack is unique because the tie rods are mounted to the center of the rack rather than at the ends of the rack as in a conventional Honda power steering arrangement. See Figure 91–33.

If a major fault were to occur, the control module would first try to maintain power-assisted steering even if some sensors had failed. If the problem is serious, then the vehicle can be driven and steered manually. The EPS control unit will turn on the EPS dash warning light if a fault has been detected. A fault in the system will not cause the malfunction indicator light to come on because that light is reserved for emission-related faults only. Fault codes can be retrieved by using a scan tool and the codes will be displayed by the flashing of the EPS warning lamp.

The EPS system includes the following components and inputs/outputs:

- Power train control module (PCM)
- Body control module (BCM)
- Power steering control module (PSCM)
- Battery voltage
- Steering shaft torque sensor
- Steering wheel position sensor
- Power steering motor
- Driver information center (DIC)
- Serial data circuit to perform the system functions

The **power steering control module (PSCM)** and the power steering motor are serviced as an assembly and are serviced separately from the steering column assembly. See Figure 91–34.

The steering shaft torque sensor and the steering wheel position sensor are not serviced separately from each other or from the steering column assembly. The steering column assembly does not include the power steering motor and module assembly.

Steering Shaft Torque Sensor The PSCM uses the steering shaft torque sensor as a main input for determining steering direction and the amount of assist needed. The steering column has an input shaft, from the steering wheel to the torque sensor, and an output shaft, from the torque sensor to the steering shaft couplet. The input and output shafts are separated by a section of torsion bar, where the torque sensor is located. The sensor is a 5-volt dual-analog inverse signal device with a signal voltage range of 0.25 to 4.75 volts. The sensors are used to detect the direction the steering wheel is being rotated.

- When torque is applied to the steering column shaft during a right turn, the sensor signal 1 voltage increases, while the signal 2 voltage decreases.
- When torque is applied to the steering column shaft during a left turn, the sensor signal 1 voltage decreases, while the signal 2 voltage increases.

The PSCM recognizes this change in signal voltage as steering direction and steering column shaft torque.

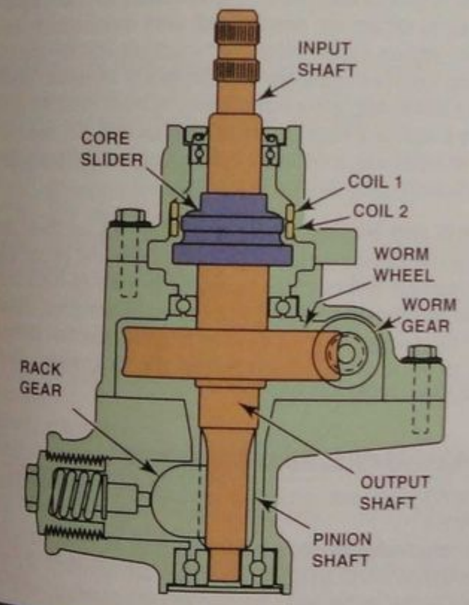


Figure 91–32 A cross-sectional view of a Honda electric power steering (EPS) gear showing the torque sensor and other components.



Figure 91–33 Honda electric power steering unit cutaway.

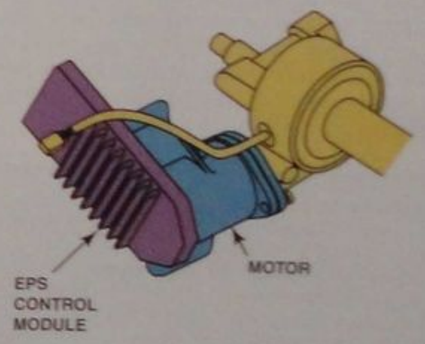


Figure 91–34 The Power Steering Control Module (PSCM) is attached to the motor of the electric power steering assembly.

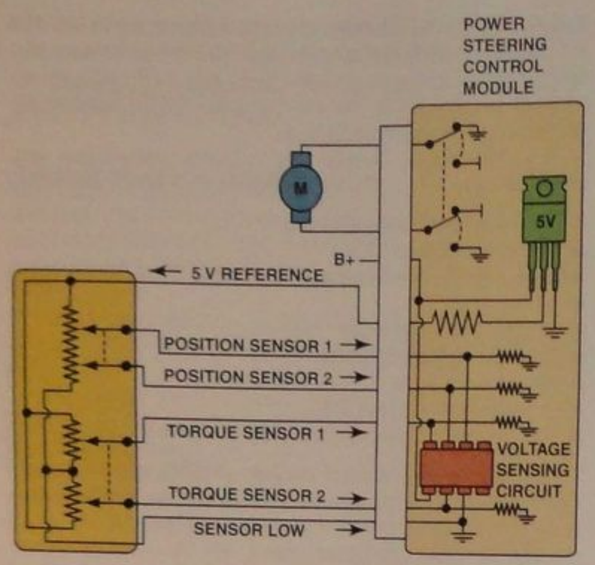


Figure 91–35 Schematic showing the electric power steering and the torque/position sensor.

Steering Wheel Position Sensor The PSCM uses the **steering position sensor (SPS)** to determine the steering system on-center position. Because the power steering motor provides a slight amount of return-to-center assist, the PSCM will command the power steering motor to the steering system center position and not beyond. The sensor is a 5-volt dual-analog signal device with a signal voltage range of 0 to 5 volts. The sensor's signal 1 and signal 2 voltage values will increase and decrease within 2.5 to 2.8 volts of each other as the steering wheel is turned. See Figure 91–35.

Power Steering Motor The power steering motor is a 12-volt brushless DC reversible motor with a 65-amp rating. The motor assists steering through a worm gear and reduction gear located in the steering column housing.

Power Steering Control Module (PSCM) The PSCM uses a combination of steering shaft torque sensor input, vehicle speed, calculated system temperature, and steering tuning to determine the amount of steering assist. When the steering wheel is turned, the PSCM uses signal voltage from the steering shaft torque sensor to detect the amount of torque and steering direction being applied to the steering column shaft and then commands the proper amount of current to the power steering motor. The PSCM receives a vehicle speed message from the PCM by way of the serial data circuit. At low speeds more assist is provided for easy turning during parking maneuvers, and at higher speeds, less assist is provided for improved road feel and directional stability.

NOTE: The PSCM and the power steering motor are not designed to handle 65 amps continuously. If the power steering system is exposed to excessive amounts of static steering conditions, the PSCM will go into a protection mode to avoid thermal damage to the power steering components. In this mode the PSCM will limit the amount of current commanded to the power steering motor, which reduces system temperature and steering assist levels. The PSCM has the ability to detect malfunctions within the power steering system. Any malfunction detected will cause the DIC to display the *power steering warning message* and/or the *service vehicle soon* indicator.

The PSCM must also be set up with the correct steering tunings, which are different in relation to the vehicle's power train configuration, model type, tire and wheel size.

SELF-PARKING SYSTEM

Several vehicle manufacturers offer a **self-parking** feature that uses the electric power steering to steer the vehicle. The driver has control of the brakes. Most systems use the following sensors:

- Wheel speed sensor (WSS)
- Steering-angle sensor
- Ultrasonic sensors, which are used to plot a course into a parking space

Some systems, such as those manufactured by Valeo for Volkswagen, allow the driver to control the accelerator as well as the brakes, making it possible to add power to park uphill. The Toyota/Lexus system stops working if the accelerator is depressed during a self-parking event. The Toyota/Lexus system is camera based and uses the navigation system to display the parking spot with touch-screen controls. The system displays a green video box to indicate that the spot is large enough and a red box to indicate that the spot is too small. The driver positions a yellow flag on the video screen to mark the front corner of the parking spot and then the vehicle backs into the space at idle speed. The driver has to complete the parking event by straightening the vehicle and pulling forward in the spot.

Diagnosis and Testing Self-parking systems use many sensors to achieve the parking event, and a fault in any one sensor will disable self-parking. Before trying to diagnose a self-parking fault, be sure that the driver is operating the system as designed. For example, the self-parking event is cancelled if the accelerator pedal is depressed on some units. Always follow the factory-recommended diagnostic and testing procedures.

ELECTROHYDRAULIC POWER STEERING

Electrohydraulic power steering is used on the Chevrolet Silverado hybrid truck.

The **electrohydraulic power steering (EHPS)** module controls the power steering motor, which has the function of providing hydraulic power to the brake booster and the steering gear.

A secondary function includes the ability to improve fuel economy by operating on a demand basis and the ability to provide speed-dependent variable-effort steering.

The EHPS module controls the EHPS powerpack, which is an integrated assembly consisting of the following components:

- Electric motor
- Hydraulic pump
- Fluid reservoir
- Reservoir cap
- Fluid level sensor
- Electronic controller
- Electrical connectors

See Figure 91–36.

EHPS Module The electrohydraulic power steering (EHPS) module is operated from the 36-volt (nominal) power supply. The EHPS module uses class 2 for serial communications. A 125-amp, 36-volt fuse is used to protect the EHPS module. If this fuse were to blow open, the EHPS system would not operate and communication codes would be set by the modules that communicate with the EHPS module. The power train control module (PCM) is the gateway



Figure 91–36 An electrohydraulic power steering assembly on a Chevrolet hybrid pickup truck.

that translates controller area network (CAN) messages into class 2 messages when required for diagnostic purposes. The EHPS module receives the following messages from the CAN bus:

- Vehicle speed
- Service disconnect status
- PRNDL (shift lever) position
- Torque converter clutch (TCC)/Cruise Dump signal (gives zero-adjust brake switch position)

The EHPS module outputs the following messages to the CAN bus:

- Brake pedal rate, position, in-range rationality, and out-of-range diagnosis
- EHPS system status
- Diagnostic messages to driver information center (DIC) via hybrid control module (HCM)
- Diagnostic information requested by service technicians via Tech 2 link (class 2 via PCM)
- Steering wheel sensor diagnostic message (in-range, out-of-range failure)

The EHPS module is not attached to class 2 data and receives several signals through wiring. The signals received and used by the EHPS module include:

- The digital steering wheel speed signals from the steering wheel sensor mounted on the steering column. The steering wheel speed sensor output contains three digital signals that indicate the steering wheel position. The signals are accurate to within 1 degree. The index output references a steering wheel position of 0 degrees plus or minus 10 degrees (steering wheel centered) and is repeated every 360 degrees of steering wheel rotation.
- An analog brake pedal position signal from the brake-pedal-mounted **brake pedal position (BPP)** sensor. The BPP sensor outputs an analog signal, referenced to 5 volts, that increases or decreases with brake pedal depression. The electrical range of the BPP sensor motion is −55 degrees to +25 degrees. The mechanical range of the BPP sensor is −70 degrees to +40 degrees.
- The EHPS module also receives ignition key position signals. These signals are the ignition signal and the accessory signal. The EHPS module receives an input from the ignition 0 circuit indicating when the key is in the ACCY position. This input is used to provide an independent wake-up signal in the event of loss of the ignition input, and to activate the EHPS module when the key remains in the ACCY position.

EHPS system performance may be reduced with power steering fluid temperature change.

POWER STEERING DIAGNOSIS AND TROUBLESHOOTING

Power steering systems are generally very reliable, yet many problems are caused by not correcting simple service items such as the following:

1. **A loose, worn, or defective power steering pump drive belt.** This can cause jerky steering and belt noise, especially when turning. It is generally recommended that all belts, including the serpentine (or Poly V) belts, be replaced every four years.

   If the vehicle does not use a belt tensioner, then a belt tension gauge is needed to achieve the specified belt tension. Install the belt and operate the engine with all of the accessories turned on to "run-in" the belt for at least five minutes. Adjust the tension of the accessory drive belt to factory specifications or use the following table for an example of the proper tension based on the size of the belt.

Serpentine Belts

Number of Ribs Used	Tension Range (lbs.)
3	45–60
4	60–80
5	75–100
6	90–125
7	105–145

Replace any serpentine belt if more than three cracks appear in any one rib within a 3-inch span.

NOTE: Do not guess at the proper belt tension. Always use a belt tension gauge or observe the marks on the tensioner. See Figure 91–37.

2. **A bent or misaligned drive pulley** is usually caused by an accident or improper reassembly of the power steering pump after an engine repair procedure. This can cause a severe grinding noise whenever the engine is running and may sound like an engine problem.
3. **Low or contaminated power steering fluid** is usually caused by a slight leak at the high-pressure hose or defective inner rack seals on a power rack-and-pinion power steering system. This can cause a loud whine and a lack of normal power steering assist. See the Tech Tip, "The Visual Test."
4. **Broken or loose power steering pump mounting brackets.** In extreme cases, the pump mounting bolts can be broken. These problems can cause jerky steering. It is important to inspect the pump mounting brackets and hardware carefully when diagnosing a steering-related problem. The brackets tend to crack at the adjustment points and pivot areas. Tighten all the hardware to ensure the belt will remain tight and not slip, which would cause noise or a power-assist problem.
5. **Underinflated tires.**
6. **Engine idle speed below specifications.**
7. **A defective power steering pressure switch.** If this switch fails, the computer will not increase engine idle speed while turning.
8. **Internal steering gear mechanical binding.**

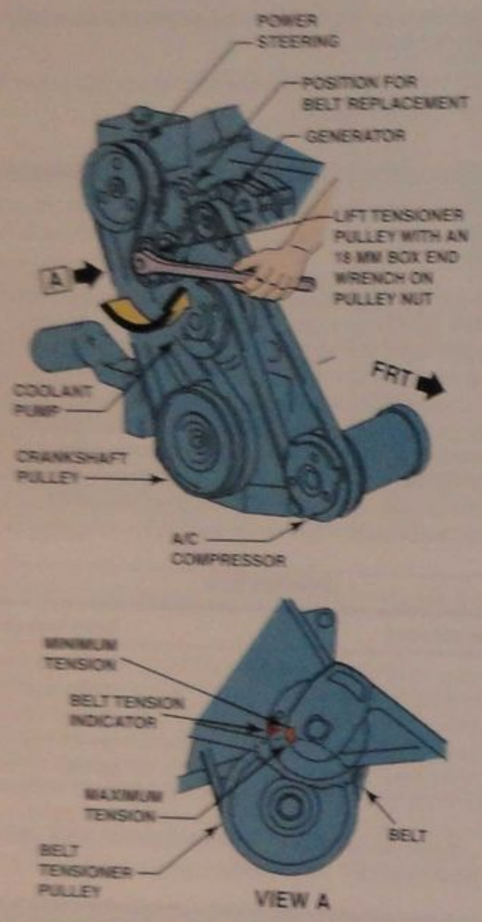


Figure 91–37 A typical service manual illustration showing the method to use to properly tension the accessory drive belt.

TECH TIP ✓ **The Visual Test**

Whenever diagnosing any power steering complaint, check the level and condition of the power steering fluid. Often this is best accomplished by putting your finger down into the power steering fluid reservoir and pulling it out to observe the texture and color of the fluid. See Figure 91–38.

A common problem with some power rack-and-pinion units is the wearing of grooves in the housing by the Teflon sealing rings of the spool (control) valve. When this wear occurs, aluminum particles become suspended in the power steering fluid, giving it a grayish color and thickening the fluid.

Normally clear power steering fluid that is found to be grayish in color and steering that is difficult when cold are clear indications as to what has occurred and why the steering is not functioning correctly.

As part of a complete steering system inspection and diagnosis, a steering wheel turning effort test should be performed. The power steering force, as measured by a spring scale during turning, should be less than 5 lb (2.3 kg).



Figure 91–38 A check of the power steering fluid should include inspecting not only the level but the condition and color of the fluid, which could indicate a possible problem with other components in the steering system.

NOTE: Some vehicles use power steering reservoir caps with *left-hand* threads. Always clean the top of the cap and observe all directions and cautions. Many power steering pump reservoirs and caps have been destroyed by technicians attempting to remove a cap in the wrong direction using large pliers.

Power Steering Fluid The correct power steering fluid is *critical* to the operation and service life of the power steering system! The exact power steering fluid to use varies as to vehicle manufacturer. There are even differences within the same company because of various steering component suppliers.

NOTE: Remember, multiple-purpose power steering fluid does not mean all-purpose power steering fluid. Always consult the power steering reservoir cap, service manual, or owner's manual for the exact fluid to be used in the vehicle being serviced.

The main reason for using the specified power steering fluid is the compatibility of the fluid with the materials used in seals and hoses of the system. Using the wrong fluid (substituting ATF, for example) can lead to seal or hose deterioration and/or failure and fluid leaks.

NOTE: Always use the power steering fluid recommended by the manufacturer. The correct fluid to use is usually imprinted on or near the power steering reservoir fill cap. See Figure 91–39.

1. Check the power steering fluid level. Bleed the air from the system by turning the steering wheel lock-to-lock with the engine cranking.
2. Check the condition and tension of the drive belt. If in doubt, replace the belt.
3. Inspect the condition of all hoses, checking for any soft hose or places where the hose could touch another component.
4. Check the tightness of all mounting bolts of the pump and gear.

Power Steering Fluid Flushing Procedure Whenever there is any power steering service performed, such as replacement



Figure 91–39 Some power steering fluid is unique to the climate, such as this **cold climate fluid** recommended for use in General Motors vehicles when temperatures are low.

of a defective pump or steering gear or rack-and-pinion unit, the entire system should be flushed. If all of the old fluid is not flushed from the system, small pieces of a failed bearing or rotor could be circulated through the system. These metal particles can block paths in the control valve and cause failure of the new power steering pump or gear assembly.

NOTE: Besides flushing the old power steering fluid from the system and replacing it with new fluid, many technical experts recommend installing a filter in the low-pressure return line as an added precaution against serious damage from debris in the system. Power steering filters are commonly available through vehicle dealer parts departments, as well as aftermarket sources from local auto supply stores.

Always follow the vehicle manufacturer's recommended flushing procedure. Two people are needed to flush the system. Use the following steps:

Step #1 Raise the front wheels off the ground.

Step #2 Remove the low-pressure return hose from the pump and plug the line fitting on the pump.

Step #3 Place the low-pressure return hose into an empty container.

Step #4 Fill the pump reservoir with fresh fluid and start the engine.

Step #5 As the old and dirty power steering fluid is being pumped into the container, keep the reservoir full of clean fluid while the assistant turns the steering wheel full lock one way to full lock the other way.

CAUTION: Never allow the pump reservoir to run dry of power steering fluid. Severe internal pump damage can result.

Step #6 When the fluid runs clean, stop the engine and reattach the low-pressure return hose to the pump reservoir.

Step #7 Restart the engine and fill the reservoir to the full mark. Turn the steering wheel back and forth, avoiding the stops one or two times to bleed any trapped air in the system.

Bleeding Air out of the System If the power steering fluid is tan, there may be air bubbles trapped in the fluid. Stop the engine and allow the air to burp out to the surface for several minutes. Lift the vehicle off the ground, then rotate the steering wheel. This method prevents the breakup of large air bubbles into thousands of smaller bubbles that are more difficult to bleed out of the system.

NOTE: To help rid the power steering system of unwanted trapped air, it is recommend that the engine be cranked and that the wheels be turned from stop to stop *with the tires off the ground*. Do not crank the engine for longer than 15 seconds to prevent starter damage due to overheating. Allow the starter to cool at least 30 seconds before cranking again.

Sometimes trapped air just cannot be bled out of the system using ordinary methods. This trapped air makes the pump extremely noisy and this noise sometimes convinces the technician that the pump itself is defective. If the power steering system has been opened for repairs and the system has been drained, trapped air may be the cause.

Hose Inspection Both high-pressure and low-pressure return hoses should be inspected as part of any thorough vehicle inspection. While the low-pressure return hose generally feels softer than the high-pressure return hose, neither should feel *spongy*. A soft, spongy hose should always be replaced. See Figure 91–40.

When replacing any power steering hose, make certain that it is routed the same as the original and does not interfere with any

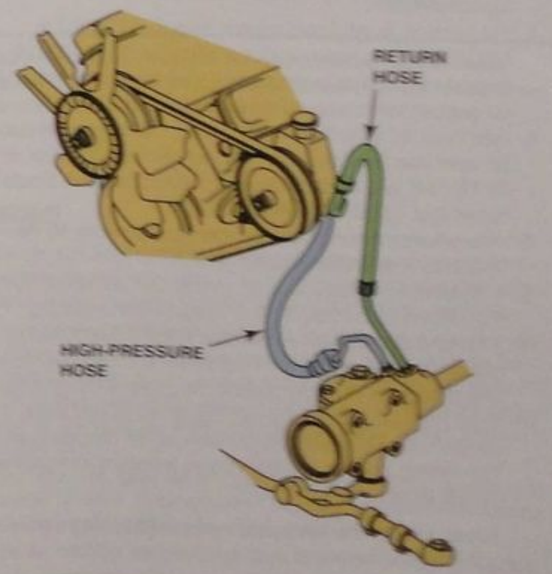


Figure 91–40 Inspect both high-pressure and return power steering hoses. Make sure the hoses are routed correctly and not touching sections of the body to prevent power steering noise from being transferred to the passenger compartment.

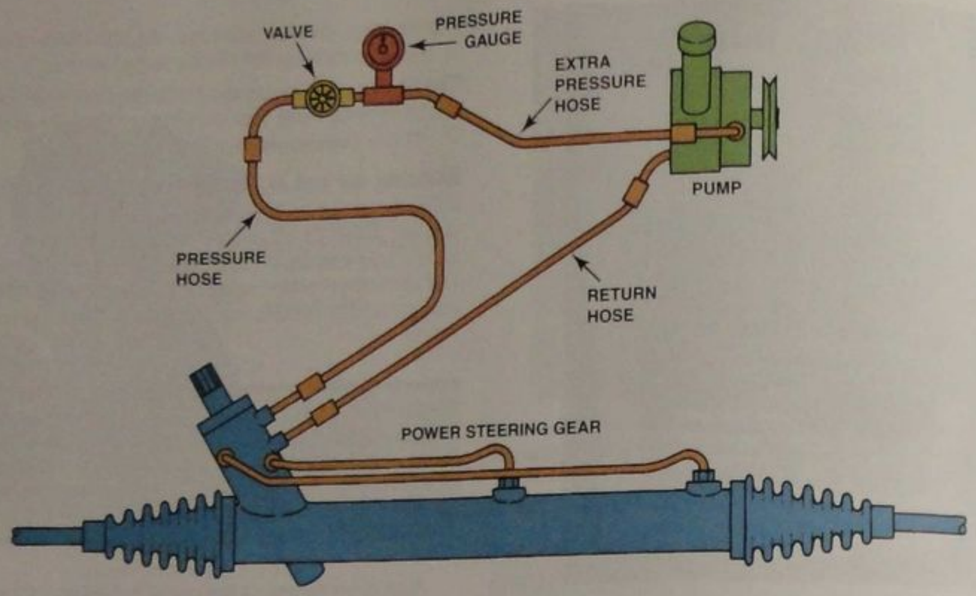


Figure 91–41 A drawing showing how to connect a power steering analyzer to the system.

accessory drive belt, pulley, or other movable component such as the intermediate steering shaft.

Pressure Testing Use of a power steering pressure tester involves the following steps:

1. Disconnect the pressure hose at the pump.
2. Connect the leads of the tester to the pump and the disconnected pressure line. See Figure 91–41.
3. Open the valve on the tester.
4. Start the engine. Allow the power steering system to reach operating temperatures.
5. The pressure gauge should register 80 to 125 PSI (550 to 860 kPa). If the pressure is greater than 150 PSI (1,400 kPa), check for restrictions in the system, including the operation of the **poppet valve** located in the inlet of the steering gear.
6. Fully close the valve three times. (Do not leave the valve closed for more than five seconds!) All three readings should be within 50 PSI (345 kPa) of each other and the peak pressure should be higher than 1,000 PSI (6,900 kPa).
7. If the pressure readings are high enough *and* within 50 PSI (345 kPa) of each other, the pump is OK.
8. If the pressure readings are high enough, yet not within 50 PSI (345 kPa) of each other, the flow control valve is sticking.
9. If the pressure readings are less than 1,000 PSI (6,900 kPa), replace the flow control valve and recheck. If the pressures are still low, replace the rotor and vanes in the power steering pump.
10. If the pump is OK, turn the steering wheel to both stops. If the pressure at both stops is not the same as the maximum pressure, the steering gear (or rack and pinion) is leaking internally and should be repaired or replaced.

Many vehicle manufacturers recommend using a power steering analyzer that measures both pressure and volume, as shown in Figure 91–42.

Knowing the volume flow in the system provides information to the technician in addition to that of the pressure gauge. Many manufacturers' diagnostic procedures specify volume measurements



Figure 91–42 A power steering analyzer that measures both pressure and volume. The shut-off valve is used to test the maximum pressure of the pump.

and test results that can help pinpoint flow control or steering gear problems. Always follow the vehicle manufacturer's recommended testing procedures. Pressure and volume measurements specified by the manufacturer usually fall within the range noted in the following chart.

Typical Power Steering Pressures and Volume

Steering Action	Pressure, PSI (kPa)	Volume* (gal/min) (l/min)
Straight ahead, no steering	Less than 150 PSI (1,000 kPa)	2.0 to 3.3 gpm (10 to 15 lpm)
Slow cornering	300–450 PSI (2,000–3,000 kPa)	Within 1 gpm (4 lpm) of straight ahead
Full turn at stops	750–1,450 PSI** (5,200–10,000 kPa)	Less than 1 gpm (4 lpm)

*Volume is determined by orifice size in the outlet of the pump and is matched to the steering gear.

**Upper-limit pressure is determined by the calibration of the pressure-relief valve.

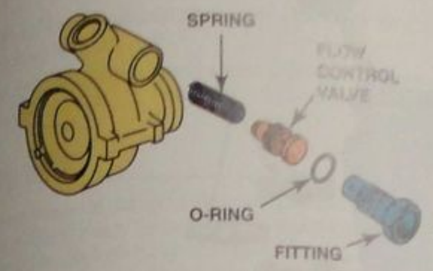


Figure 91–43 Typical power steering pump showing the order of assembly. The high-pressure (outlet) hose attaches to the fitting (#16). The flow control valve can be removed from the pump by removing the fitting.

Pump Service Some power steering pump service can usually be performed without removing the pump, including the following:

1. Replacing the high-pressure and return hoses
2. Removing and cleaning the flow control valve assembly. See Figure 91–43.

Most power steering pump service requires the removal of the pump from the engine mounting and/or removal of the drive pulley.

NOTE: Most replacement pumps are not equipped with a pulley. The old pulley must be removed and installed on the new pump. The old pulley should be carefully inspected for dents, cracks, or warpage. If the pulley is damaged, it must be replaced.

The pulley must be removed and installed with a pulley removal and installation tool. See Figure 91–44.

CAUTION: Do not hammer the pump shaft or pulley in an attempt to install the pulley. The shock blows will damage the internal components of the pump.

After removing the pump from the vehicle and removing the drive pulley, disassemble the pump according to the manufacturer's recommended procedure. See Figures 91–45 through 91–49 for the disassembly and reassembly of a typical power steering pump.

Clean all parts in power steering fluid. Replace any worn or damaged parts and all seals.

TECH TIP ✔ **Pocket the Ignition Key to Be Safe**

When replacing any steering gear such as a rack-and-pinion steering unit, be sure that no one accidentally turns the steering wheel! If the steering wheel is turned without being connected to the steering gear, the airbag wire coil (clock spring) can become off center. This can cause the wiring to break when the steering wheel is rotated after the steering gear has been replaced. To help prevent this from occurring, simply remove the ignition key from the ignition (make sure the steering wheel is locked) and put it in your pocket while servicing the steering gear.

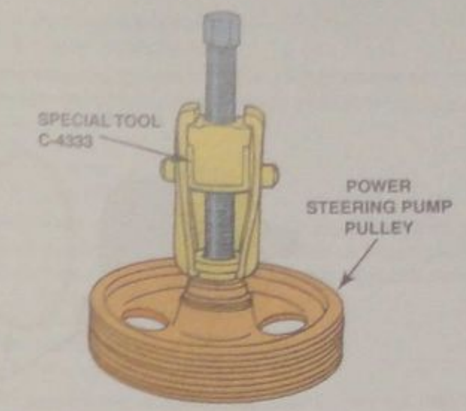


Figure 91–44 Typical tools required to remove and install a drive pulley on a power steering pump. Often these tools can be purchased at a relatively low cost from automotive parts stores and will work on many different makes of vehicles.

SUMMARY

1. Always use a belt tension gauge when checking, replacing, or tightening a power steering drive belt. The proper power steering fluid should always be used to prevent possible seal or power steering hose failure.
2. Power steering troubles can usually be diagnosed using a power steering pressure gauge. Lower-than-normal pump pressure could be due to a weak (defective) power steering pump or internal leakage inside the steering gear itself. If the pressure reaches normal when the shut-off valve on the gauge is closed, then the problem is isolated to being a defective gear.
3. Care should be taken when repairing or replacing any steering gear assembly to follow General Motors' recommended procedures exactly; do not substitute parts from one steering gear to another.

REVIEW QUESTIONS

1. List five possible causes for hard steering.
2. Explain the procedure for flushing a power steering system.

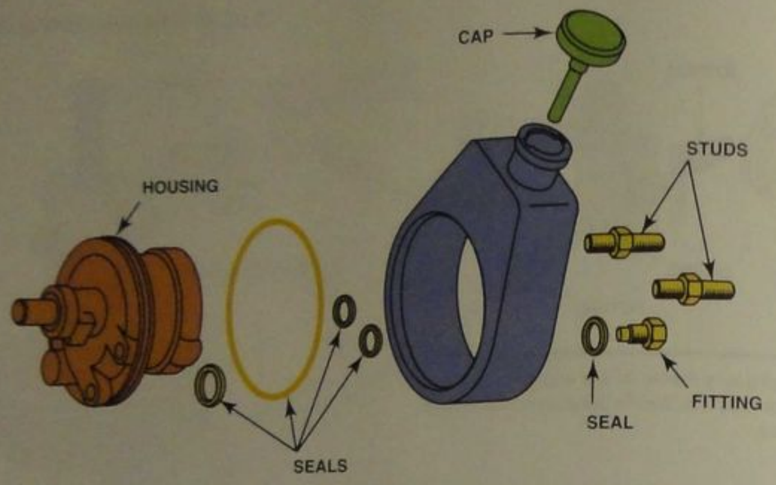


Figure 91–45 A typical submerged-type power steering pump. The pump is housed inside the fluid reservoir. *(Courtesy of Chrysler Corporation)*



Figure 91–46 A punch is used to dislodge the retaining ring.

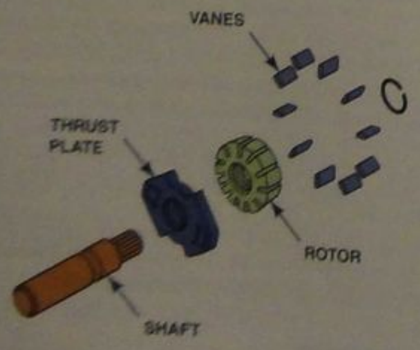


Figure 91–47 The driveshaft attaches to the drive pulley at one end and is splined to the pump rotor at the other end. The vanes are placed in the slots of the rotor.

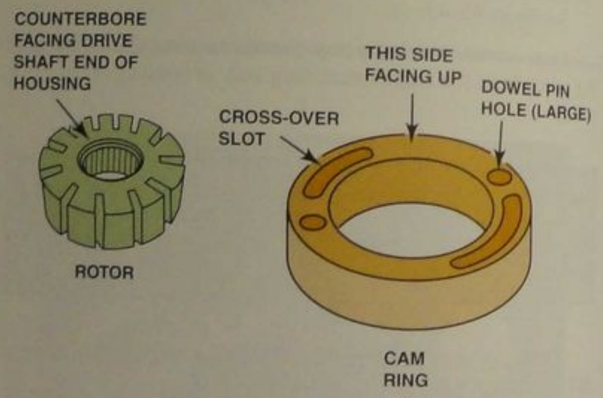


Figure 91–48 The pump ring *must* be installed correctly. If it is installed upside down, the internal passages will not line up and the pump will have no output.

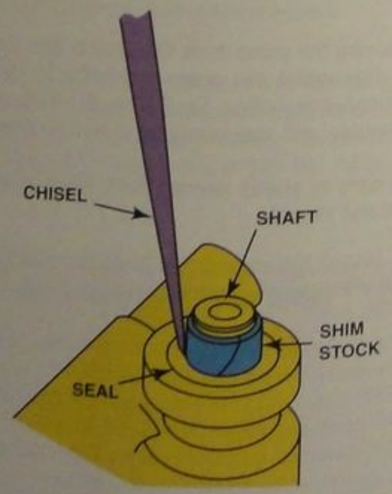


Figure 91–49 The shaft seal must be chiseled out. A thin metal shim stock should be used to protect the shaft from damage.

3. Briefly describe adjustment and service procedures for a conventional power steering gear.
4. Briefly describe adjustment and service procedures for a power rack-and-pinion steering unit.

CHAPTER QUIZ

1. Two technicians are discussing the proper procedure for bleeding air from a power steering system. Technician A says that the front wheels of the vehicle should be lifted off the ground before bleeding. Technician B says that the steering wheel should be turned left and right with the engine off during the procedure. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

2. A power steering pressure test is being performed, and the pressure is higher than specifications with the engine running and the steering wheel stationary in the straight-ahead position. Technician A says that a restricted high-pressure line could be the cause. Technician B says that internal leakage inside the steering gear or rack-and-pinion unit could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

3. A vehicle with power rack-and-pinion steering is hard to steer when cold (temporary loss of power assist when cold). The most likely cause is _____.
   a. Leaking rack seals
   b. A defective or worn power steering pump
   c. Worn grooves in the housing by the spool valve seals
   d. Use of incorrect power steering fluid

4. Integral power steering gears use _____ for lubrication of the unit.
   a. SAE 80W-90 gear lube
   b. Chassis grease (NLGI #2)
   c. Power steering fluid in the system
   d. Molybdenum disulfide

5. Two technicians are discussing replacement of the pitman shaft seal on an integral power steering gear. Technician A says that the pitman arm must be removed before the old seal can be removed. Technician B says that the steering gear unit should be removed from the vehicle before the seal can be removed. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

6. High-pressure hoses have to be used on the high-pressure side of the power steering system because pressures can reach as high as _____.
   a. 200 PSI
   b. 750 PSI
   c. 1,500 PSI
   d. 2,500 PSI

7. Some vehicles are equipped to signal the computer whenever the power steering pressures increase so that the idle speed can be increased to prevent stalling during turns at low speeds. What component signals the computer?
   a. Pressure-relief valve
   b. Power steering pressure switch
   c. Rotary valve
   d. Flow control valve

8. Some high-performance vehicles have firmer steering than other similar vehicles. Technician A says that the power steering pump pulley size is larger on those with stiffer steering, which reduces the speed of the pump. Technician B says that a torsion bar inside of the rotary valve is larger in diameter. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

9. Electronically controlled variable-assist power steering systems vary the amount of boost by _____.
   a. Varying the pump output orifice size
   b. Speeding up or slowing down the power steering pump
   c. Changing the flow of fluid through the steering gear
   d. Bypassing some of the fluid back into the reservoir

10. Power steering fluid is discovered to be pink in color. Technician A says that air could be trapped in the fluid. Technician B says that engine coolant has leaked into the power steering fluid. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 92 Wheel Alignment Principles

OBJECTIVES: After studying Chapter 92, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "D" (Wheel Alignment Diagnosis, Adjustment, and Repair). • Discuss which vehicle handling problems can and cannot be corrected by an alignment. • Define camber, toe, caster, SAI, included angle, scrub radius, turning radius, setback, and thrust line. • Explain how camber, caster, and toe affect the handling and tire wear of the vehicle.

KEY TERMS: BJI • camber • camber roll • caster • dog tracking • drift • four-wheel alignment • included angle • KPI • lead • MSI • pull • returnability • road crown • SAI • scrub radius • setback • shimmy • steering dampener • steering offset • thrust line • toe • TOOT • tramp • wander

A wheel alignment is the adjustment of the suspension and steering to ensure proper vehicle handling with minimum tire wear. When a vehicle is new, the alignment angles are set at the factory. After many miles and/or months of driving, the alignment angles can change slightly. The change in alignment angles may result from one or more of the following conditions:

1. Wear of the steering and the suspension components
2. Bent or damaged steering and suspension parts
3. Sagging springs, which can change the ride height of the vehicle and therefore the alignment angles

By adjusting the suspension and steering components, proper alignment angles can be restored. An alignment includes checking and adjusting, if necessary, both front and rear wheels.

ALIGNMENT-RELATED PROBLEMS

Most alignment diagnosis is symptom-based diagnosis. This means that the problem with the alignment is determined from symptoms such as excessive tire wear or a pull to one side of the road. The definitions of alignment symptom terms used in this book are discussed next.

Pull A **pull** is generally defined as a definite tug on the steering wheel toward the left or the right while driving straight on a level road. See Figure 92–1. Bent, damaged, or worn suspension and/or steering components can cause this problem, as well as a tire problem.

Lead or Drift A **lead** or **drift** is a mild pull that does not cause a force on the steering wheel that the driver must counteract. A lead or drift is observed by momentarily removing your hands from the steering wheel while driving on a straight, level road. When the vehicle moves toward one side or the other, this is called a lead or a drift.

CAUTION: When test-driving a vehicle for a lead or a drift, make sure that the road is free of traffic and that your hands remain close to the steering wheel. Your hands should be held away from the steering wheel for just a second or two—just long enough to check for a lead or drift condition.

Road Crown Effects Most roads are constructed with a slight angle to permit water to drain from the road surface. On a two-lane road, the center of the road is often higher than the berms, resulting in a **road crown**. See Figure 92–2.

On a four-lane expressway (freeway), the crown is often *between the two sets* of lanes. Because of this slight angle to the road, some vehicles may lead or drift away from the road crown. In other words, it may be perfectly normal for a vehicle to lead toward the right while being driven in the slow lane and toward the left while being driven in the fast (or inside) lane of a typical divided highway.

Wander A **wander** is a condition where constant steering wheel corrections are necessary to maintain a straight-ahead direction on a straight, level road. See Figure 92–3.

Worn suspension and/or steering components are the most likely cause of this condition. Incorrect or unequal alignment angles such as caster and toe, as well as defective tire(s), can also cause this condition.

Stiff Steering or Slow Return to Center Hard-to-steer problems are commonly caused by leaks, either low tire pressure (due to the leak of air) and/or lack of proper power steering (due to the leak of power steering fluid). Other causes include excessive positive caster on the front wheels or binding steering linkage.

Tramp or Shimmy Vibration **Tramp** is a vertical-type (up-and-down) vibration usually caused by out-of-balance or defective tires or wheels. **Shimmy** is a back-and-forth vibration that can be caused by an out-of-balance tire or defective wheel or by an alignment problem.

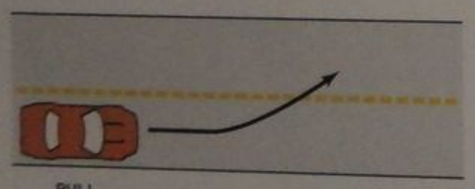


Figure 92–1 A pull is usually defined as a tug on the steering wheel toward one side or the other.

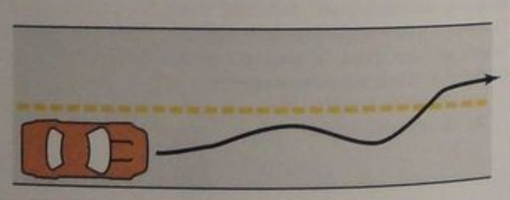


Figure 92–3 Wander is an unstable condition requiring constant driver corrections.

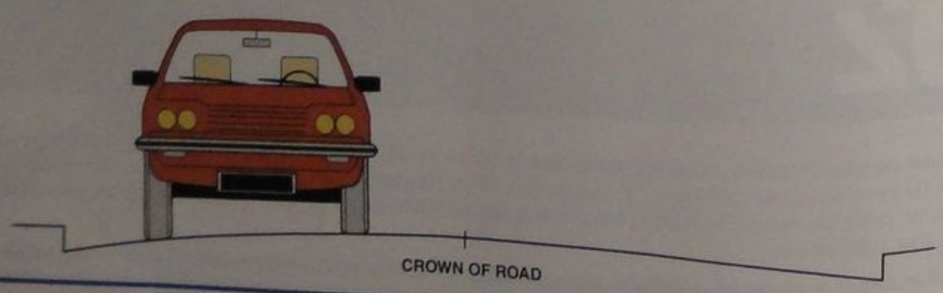


Figure 92–2 The crown of the road refers to the angle or slope of the roadway needed to drain water off the pavement. *(Courtesy of Hunter Engineering Company)*

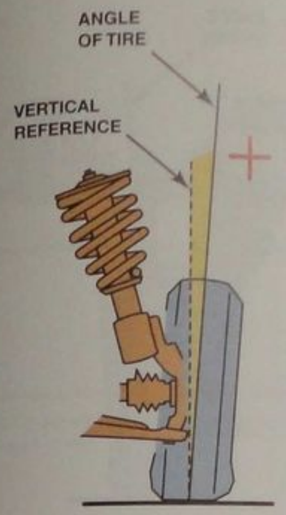


Figure 92–4 Positive camber. The solid vertical line represents true vertical, and the dotted line represents the angle of the tire.

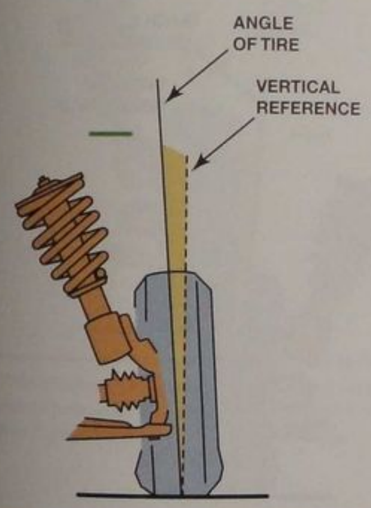


Figure 92–5 Negative camber. The solid vertical line represents true vertical, and the dotted line represents the angle of the tire.

NOTE: Wheel alignment will not correct a tramp-type vibration.

Camber **Camber** *is the inward or outward tilt of the wheels from true vertical as viewed from the front or rear of the vehicle.*

1. If the top of the tire is tilted out, then camber is positive (+), as shown in Figure 92–4.
2. If the top of the tire is tilted in, then camber is negative (−), as shown in Figure 92–5.
3. Camber is zero (0 degrees) if the tilt of the wheel is true vertical, as shown in Figure 92–6.
4. Camber is measured in degrees or fractions of degrees.
5. *Camber can cause tire wear if not correct.*
   a. *Excessive positive camber* causes scuffing and wear on the outside edge of the tire, as shown in Figure 92–7.

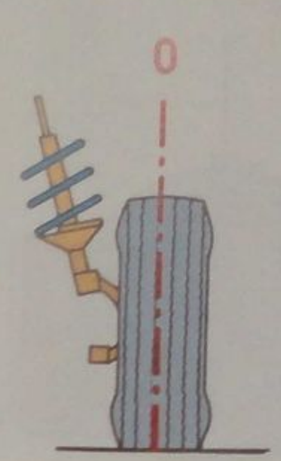


Figure 92–6 Zero camber. Note that the angle of the tire is true vertical.

   b. *Excessive negative camber* causes scuffing and wear on the inside edge of the tire, as shown in Figure 92–8.
6. Camber can cause pull if it is unequal side-to-side. **The vehicle will pull toward the side with the most positive camber.** A difference of more than 1/2 degree from one side to the other will cause the vehicle to pull. See Figures 92–9 through 92–11 on pages 1168–1169.
7. Incorrect camber can cause excessive wear on wheel bearings, as shown in Figures 92–12 and 92–13 on page 1169. Many vehicle manufacturers specify positive camber so that the vehicle's weight is applied to the larger inner wheel bearing and spindle. As the vehicle is loaded or when the springs sag, camber usually decreases. If camber is kept positive, then the running camber is kept near zero degrees for best tire life.

NOTE: Many front-wheel-drive vehicles that use sealed wheel bearings often specify negative camber.

8. Camber is *not* adjustable on many vehicles.
9. If camber is adjustable, the change is made by moving the upper or the lower control arm or strut assembly by means of one of the following methods:
   a. Shims
   b. Eccentric cams
   c. Slots
10. Camber should be equal on both sides; however, if camber cannot be adjusted exactly equal, make certain that there is more camber on the front of the left side to help compensate for the road crown (1/2 degree maximum difference).

CASTER

Caster *is the forward or rearward tilt of the steering axis in reference to a vertical line as viewed from the side of the vehicle.* The steering axis is defined as the line drawn through the upper and lower steering pivot points. On an SLA suspension system, the upper pivot is the upper ball joint and the lower pivot is the lower ball joint. On a MacPherson strut system, the upper pivot is the center of the upper bearing mount and the lower pivot point is the lower ball joint. Zero caster means that the steering axis is straight up and down, also called 0 degrees or perfectly vertical, as shown in Figure 92–14 on page 1169.

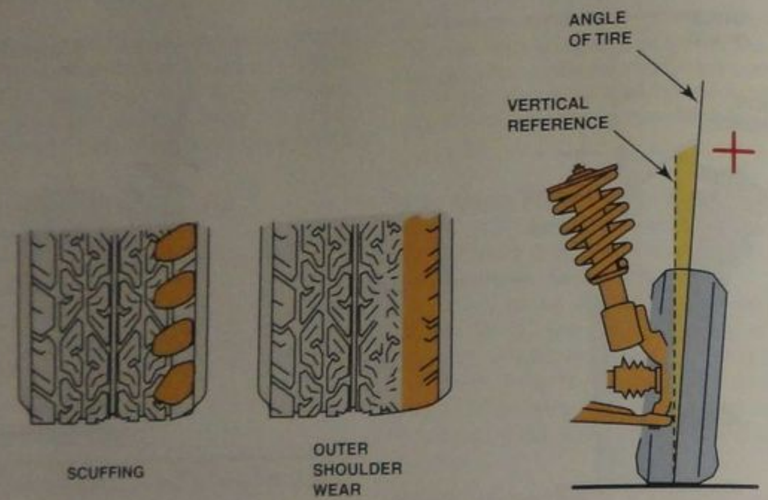


Figure 92–7 Excessive positive camber and how the front tires would wear due to the excessive camber.

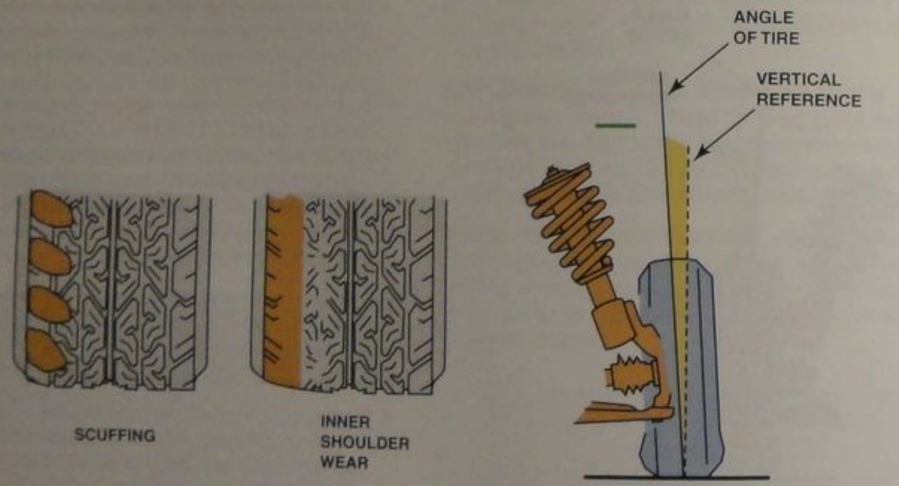


Figure 92–8 Excessive negative camber and how the front tires would wear due to the excessive camber.

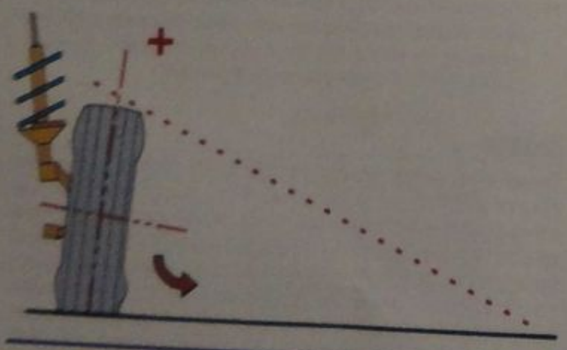


Figure 92–9 Positive camber tilts the tire and forms a cone shape that causes the wheel to roll away or pull outward toward the point of the cone.

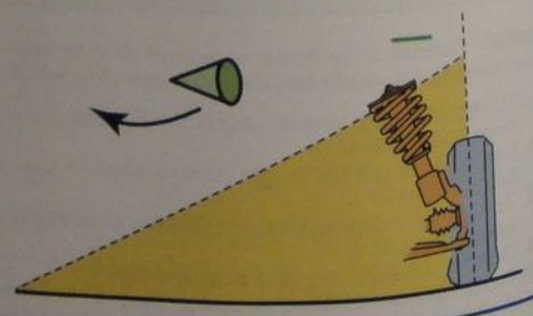


Figure 92–10 Negative camber creates a pulling force toward the center of the vehicle.

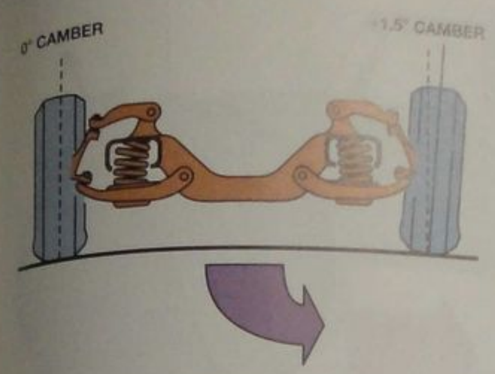


Figure 92–11 If camber angles are different from one side to the other, the vehicle will pull toward the side with the most camber.

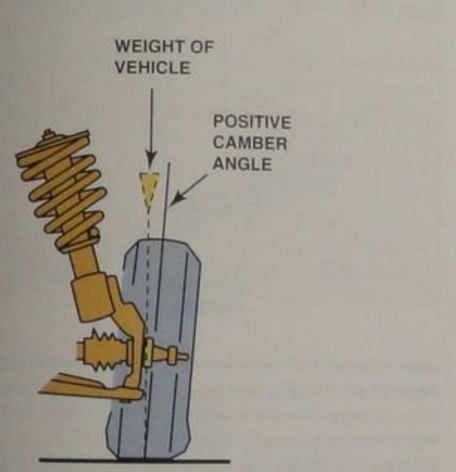


Figure 92–12 Positive camber applies the vehicle weight toward the larger inner wheel bearing. This is desirable because the larger inner bearing is designed to carry more vehicle weight than the smaller outer bearing.

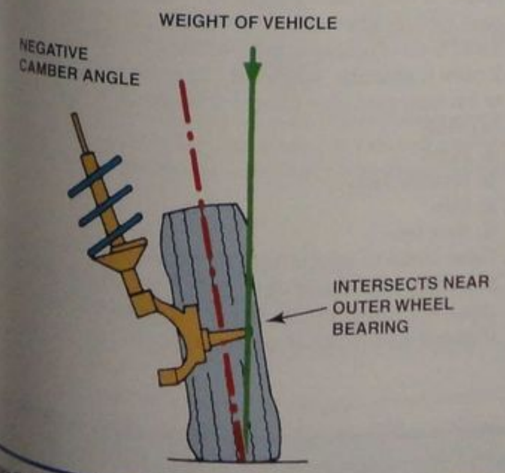


Figure 92–13 Negative camber applies the vehicle weight to the smaller outer wheel bearing. Excessive negative camber, therefore, may contribute to outer wheel bearing failure.

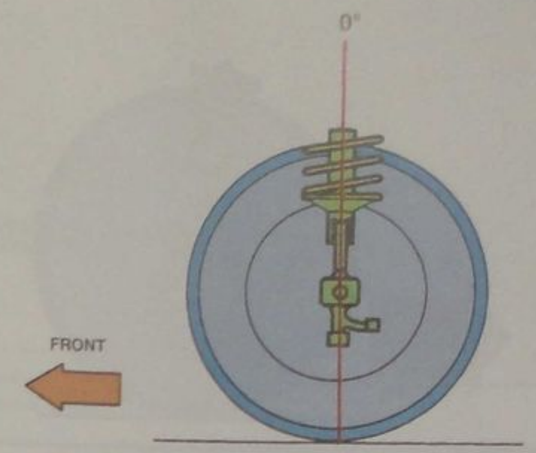


Figure 92–14 Zero caster.

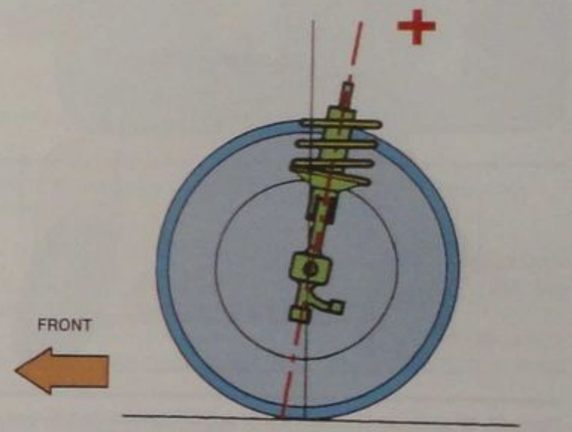


Figure 92–15 Positive (+) caster.

1. Positive (+) caster is present when the upper suspension pivot point is behind the lower pivot point (ball joint) as viewed from the side. See Figure 92–15.
2. Negative (–) caster is present when the upper suspension pivot point is ahead of the lower pivot point (ball joint) as viewed from the side. See Figure 92–16.
3. Caster is measured in degrees or fractions of degrees.
4. Caster is not a tire-wearing angle, but positive caster does cause changes in camber during a turn. See Figure 92–17. This condition is called **camber roll** (see the Tech Tip titled "Caster Angle Tire Wear").
5. Caster is a stability angle.
   a. If caster is excessively positive, the vehicle steering will be very stable (will tend to go straight with little steering wheel correction needed). This degree of caster helps with steering wheel **returnability** after a turn. See Figure 92–18.
   b. If the caster is positive, steering effort will increase with increasing positive caster. Greater road shocks will be felt by the driver when driving over rough road surfaces. See Figure 92–19. Vehicles with as many as 11 degrees positive caster usually use a steering dampener to control possible

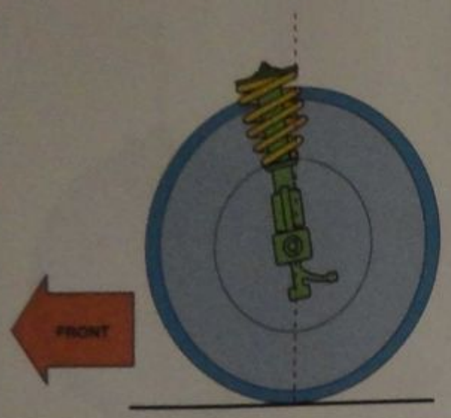


Figure 92–16 Negative (−) caster is seldom specified on today's vehicles because it tends to make the vehicle unstable at highway speeds. Negative caster was specified on some older vehicles not equipped with power steering to help reduce the steering effort.

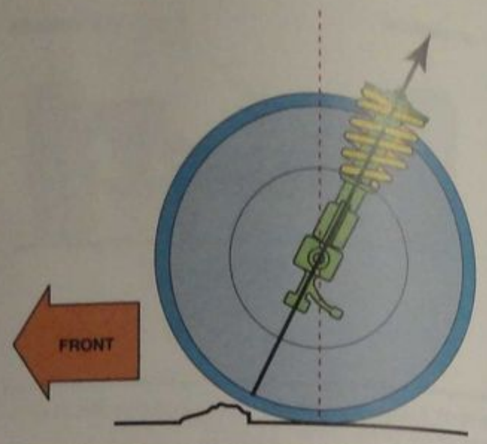


Figure 92–19 High caster provides a road shock path to the vehicle.

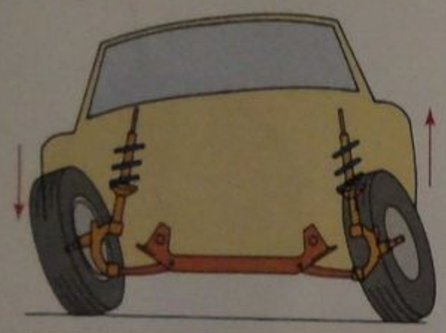


Figure 92–17 As the spindle rotates, it lifts the weight of the vehicle due to the angle of the steering axis. *(Courtesy of Hunter Engineering Company)*

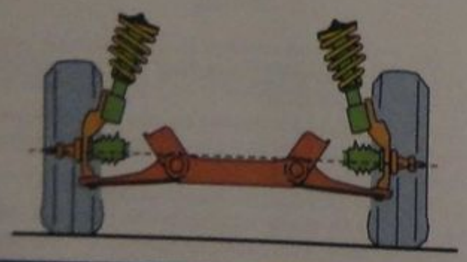


Figure 92–18 Vehicle weight tends to lower the spindle, which returns the steering to the straight-ahead position.

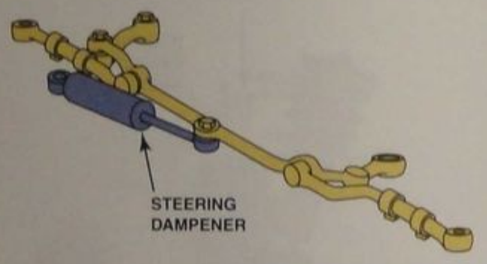


Figure 92–20 A **steering dampener** is used on many pickup trucks, sport utility vehicles (SUVs), and many luxury vehicles designed with a high-positive-caster setting. The dampener helps prevent steering wheel kickback when the front tires hit a bump or hole in the road and also helps reduce steering wheel shimmy that may result from the high-caster setting.

shimmy at high speeds and to dampen the snap-back of the spindle after a turn. See Figure 92–20.

c. If caster is negative, or excessively unequal, the vehicle will not be as stable and will tend to wander (constant steering wheel movement will be required to maintain straight-ahead direction). If a vehicle is heavily loaded in the rear, caster increases. See Figure 92–21.

6. Caster can cause pull if unequal; **the vehicle will pull toward the side with the least positive caster.** However, the pulling force of unequal caster is only about one-fourth the pulling force of camber. It would require a difference of caster of one full degree to equal the pulling force of only 1/4-degree difference of camber.
7. Caster is *not* adjustable on many vehicles.
8. If caster is adjustable, it is changed by moving either the lower or the upper pivot point forward or backward by means of the following:
   a. Shims
   b. Eccentric cams
   c. Slots
   d. Strut rods
9. Caster should be equal on both sides; however, if caster cannot be adjusted to be exactly equal, make certain that there is more caster on the right side (maximum 1/2-degree difference) to help compensate for the crown of the road.

NOTE: Caster is only measured on the front turning wheels of the vehicle. While some caster is built into the rear suspension of many vehicles, rear caster is not measured as part of a four-wheel alignment.

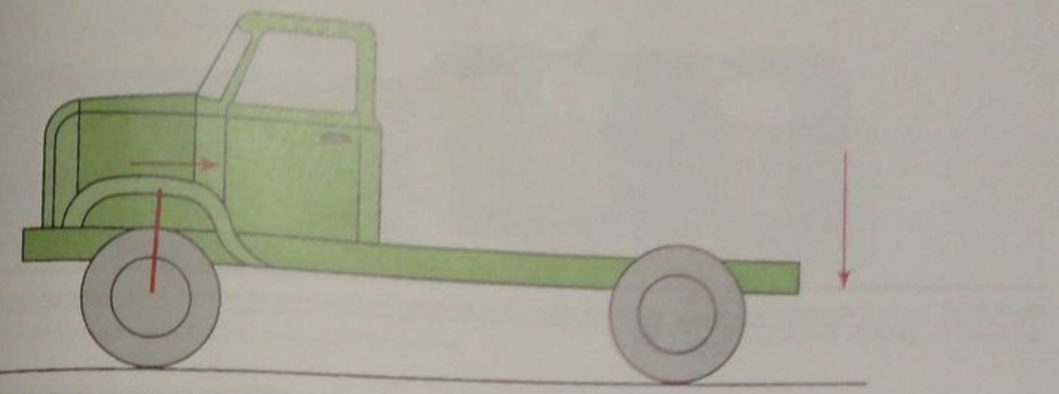


Figure 92–21 As the load increases in the rear of a vehicle, the top steering axis pivot point moves rearward, increasing positive (+) caster.

TECH TIP ✔ **Caster Angle Tire Wear**

The caster angle is generally considered to be a *non*-tire-wearing angle. However, excessive or unequal caster can *indirectly* cause tire wear. When the front wheels are turned on a vehicle with a lot of positive caster, they become angled. This is called *camber roll*. (Caster angle is a measurement of the difference in camber angle from when the wheel is turned inward compared to when the wheel is turned outward.) Most vehicle manufacturers have positive caster designed into the suspension system. This positive caster increases the directional stability.

However, if the vehicle is used exclusively in city driving, positive caster can cause tire wear to the outside shoulders of both front tires. See Figure 92–22.

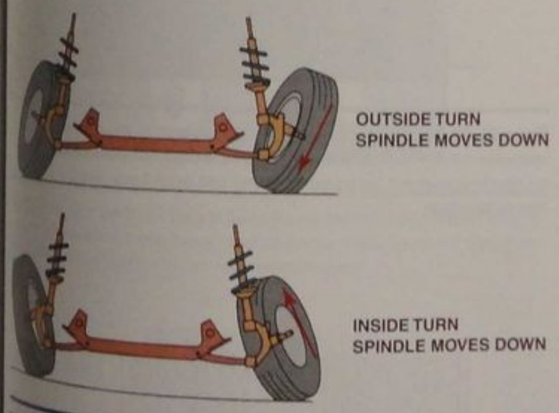


Figure 92–22 Note how the front tire becomes tilted as the vehicle turns a corner with positive caster. The higher the caster angle, the more the front tires tilt, causing camber-type tire wear.

TOE

Toe is the difference in distance between the front and rear of the tires. As viewed from the top of the vehicle (a bird's eye view), zero toe means that both wheels on the same axle are parallel, as shown in Figure 92–23.

Toe is also described as a comparison of horizontal lines drawn through both wheels on the same axle, as shown in Figure 92–24.

If the front of the tires is closer than the rear of the same tires, then the toe is called *toe-in* or positive (+) toe. See Figure 92–25.

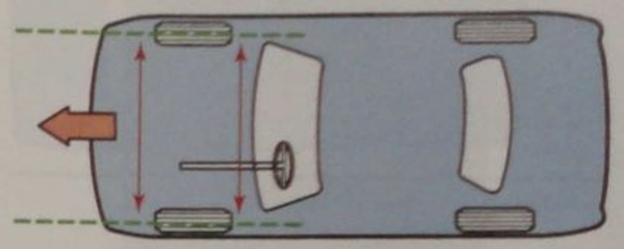


Figure 92–23 Zero toe. Note how both tires are parallel to each other as viewed from above the vehicle.

If the front of the tires is farther apart than the rear of the same tires, then the wheels are *toed-out*, or have negative (−) toe. See Figure 92–26.

The purpose of the correct toe setting is to provide maximum stability with a minimum of tire wear when the vehicle is being driven.

1. Toe is measured in fractions of degrees or in fractions of an inch (usually 1/16s), millimeters (mm), or decimals of an inch (such as 0.06 in.).
2. *Incorrect toe is the major cause of excessive tire wear!* See Figure 92–27.

NOTE: If the toe is improper by just 1/8 in. (3 mm), the resulting tire wear is equivalent to dragging a tire sideways 28 feet (8.5 m) for every mile traveled (1.6 km).

If not correct, toe causes camber-type wear on one side of the tire. See Figures 92–28 and 92–29 on page 1172–1173. Feather-edge wear is also common, especially if the vehicle is equipped with nonradial tires. See Figure 92–30 on page 1173.

3. *Incorrect front toe does not cause a pull condition.* Incorrect toe on the front wheels is split equally as the vehicle is driven because the forces acting on the tires are exerted through the tie rod and steering linkage to both wheels.
4. *Incorrect (or unequal) rear toe can cause tire wear.* See Figures 92–31 through 92–33 on page 1173. If the toe of the rear wheels is not equal, the steering wheel will not be straight and will pull toward the side with the most toe-in.
5. Front toe adjustment must be made correctly by adjusting the tie rod sleeves. See Figure 92–34 on page 1173.

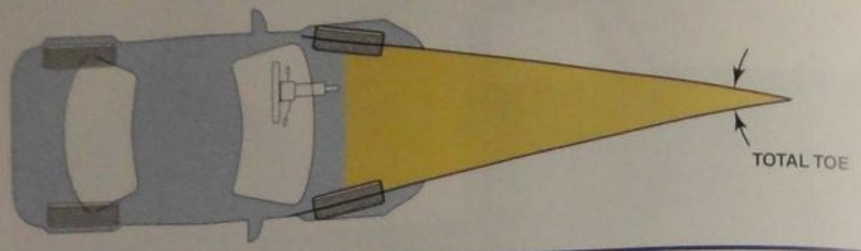


Figure 92–24 Total toe is often expressed as an angle. Because both front wheels are tied together through the tie rods and center link, the toe angle is always equally split between the two front wheels when the vehicle moves forward.

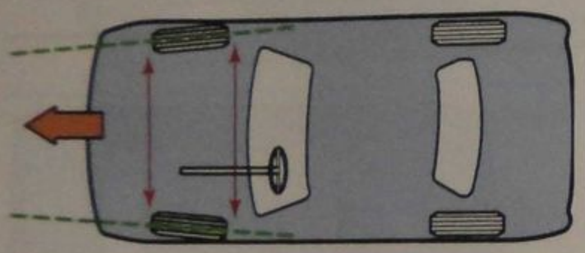


Figure 92–25 Toe-in, also called positive (+) toe.

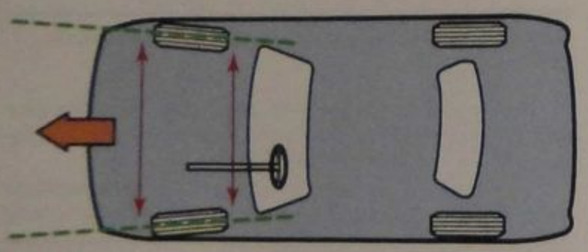


Figure 92–26 Toe-out, also called negative (−) toe. *(Courtesy of Hunter Engineering Company)*

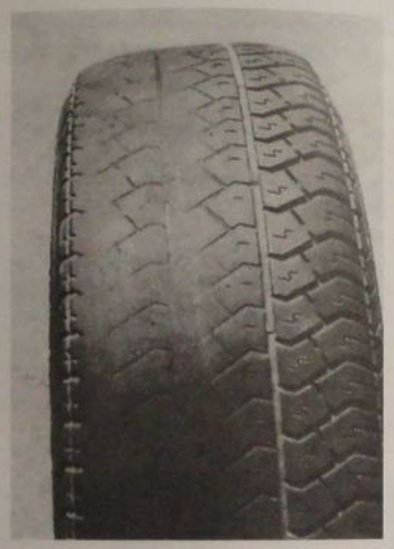
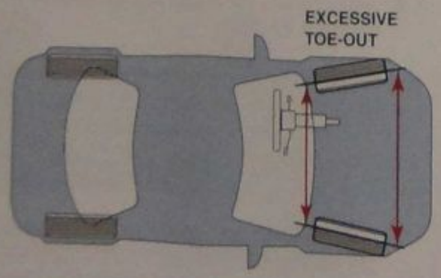


Figure 92–27 This tire is just one month old! It was new and installed on the front of a vehicle that had about 1/4 inch (6 mm) of toe-out. By the time the customer returned to the tire store for an alignment, the tire was completely bald on the inside. Note the almost new tread on the outside.



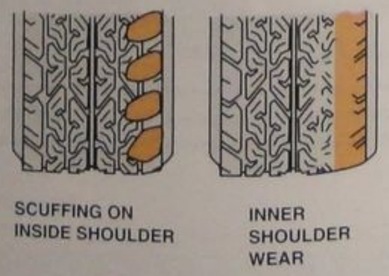


Figure 92–28 Excessive toe-out and the type of wear that can occur to the side of both front tires.

6. Many vehicle manufacturers specify a slight amount of toe-in to compensate for the natural tendency of the front wheels to spread apart (become toed-out) due to centrifugal force of the rolling wheels acting on the steering linkage.

NOTE: Some manufacturers of front-wheel-drive vehicles specify a toe-out setting to compensate for the toe-in forces created by the engine drive forces on the front wheels.

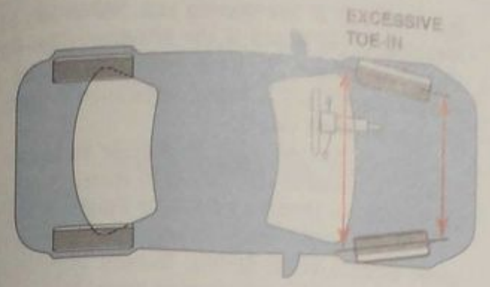




Figure 92–29 Excessive toe-in and the type of wear that can occur to the outside of both front tires.

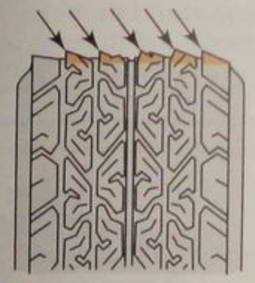


Figure 92–30 Feather-edge wear pattern caused by excessive toe-in or toe-out.

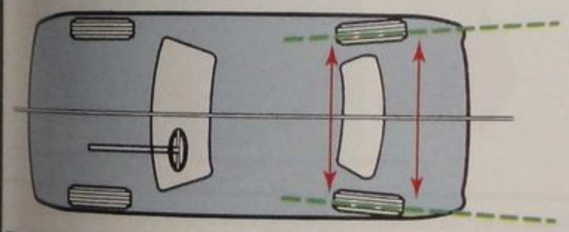


Figure 92–31 Rear toe-in (+). The rear toe (unlike the front toe) can be different for each wheel while the vehicle is moving forward because the rear wheels are not tied together as they are in the front. *(Courtesy of Hunter Engineering Company)*



Figure 92–32 Incorrect toe can cause the tire to run sideways as it rolls, resulting in a feather wear.

7. Normal wear to the tie rod ends and other steering linkage parts usually causes toe-out.

Excessive front toe-out will cause wandering (lack of directional stability), especially during braking. Incorrectly set toe will cause an uncentered steering wheel. If toe is unequal side to side, the vehicle will pull toward the side with the most toe-out.



Figure 92–33 Diagonal wear such as shown here is usually caused by incorrect toe on the rear of a front-wheel-drive vehicle.

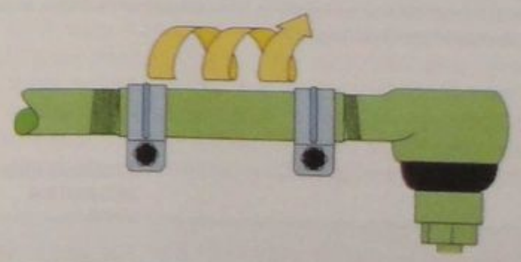


Figure 92–34 Toe on the front of most vehicles is adjusted by turning the tie rod sleeve as shown. *(Courtesy of John Bean Company)*

FREQUENTLY ASKED QUESTION ???

Why Doesn't Unequal Front Toe on the Front Wheels Cause the Vehicle to Pull?

Each wheel could have individual toe, but as the vehicle is being driven, the forces on the tires tend to split the toe, causing the steering wheel to cock at an angle as the front wheels both track the same. If the toe is different on the rear of the vehicle, the rear will be "steered" similar to a rudder on a boat because the rear wheels are not tied together as are the front wheels.

TECH TIP ✓ **Smooth In, Toed-In; Smooth Out, Toed-Out**

Wherever the toe setting is not zero, a rubbing action occurs that causes a feather-edge-type wear. See Figure 92–35. A quick, easy method to determine if incorrect toe could be causing problems is simply to rub your hand across the tread of the tire. If it feels smoother moving your hand toward the center of the vehicle than when you move your hand toward the outside, then the cause is excessive toe-in. The opposite effect is caused by toe-out. This may be felt on all types of tires, including radial-ply tires where the wear may not be seen as feather edged. Just remember this simple saying: "Smooth in, toed-in; smooth out, toed-out."

STEERING AXIS INCLINATION (SAI)

The steering axis is the angle formed between true vertical and an imaginary line drawn between the upper and lower pivot points of the spindle. See Figure 92–36. **Steering axis inclination (SAI)** is the inward tilt of the steering axis. SAI is also known as **kingpin inclination (KPI)** and is the imaginary line drawn through the kingpin as viewed from the front. SAI is also called **ball joint inclination (BJI),** if SLA-type suspension is used, or **MacPherson strut inclination (MSI).**

The purpose of SAI is to provide an upper suspension pivot location that causes the spindle to travel in an arc when turning, which tends to raise the vehicle, as shown in Figure 92–37.

Vehicle weight tends to keep the front wheels in a straight-ahead position when driving, thereby increasing vehicle stability, directional control, and steering wheel returnability. The greater the SAI, the more stable the vehicle. It also helps center the steering wheel after making a turn and reduces the need for excessive positive caster. The SAI/KPI angle of all vehicles ranges between 2 and 16 degrees. Front-wheel-drive vehicles usually have greater than 9 degrees SAI (typically 12 to 16 degrees) for directional stability, whereas rear-wheel-drive vehicles usually have less than 8 degrees of SAI. The steering axis inclination angle and the camber angle together are called the *included angle.*

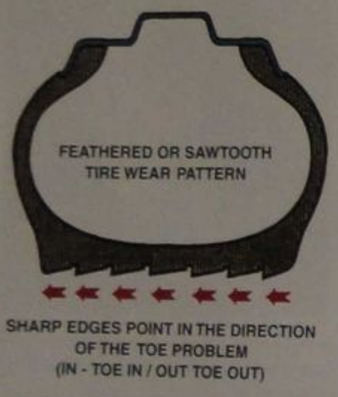


Figure 92–35 While the feathered or sawtooth tire tread wear pattern may not be noticeable to the eye, this wear can usually be felt by rubbing your hand across the tread of the tire. *(Courtesy of John Bean Company)*

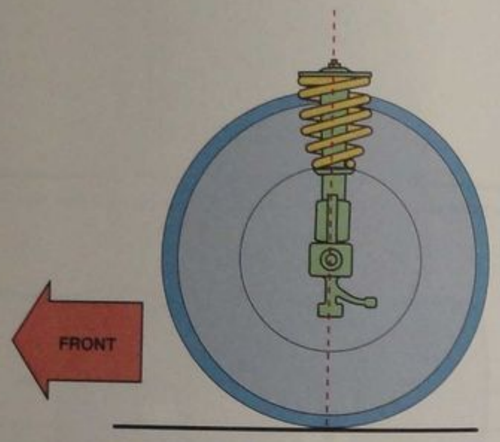


Figure 92–37 The SAI causes the spindle to travel in an arc when the wheels are turned. The weight of the vehicle is therefore used to help straighten the front tires after a turn and to help give directional stability.

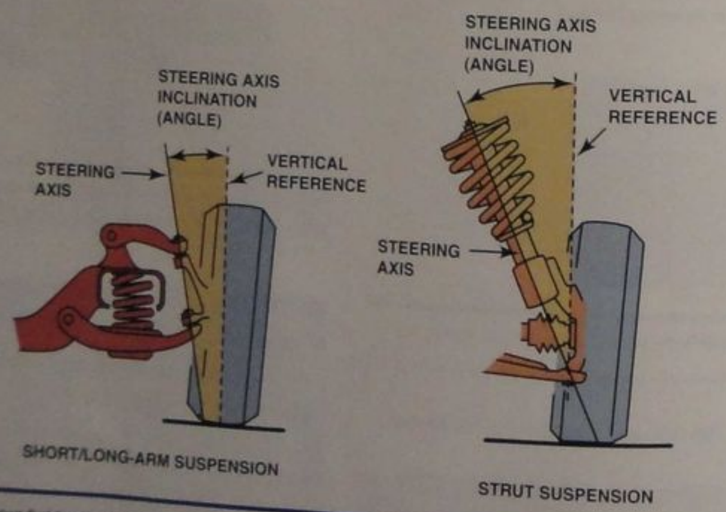


Figure 92–36 The top illustration shows that the steering axis inclination angle is determined by drawing a line through the center of the upper and lower ball joints. This represents the pivot points of the front wheels when the steering wheel is rotated during cornering. The lower illustration shows that the steering axis inclination angle is determined by drawing a line through the axis of the upper strut bearing mount assembly and the lower ball joint.

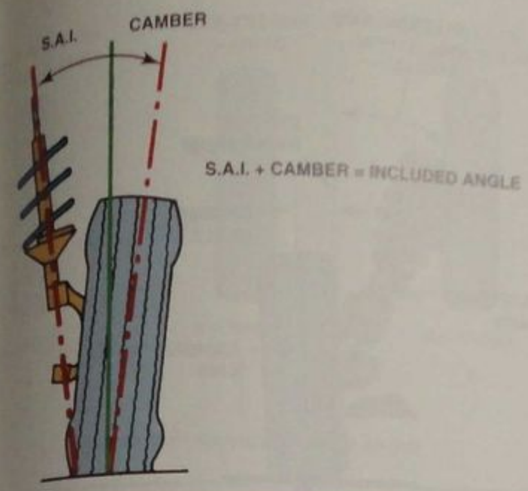


Figure 92–38 Included angle on a MacPherson-strut-type suspension.

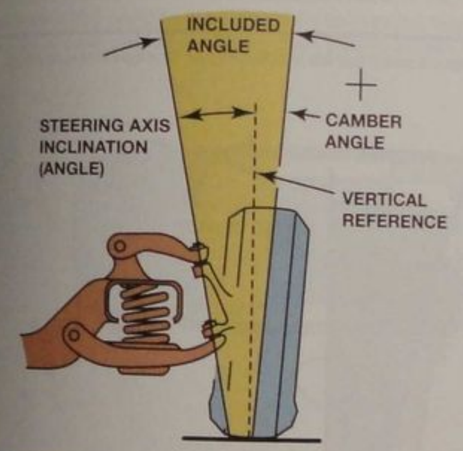


Figure 92–39 Included angle on an SLA-type suspension. The included angle is the SAI angle and the camber angle added together. If the camber angle is negative (−) (tire tilted inward at the top), the camber is subtracted from the SAI angle to determine the included angle.

INCLUDED ANGLE

The **included angle** is the SAI added to the camber reading of the front wheels only. *The included angle is determined by the design of the steering knuckle, or strut construction.* See Figures 92–38 and 92–39.

Included angle is an important angle to measure for diagnosis of vehicle handling or tire wear problems. For example, if the cradle is out of location due to previous service work or an accident, know-ing SAI, camber, and the included angle can help in determining what needs to be done to correct the problem. See Figure 92–40.

If the included angles are equal side-to-side, but the camber is unequal on both sides, then the SAI must be unequal. For best han-dling, the included angle should be within 1/2 degree of the SAI of the other side of the vehicle.

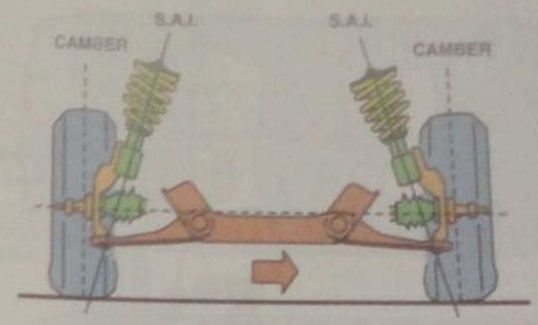


Figure 92–40 Cradle placement. If the cradle is not replaced in the exact position after removal for a transmission or clutch replacement, the SAI, camber, and included angle will not be equal side-to-side.

SCRUB RADIUS

Scrub radius refers to the *distance* between the line through the steering axis and the centerline of the wheel at the contact point with the road surface. See Figure 92–41.

Scrub radius is *not* adjustable and cannot be measured. Scrub radius can be zero, positive, or negative. Zero scrub radius means that the line through the steering axis intersects the centerline of the tire at the road surface. Positive scrub radius means that the line intersects the centerline of the tire below the road surface. Negative scrub radius means that the line intersects the centerline of the tire above the road surface. Scrub radius is also called **steering offset** by some vehicle manufacturers. If a wheel is permitted to roll rather than pivot, then steering will be more difficult because a tire can pivot more easily than it can roll while turning the front wheels. If the point of intersection is inside the centerline of the tire and below the road surface, this creates a toe-out force on the front wheels. Negative scrub radius is required on front-wheel-drive vehicles to provide good steering stability during brak-ing. See Figures 92–42 and 92–43 on pages 1176–1177.

Scrub radius is designed into each vehicle to provide acceptable handling and steering control under most conditions. Scrub radius also causes resistance to rolling of the front wheels to exert force on the steering linkage. This tends to dampen the effect of minor movements of the front wheels. Negative scrub radius causes the tire to toe-in during acceleration, braking, or traveling over bumps.

NOTE: It is this tendency to toe-in caused by the negative scrub radius and engine torque that requires many front-wheel-drive vehicles to specify a toe-out setting for the front-drive wheels.

Zero scrub radius is acceptable; positive scrub radius is less desir-able because it causes the wheel to toe-out during acceleration, brak-ing, or traveling over bumps and causes instability. Positive scrub radius is commonly used on rear-wheel-drive vehicles and requires a toe-in setting to help compensate for the tendency to toe-out.

A bent spindle can cause a change in the scrub radius and could cause hard steering, wander, or pull.

Also, changing tire or wheel sizes can affect the centerline location of the wheel or the height of the tire assembly and will change the scrub radius, which can negatively affect the steering control. When larger-diameter tires and positive-offset wheels are installed, the scrub radius becomes positive and the wheels tend to toe-out, causing wander, poor handling, and tire wear.

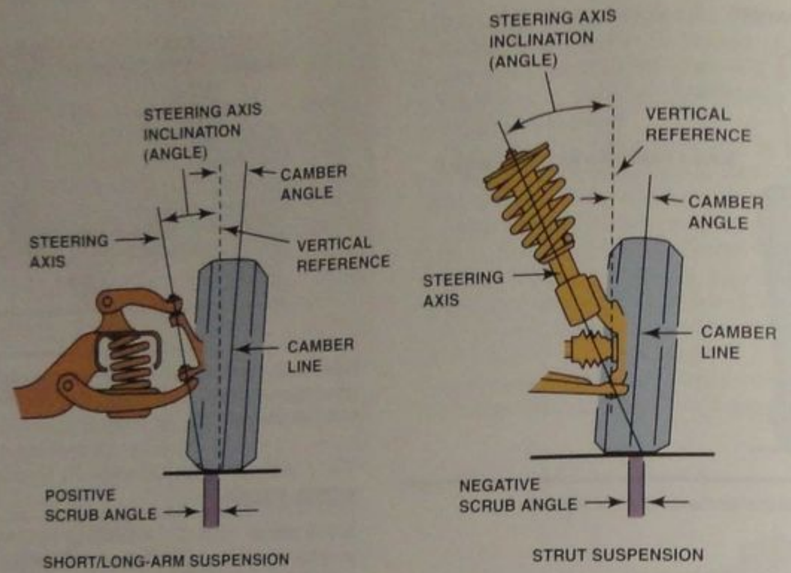


Figure 92–41 A positive scrub radius is usually built into most SLA front suspensions, and a negative scrub radius is usually built into most MacPherson-strut-type front suspensions.

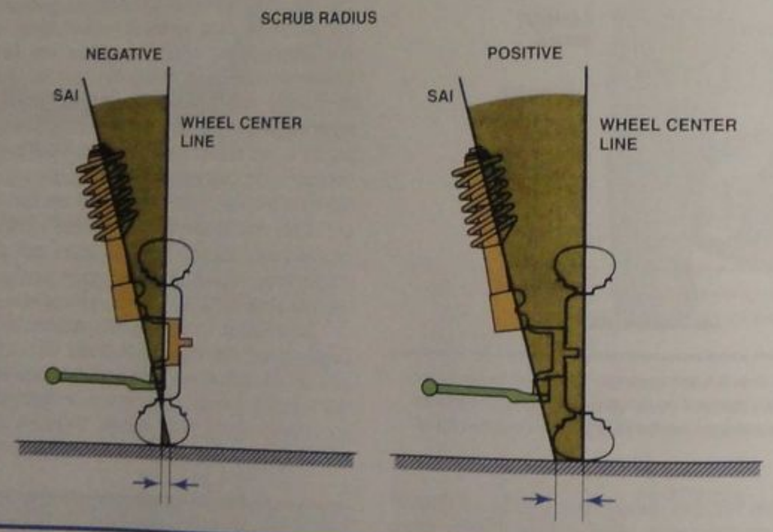


Figure 92–42 With negative scrub radius, the imaginary line through the steering axis inclination (SAI) intersects the road outside of the centerline of the tire. With positive scrub radius, the SAI line intersects the road inside the centerline of the tires.

TURNING RADIUS (TOE-OUT ON TURNS)

Whenever a vehicle turns a corner, the inside wheel has to turn at a sharper angle than the outside wheel because the inside wheel has a shorter distance to travel. See Figure 92–44.

Turning radius is also called **toe-out on turns,** abbreviated TOT or **TOOT,** and is determined by the angle of the steering knuckle arms. **Turning radius is a nonadjustable angle.** The turning radius can and should be measured as part of an alignment to check if the steering arms are bent or damaged. Symptoms of out-of-specification turning angle include the following:

1. Tire squeal noise during normal cornering, even at low speeds
2. Scuffed tire wear

The proper angle of the steering arms is where imaginary lines drawn from the steering arms should intersect exactly at the center of the rear axle. See Figure 92–45. This angle is called the Ackerman Effect (named for its promoter, an English publisher, Rudolph Ackerman, circa 1898).

SETBACK

Setback is the angle formed by a line drawn perpendicular (at 90 degrees) to the front axles. See Figure 92–46.

Setback is a nonadjustable measurement, even though it may be corrected. Positive setback means the right front wheel is set back farther than the left; negative setback means the left front wheel is set back farther than the right.

Setback can be measured with a four-wheel alignment machine or can be determined by measuring the wheel base on both sides of the vehicle.

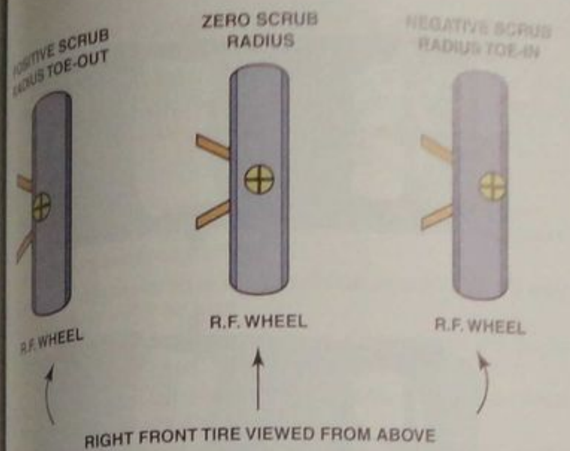


Figure 92–43 With a positive scrub radius, the pivot point, marked with a + mark, is inside the centerline of the tire and will cause the wheel to turn toward the outside, especially during braking. Zero scrub radius does not create any force on the tires and is not usually used on vehicles because it does not create an opposing force on the tires, which in turn makes the vehicle more susceptible to minor bumps and dips in the road. Negative scrub radius, as is used with most front-wheel-drive vehicles, generates an inward force on the tires.

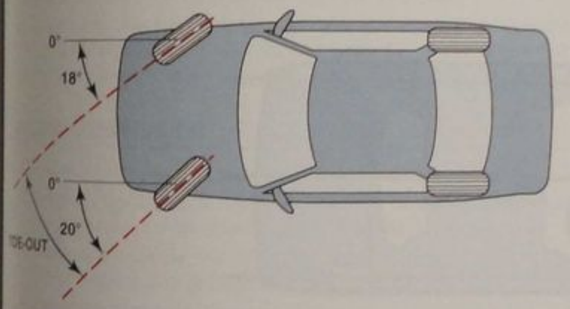


Figure 92–44 To provide handling, the inside wheel has to turn at a greater turning radius than the outside wheel.

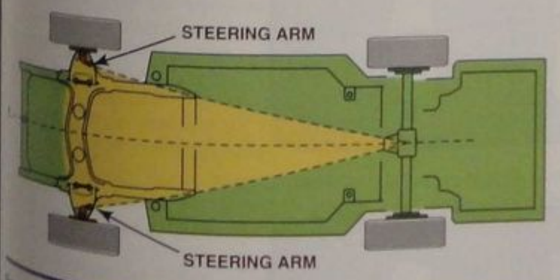


Figure 92–45 The proper toe-out on turns is achieved by angling the steering arms.

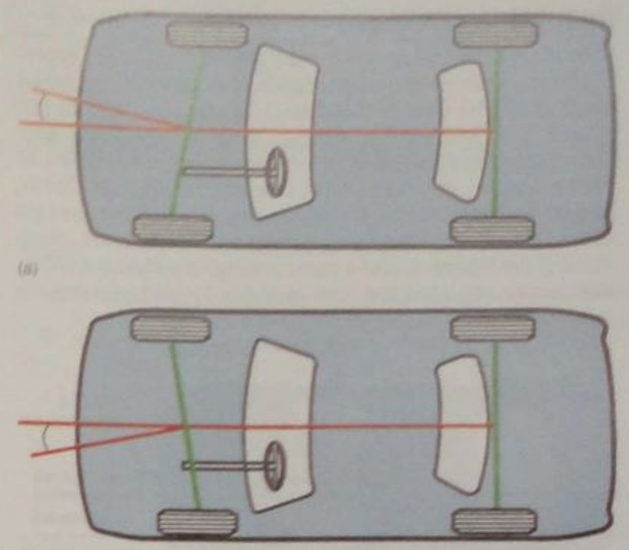


Figure 92–46 (a) Positive setback. (b) Negative setback.

NOTE: The wheel base of any vehicle is the distance between the center of the front wheel and the center of the rear wheel on the same side. The wheel base should be within 1/8 in. (3 mm) side-to-side.

The causes of setback include the following:

1. Cradle placement not correct on a front-wheel-drive vehicle. This can be caused by incorrectly installing the cradle after a transmission, clutch, or engine replacement or service. See Figure 92–47.
2. An accident that affected the frame or cradle of the vehicle and was unnoticed or not repaired.

Most vehicle manufacturers do not specify a minimum setback specification. However, a reading of 0.50 degrees or 0.5 in. (13 mm) or less of setback is generally considered to be acceptable.

THRUST ANGLE

Thrust angle is the angle of the rear wheels as determined by the total rear toe. If both rear wheels have zero toe, then the thrust angle is the same as the geometric centerline of the vehicle. The total of the rear toe setting determines the **thrust line,** or the direction the rear wheels are pointed. See Figure 92–48.

On vehicles with an independent rear suspension, if both wheels do not have equal toe, the vehicle will pull in the direction of the side with the most toe-in.

TRACKING

The rear wheels should track directly behind the front wheels. If the vehicle has been involved in an accident, it is possible that the frame or rear axle mounting could cause **dog tracking.**

To check the frame for possible damage, two diagonal measurements of the frame and/or body are required. The diagonal measurements from known points at the front and the rear should be within 1/8 in. (3 mm) of each other. See Figure 92–49.

FOUR-WHEEL ALIGNMENT

Four-wheel alignment refers to the checking and/or adjustment of all four wheels. Four-wheel alignment is important for proper handling and tire wear, to check the camber and the toe of the rear wheels of front-wheel-drive vehicles. Some rear-wheel-drive vehicles equipped with independent rear suspension can be adjusted for camber and toe. Rear-wheel caster cannot be measured or adjusted because to measure caster, the wheels must be turned from straight ahead. Since rear wheels are securely attached, a caster *sweep* (turning the wheels to take a caster reading) is not possible. While rear camber can cause tire wear problems, by far the greatest tire

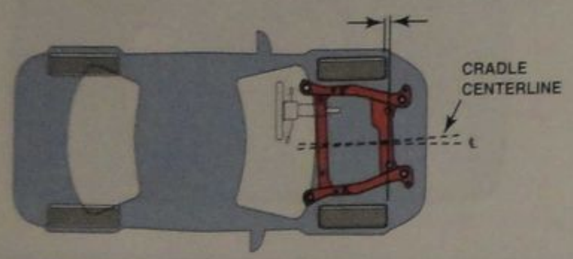


Figure 92–47 Cradle placement affects setback.

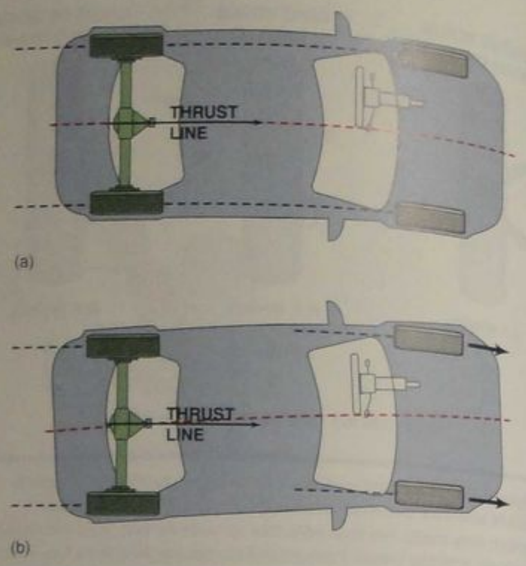


Figure 92–49 (a) Proper tracking. (b) Front wheels steering toward thrust line.

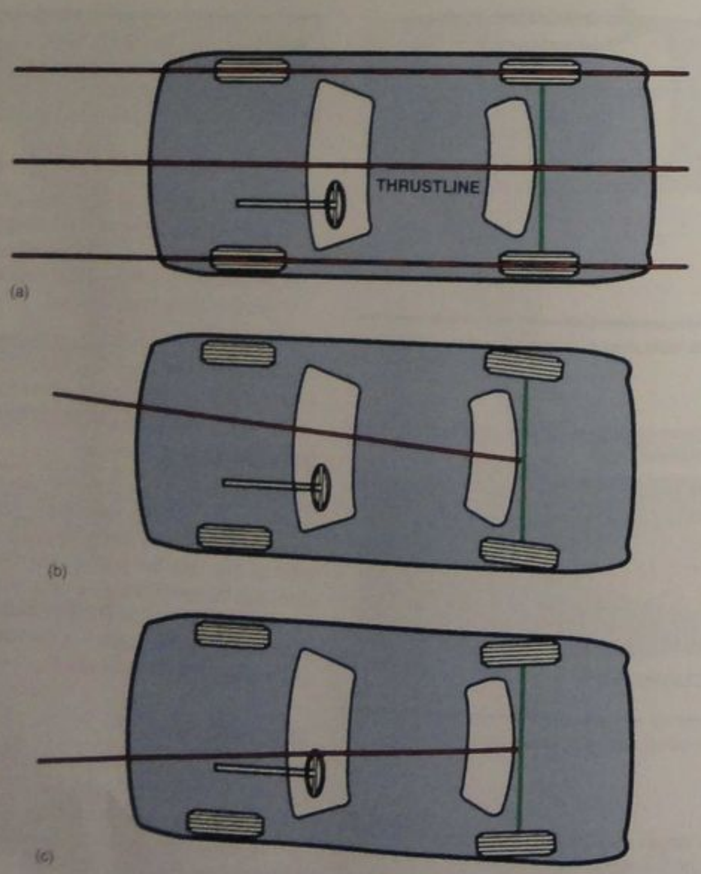


Figure 92–48 (a) Zero thrust angle. (b) Thrust line to the right. (c) Thrust line to the left.

wear occurs due to toe settings. *Unequal* toe in the rear can cause the vehicle to pull or lead. The rear camber and toe are always adjusted first before adjusting the front caster, camber, and toe. This procedure ensures that the thrust line and centerline of the vehicle are the same.

SUMMARY

1. The need for a wheel alignment results from wear or damage to suspension and steering components.
2. Low or unequal tire pressures can often cause symptoms such as wander, pull, and excessive tire wear.
3. Camber is both a pulling angle (if not equal side-to-side) as well as a tire wearing angle (if not set to specifications).
4. Incorrect camber can cause tire wear and pulling if camber is not within 1/2 degree from one side to the other.
5. Toe is the most important alignment angle because toe is usually the first requiring correction. When incorrect, toe causes severe tire wear.
6. Incorrect toe causes excessive tire wear and creates instability if not within specifications.
7. Caster is the basic stability angle, yet it does not cause tire wear (directly) if not correct or equal side-to-side.
8. SAI and included angle (SAI and camber added together) are important diagnostic tools.
9. If the toe-out on turns (TOOT) reading is not within specifications, a bent steering spindle (steering knuckle) is the most likely cause.
10. A four-wheel alignment includes aligning all four wheels of the vehicle; a thrust line alignment sets the front toe equal to the thrust line (total rear toe) of the rear wheels.

REVIEW QUESTIONS

1. Explain the three basic alignment angles of camber, caster, and toe.
2. Describe what happens to tire wear and vehicle handling if toe, camber, and caster are out of specification or *not* equal side-to-side.
3. Explain how knowing SAI, TOOT, and included angle can help in the correct diagnosis of an alignment problem.
4. Explain what thrust angle means.

CHAPTER QUIZ

1. Technician A says that loose tie rod ends can change the camber angle. Technician B says that a defective universal joint between the steering column and the steering gear box stub shaft can cause excessive steering wheel play. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that a vehicle will pull (or lead) to the side with the most camber (or least negative camber). Technician B says that a vehicle will pull (or lead) to the side with the most positive caster. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that the vehicle will pull to the side with the most toe in the rear. Technician B says that the rear toe angle determines the thrust angle. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Strut rods, if they are adjustable, can be used to adjust which angle?
   a. Toe
   b. Camber
   c. Caster
   d. Toe-out on turns
5. If metal shims are used for alignment adjustment in the front, they adjust _____.
   a. Camber
   b. Caster
   c. Toe
   d. Both a and b
6. Technician A says that as wear occurs, camber usually becomes negative. Technician B says that as steering linkage wear occurs, toe usually becomes toe-out from an original toe-in specification. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

Use the following information to answer question 7:

Specifications:	Min.	Preferred	Max.
Camber (degree)	0	1.0	1.4
Caster (degree)	.8	1.5	2.1
Toe (inch)	−.10	.06	.15
Results:	**L**	**R**	
Camber (degree)	−.1	.6	
Caster (degree)	1.8	1.6	
Toe (inch)	1.12	+.12	

7. The vehicle above will _____.
   a. Pull toward the right and feather-edge both tires
   b. Pull toward the left
   c. Wear the outside of the left tire and the inside of the right tire
   d. None of the above

Use the following information to answer questions 8 and 9:

Specifications:	Min.	Preferred	Max.
Camber (degree)	−1/4	+1/2	1
Caster (degree)	0	+2	+4
Toe (inch)	−1/16	1/16	3/16
Results:	**L**	**R**	
Camber (degree)	−0.3	−0.1	
Caster (degree)	3.6	1.8	
Toe (inch)	−.16	+.32	

8. The vehicle above will _____.
   a. Pull toward the left
   b. Pull toward the right
   c. Wander
   d. Lead to the left slightly
9. The vehicle above will _____.
   a. Wander
   b. Wear tires, but will not pull
   c. Will pull, but not wear tires
   d. Pull toward the left and cause feather-edge tire wear
10. Which alignment angle is most likely to need correction and cause the most tire wear?
    a. Toe
    b. Camber
    c. Caster
    d. SAI/KPI

CHAPTER

93 Alignment Diagnosis and Service

OBJECTIVES: After studying Chapter 93, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "D" (Wheel Alignment Diagnosis, Adjustment, and Repair). • List the many checks that should be performed before aligning a vehicle. • Describe the proper alignment setup procedure. • Explain how to correct for memory steer, torque steer, pull, drift (lead), and wander. • Describe the use of unit conversion and diagnostic charts. • Discuss tolerance alignment and how to check for accident damage.

KEY TERMS: degrees • eccentric cam • five-wheel alignment • four-wheel alignment • fractional • geometric centerline • memory steer • minutes • prealignment checks • ride height • shim chart • spoke angle • thrust line • tolerance adjustment • torque steer • total toe

Proper wheel alignment of all four wheels is important for the safe handling of any vehicle. When all four wheels are traveling the same path and/or being kept nearly vertical, tire life and fuel economy are maximized and vehicle handling is sure and predictable. A complete wheel alignment is a complex process that includes many detailed steps and the skill of a highly trained technician.

PREALIGNMENT CORRECTION TECHNIQUES

There are four basic steps in the correction of any problem:

1. **Verify.** What, when, where, and to what extent does the problem occur?
2. **Isolate.** Eliminate known good parts and systems. Always start with the simple things first. For example, checking and correcting tire pressure and rotation of the tires should be one of the first things performed whenever trying to isolate the cause of an alignment-related problem.
3. **Repair the problem.** This step involves replacing any worn or damaged components and making sure that the alignment is within factory specifications. See Figure 93–1.
4. **Recheck.** *Always* test-drive the vehicle after making a repair. Never allow the customer to be the first to drive the vehicle after any service work.

A thorough inspection of the steering, suspension, and tires should be performed *before* the alignment of the vehicle is begun.

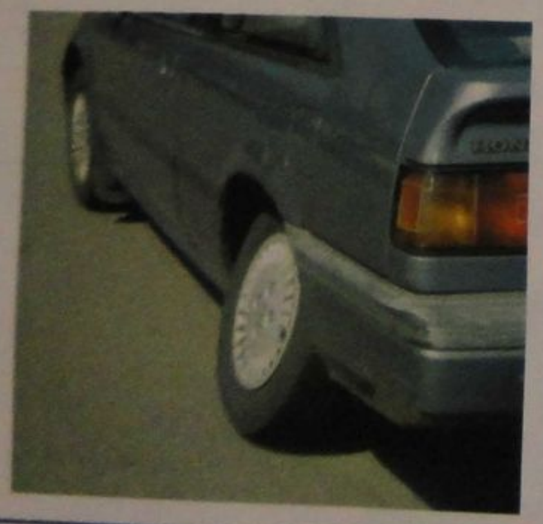


Figure 93–1 The owner of this Honda thought that all it needed was an alignment. Obviously, something more serious than an alignment caused this left rear wheel to angle inward at the top.

TECH TIP ✔ **Align and Replace at the Same Time**

Magnetic bubble-type camber/caster gauges can be mounted directly on the hub or on an adapter attached to the wheel or spindle nut on front-wheel-drive vehicles. See Figure 93–2. Besides being used as an alignment setting tool, a magnetic alignment head is a great tool to use whenever replacing suspension components.

Any time a suspension component is replaced, the wheel alignment should be checked and corrected as necessary. An easy way to avoid having to make many adjustments is to use a magnetic alignment head on the front wheels to check camber with the vehicle hoisted in the air *before* replacing front components, such as new MacPherson struts. Then, before tightening all of the fasteners, check the front camber readings again to make sure they match the original setting. This is best done when the vehicle is still off the ground. For example, a typical front-wheel-drive vehicle with a MacPherson strut suspension may have a camber reading of +1/4 degree on the ground and +2 degrees while on the hoist with the wheels off the ground. After replacing the struts, simply return the camber reading to +2 degrees and it should return to the same +1/4 degree when lowered to the ground.

Though checking and adjusting camber before and after suspension service work does not guarantee a proper alignment, it does permit the vehicle to be moved around with the alignment fairly accurate until a final alignment can be performed.

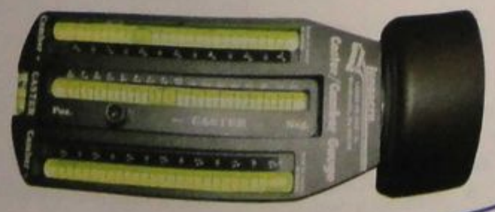


Figure 93–2 Magnetic bubble-type camber/caster gauge. To help it keep its strong magnetism, it is best to keep it stored stuck to a metal plate as shown here.

PREALIGNMENT CHECKS

Before checking or adjusting the front-end alignment, the following items should be checked and corrected, if necessary, as part of the **prealignment checks:**

1. Check all the tires for proper inflation pressures. Tires should be approximately the same size and tread depth, and the recommended size for the vehicle. See Figure 93–3.

NOTE: Some alignment technicians think that the vehicle must have new tires installed before an accurate alignment can be performed. Excessively worn tires, especially if only one tire is worn, can cause the vehicle to lean slightly. It is this unequal **ride height** that is the important fact to consider. If, for example, all four tires are equally worn, then the vehicle *can* be properly aligned. (Obviously, excessively worn tires should be replaced, and it would be best to align the vehicle with the replacement tires installed to be assured of an accurate alignment.)

2. Check the wheel bearings for proper adjustment.
3. Check for loose ball joints or torn ball joint boots.
4. Check the tie rod ends for damage or looseness.
5. Check the center link or rack bushings for play.
6. Check the pitman arm for any movement.
7. Check for runout of the wheels and the tires.
8. Check for vehicle ride height (should be level front to back as well as side-to-side). Make sure that the factory load-leveling system is functioning correctly, if the vehicle is so equipped. Check height according to the manufacturer's specifications. See Figures 93–4 and 93–5.

NOTE: Manufacturers often have replacement springs or spring spacers that can be installed between the coil spring and the spring seat to restore proper ride height.

9. Check for steering gear looseness at the frame.
10. Check for improperly operating shock absorbers.
11. Check for worn control arm bushings.
12. Check for loose or missing stabilizer bar attachments.
13. Check the trunk for excess loads.
14. Check for dragging brakes.

NOTE: Checking for dragging brakes is usually performed when installing alignment heads to the wheels prior to taking an alignment reading. A brake dragging can cause the vehicle to pull or lead toward the side with the dragging brake.

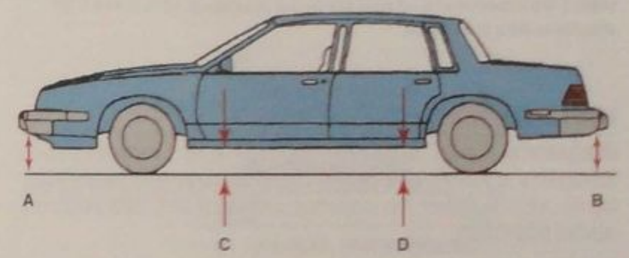


Figure 93–4 Measuring points for ride (trim) height vary by manufacturer. *(Courtesy of Hunter Engineering Company)*

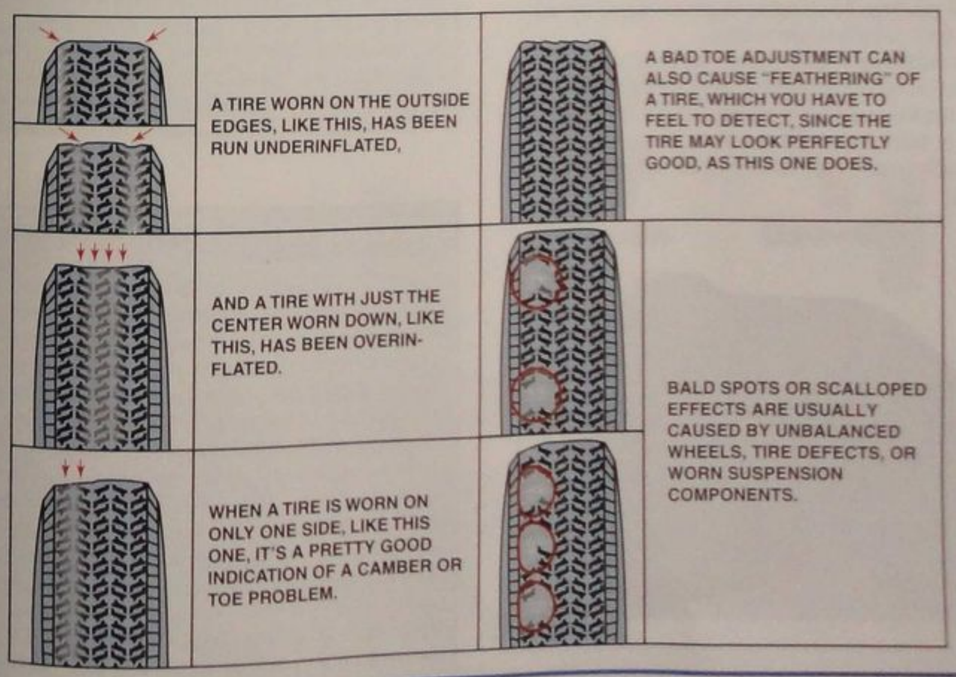


Figure 93–3 Typical tire wear chart as found in a service manual. Abnormal tire wear usually indicates a fault in a steering or suspension component that should be corrected or replaced before an alignment is performed.



Figure 93–5 Measuring to be sure the left and right sides of the vehicle are of equal height. If this measurement is not equal side-to-side by as little as 1/8 in. (3 mm), it can affect the handling of the vehicle.

LEAD/PULL

Diagnosis Many alignment requests come from customers attempting to have a lead or pull condition corrected. Before aligning the vehicle, verify the customer complaint first, then perform a careful inspection.

1. Inspect all tires for proper inflation. Both tires on the same axle (front and rear) should be the same size and brand. A lead/pull problem could be due to a defect or condition in one or more of the tires, as shown in Figure 93–6. Before attempting to correct the lead/pull condition by changing alignment angles, try rotating the tires front to back or side to side.
2. Road test the vehicle on a straight, level road away from traffic, if possible. Bring the vehicle to about 40 mph (65 km/h), shift into neutral, and feel for a pull in the steering, either to the left or to the right. A lead or drift is less severe than a pull, and may occur only if you momentarily remove your hands from the steering wheel while driving.



Figure 93–6 The bulge in this tire was not noticed until it was removed from the vehicle as part of a routine brake inspection. After replacing this tire, the vehicle stopped pulling and vibrating.

3. If the lead/pull problem is sometimes toward the left and other times toward the right, check for a **memory steer** condition. If the lead/pull problem occurs during acceleration and deceleration, check for a **torque steer** condition.

MEMORY STEER

Diagnosis *Memory steer* is a term used to describe the lead or pull of a vehicle caused by faults in the steering or suspension system. Often a defective upper strut bearing or steering gear can cause a pulling condition in one direction after making a turn in the same direction. It is as if the vehicle had a memory and pulled in the same direction. To test for memory steer, follow these simple steps during a test drive:

1. With the vehicle stopped at an intersection or in a parking area, turn the steering wheel completely to the left stop and then straighten the wheel without going past the straight-ahead position.
2. Lightly accelerate the vehicle and note any tendency of the vehicle to lead or pull toward the left.
3. Repeat the procedure, turning the steering wheel to the right.

If the vehicle first pulls to the left, then pulls to the right, the vehicle has a memory steer condition.

Correction A binding suspension or steering component is the most likely cause of memory steer. Disconnect each wheel from its tie rod end and check for free rotation of movement of each wheel. Each front wheel should rotate easily without binding or roughness. Repair or replace components as necessary to eliminate the binding condition.

NOTE: One of the most common causes of memory steer is the installation of steering or suspension components while the front wheels are turned. Most steering and suspension parts contain rubber, which has a memory if moved from its installed position. If the memory steer condition is only in one direction, then this is the most likely cause. The rubber component exerts a force on the suspension or steering that causes the vehicle to pull toward the side that the wheels were turned toward when the part was installed.

REAL WORLD FIX — **The Five-Wheel Alignment**

The steering wheel should always be straight when driving on a straight, level road. If the steering wheel is not straight, the customer will often think that the wheel alignment is not correct. One such customer complained that the vehicle pulled to the right while driving on a straight road. The service manager test drove the vehicle and everything was perfect, except that the steering wheel was not perfectly straight, even though the toe setting was correct. Whenever driving on a straight road, the customer would "straighten the steering wheel" and, of course, the vehicle went to one side. After adjusting toe with the steering wheel straight, the customer and the service manager were both satisfied. The technician learned that regardless of how accurate the alignment, the steering wheel *must* be straight; it the "fifth wheel" that the customer notice most. Therefore, a **five-wheel alignment** includes a check of the steering wheel.

NOTE: Many vehicle manufactures now include the maximum allowable steering wheel angle variation from straight. This specification is commonly ±3 degrees (plus or minus 3 degrees) or less.

TORQUE STEER

Diagnosis Torque steer occurs in front-wheel-drive vehicles when engine torque causes a front wheel to change its angle from straight ahead. See Figure 93–7. This resulting pulling effect is most noticeable during rapid acceleration, especially whenever upshifting of the transmission creates a sudden change in torque being applied to the front wheels. When turning and accelerating at the same time, torque steer has a tendency to straighten the vehicle, so more steering effort may be required to make the turn. Then, if the accelerator is released, a reversing force is applied to the front wheels. Now the driver must take corrective steering motions to counteract the change in steering effect of engine torque.

To summarize:

Torque to wheel	a toe-in condition
More torque	more toe-in
Unequal torque	unequal toe-in
Unequal drive shaft angles	unequal torque to the wheels

Most manufacturers try to reduce torque steer in the design of their vehicles by keeping drive axle angles low and equal side-to-side. If the engine and transaxle are level and the drive axle shafts are kept level, then the torque from the engine will be divided equally between the front wheels.

Correction The service technician cannot change the design of a vehicle, but the technician can, and should, check and correct problems that often cause torque steer. **Check to be sure that the condition is not normal.** It is normal for front-wheel-drive vehicles to exert a tug on the steering wheel and steer toward one side (usually to the right) during acceleration. This is especially noticeable when the transmission shifts from first to second gear under heavy acceleration. To determine how severe the problem is, place a strip of masking tape at the top of the steering wheel. Drive the vehicle and observe the amount of movement required to steer the vehicle straight during heavy acceleration. Repeat the test with a vehicle of similar make and model. If the torque steer is excessive, determine and correct the cause by carefully following the prealignment inspection steps and checking for a level power train.

A defective engine mount can cause the entire drive train to sag on one end. If the engine and transaxle of any front-wheel-drive vehicle is not level, the drive axle shaft angles will not be equal, as shown in Figure 93–8.

Hold a straightedge along the engine's supporting frame and measure up to points along the transaxle pan rail or the drive axle shaft. Side-to-side distances should be equal. Standard alignment shims can be used to shim the mounts and level the drive train.

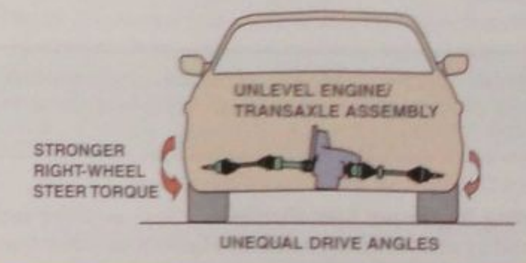


Figure 93–8 Broken or defective engine or transaxle mounts can cause the power train to sag, causing unequal drive axle shaft CV joint angles.

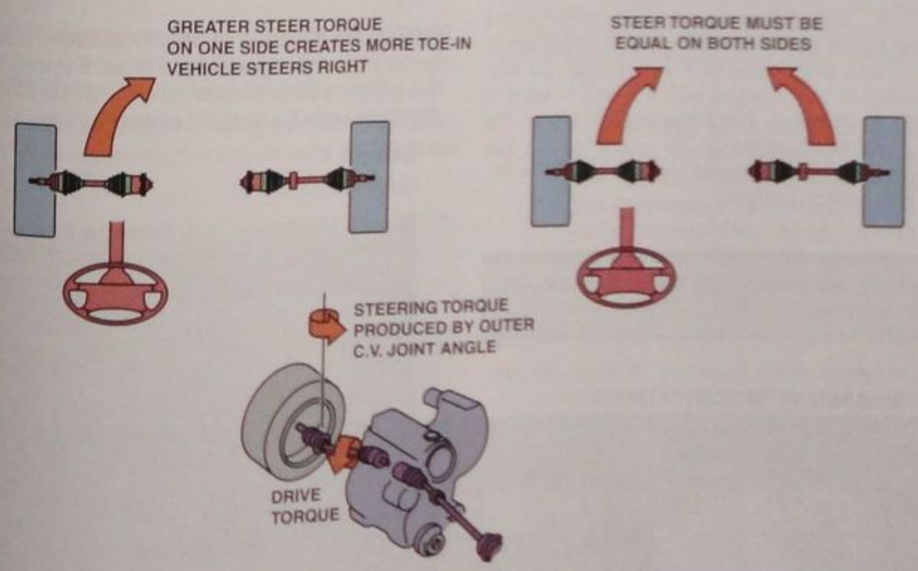


Figure 93–7 Equal outer CV joint angles produce equal steer torque (toe-in). If one side receives more engine torque, that side creates more toe-in and the result is a pull toward one side, especially during acceleration.

If torque steer is still excessive, check all alignment angles, including SAI and included angle. Unequal alignment angles can cause a pull or a lead condition. SAI and included angle should be within 1/2 (0.5) degree side-to-side for best results. A vehicle will tend to pull toward the side with the least SAI.

ALIGNMENT SPECIFICATIONS

Before attempting any alignment, consider the following:

1. Determine the make, model, and year of the vehicle.
2. Determine if the vehicle is equipped with power steering or manual steering. (Some older models use lower caster specifications for manual steering to reduce steering effort.)
3. Determine the correct specifications (if possible, check the specifications from two different sources to ensure correct readings).
4. Compensate for the lack of a full gas tank by placing an equal amount of weight in the luggage compartment. (Gasoline weighs 6 lb per gallon [0.7 kg per l]—a 20-gallon gas tank, when full, weighs 120 lb [60 liters weighs 54 kg].)
5. Determine the correct specifications for the *exact* vehicle being checked.

NOTE: Some alignment specifications are published as guidelines for acceptable values for state or local vehicle inspections. Be sure to use the correct or set of specifications.

Reading Alignment Specifications There are several methods used by vehicle manufacturers and alignment equipment manufacturers to specify alignment angles.

Maximum/Minimum/Preferred Method This method indicates the preferred setting for each alignment angle and the minimum and maximum allowable value for each. The alignment technician should always attempt to align the vehicle to the preferred setting.

Plus or Minus Method This method indicates the preferred setting with the lowest and highest allowable value indicated by a negative (−) and positive (+) sign, as in Figure 93–9. For example, if a camber reading is specified as +1/2 degree with a + and − value of 1/2 degree, it could be written as +1/2 degree ±1/2 degree. The minimum value would be 0 degree (1/2° − 1/2° = 0°) and the maximum value would be +1 degree (+1/2° + 1/2° = 1°). The range would be from 0 to 1 degree.

NOTE: The angle is assumed positive unless labeled with a negative (−) sign in front of the number.

TECH TIP ✓ **Keep the Doors Closed, but the Window Down**

An experienced alignment technician became upset with a beginning technician opened the driver's door to lock the steering wheel in a straight-ahead position on the vehicle being aligned. The weight of the open door caused the vehicle to sag. This disturbed the level position of the vehicle and changed all the alignment angles.

The beginning technician learned an important lesson that day: Keep the window down on the driver's door so that the steering wheel and brakes can be locked without disturbing the vehicle weight balance by opening a door. The brake pedal must be locked with a pedal depressor to prevent the wheels from rolling as the wheels are turned during a caster sweep. The steering must be locked in the straight-ahead position when adjusting toe.

Degrees, Minutes, and Fractions Specifications are often published in **fractional** or decimal **degrees**, or in degrees and **minutes**. There are 60 minutes (written as 60′) in 1 degree.

Angle-Unit Conversions

Units	Conversions
Fractional degrees	1/4°, 1/2°, 3/4°
Decimal degrees	0.25°, 0.50°, 0.75°
Degrees and minutes	0°15′, 0°30′, 0°45′

To help visualize the amount of these various units, think of decimal degrees as representing money or cents (100 cents = 1 dollar).

0.75 = 75 cents, or 3/4 of a dollar

Minutes can be visualized as minutes in an hour (60′ = 1 hour).

45′ = 3/4 of an hour

Now which is larger, 35 minutes or 0.40 degrees? The larger angle is 35 minutes because this is slightly greater than 1/2 degree, whereas 0.40 minutes is less than 1/2 degree.

Finding the Midpoint of Specifications Many manufacturers specify alignment angles within a range. If you are using equipment that requires a midpoint to be entered, use the following method to determine easily the midpoint of specifications.

Example 1:

Specification: 55′ to 2° 25′

Step #1 The first step is to determine the specification range or span, which is the total angle value from lowest to highest:

$$\begin{array}{r} 2^\circ\ 25' \\ -\ 55' \\ \hline 1^\circ\ 30' \end{array}$$ Specification range

WHEEL ALIGNMENT SPECIFICATIONS

	CASTER	CROSS CASTER (LH-RH)	CAMBER	CROSS CAMBER (LH-RH)	TOE (TOTAL IN) DEGREES	STEERING WHEEL ANGLE	THRUST ANGLE
FRONT	+3° ±.5°	0° ±.75°	+.2° ±.5°	0° ±.75°	0° ±.3°	0° ±3°	– –
REAR	– –	– –	-.3° ±.5°	0° ±.75°	+.1° ±.2°	– –	0° ±.1°

Figure 93–9 This alignment chart indicates the preferred setting with a plus or minus tolerance.

Step #2 Dividing the specification range by 2 will give the midpoint of the range:

$$\frac{1^\circ\ 30'}{2} = \frac{90'}{2} = 45'$$

Step #3 To find the midpoint of the specifications, add the midpoint of the range to the smaller specification (or subtract from the larger specification):

45′ midpoint of range
+55′ lowest specification
1°40′ midpoint of specification

Example 2:

Specification: −0.5° to +0.80°

Step #1 The total range of the specification is determined by adding 0.5 (1/2) to 0.80, totaling 1.30°.

NOTE: Since the lower specification is a negative number, we had to add the 0.5 degree to bring the lower range of the specification to zero. Then the total is simply the upper range specification added to the number required to bring the lower end of the range to zero.

Step #2 Dividing the specification range by 2 gives the midpoint of the range:

$$\frac{1.30^\circ}{2} = 0.65^\circ$$

Step #3 To find the midpoint of the specification, add the midpoint of the range to the smaller specification:

0.65° midpoint of range
+(−0.50°) lowest specification
+0.15° midpoint of specification

ALIGNMENT SETUP PROCEDURES

After confirming that the tires and all steering and suspension components are serviceable, the vehicle is ready for an alignment. Setup procedures for the equipment being used must always be followed. Typical alignment procedures include the following:

Step #1 Drive onto the alignment rack straight and adjust the ramps and/or turn plates so that they are centered under the tires of the vehicle. See Figure 93–10.



Figure 93–10 Using the alignment rack hydraulic jacks, raise the tires off the rack so that they can be rotated as part of the compensating process.



Figure 93–11 This wheel sensor has a safety wire that screws to the valve stem to keep the sensor from falling onto the ground if the clamps slip on the wheel lip.

Step #2 Use chocks for the wheels to keep the vehicle from rolling off the alignment rack.

Step #3 Attach and calibrate the wheel sensors to each wheel as specified by the alignment equipment manufacturer. See Figure 93–11. The calibration procedure is required whenever the head of the machine is attached to the wheel of the vehicle. All alignment angles and measurements are taken from the readings of the wheel sensors.

Calibration of these wheel sensors is needed for two reasons:

a. *The wheel may be bent.* If the wheel (rim) is bent, even slightly, this small amount of tilt would be read as an angle of the suspension.

NOTE: Compensating or calibrating the wheel sensor for a bent wheel does not correct (or repair) the bent wheel! The bent wheel is still present and can result in a shimmy-type vibration.

b. *The sensors may not be identically installed on the wheel.* Most sensors use three or four wheel-mounting locations. It is not possible to install all wheel sensors perfectly at the same depth on the wheel in all locations. If a sensor must be removed during the alignment process and reinstalled, it should be recalibrated. Always follow the manufacturer's recommended procedure for compensating the sensors.

Step #4 Unlock all rack or turn plates.

Step #5 Lower the vehicle and jounce the vehicle by pushing down on the front, then rear, bumper. This motion allows the suspension to become centered.

Step #6 Following the procedures for the alignment equipment, determine all alignment angles.

MEASURING CAMBER, CASTER, SAI, TOE, AND TOOT

Camber Camber is measured with the wheels in the straight-ahead position on a level platform. Since camber is a vertical reference angle, alignment equipment reads camber directly.

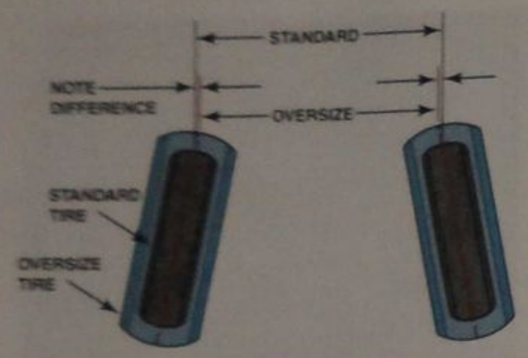


Figure 93–12 If toe for an oversize tire is set by distance, the toe angle will be too small. Toe angle is the same regardless of tire size.

Caster Caster is measured by moving the front wheels through an arc inward, then outward, from straight ahead. This necessary movement of the front wheels to measure caster is called *caster sweep*. What the alignment measuring equipment is actually doing is measuring the camber at one wheel sweep and measuring the camber again at the other extreme of the caster sweep. *The caster angle itself is the difference between the two camber readings.*

SAI Steering axis inclination (SAI) is also measured by performing a caster sweep of the front wheels. While this angle can be read at the same time as caster on many alignment machines, most experts recommend that SAI be measured separately from the caster reading. When measuring SAI separately, the usual procedure involves raising the front wheels off the ground and leveling and locking the wheel sensors before performing a caster sweep. The reason for raising the front wheels is to allow the front suspension to extend to its full droop position. When the suspension is extended, the SAI is more accurately determined because the angle itself is expanded.

Toe Toe is determined by measuring the angle of both front and/or both rear wheels from the straight-ahead (0 degree) position. Most alignment equipment reads the toe angle for each wheel and the combined toe angle of both wheels on the same axle. This combined toe is called **total toe.** Toe angle is more accurate than the center-to-center distance, especially if oversize tires are installed on the vehicle. See Figure 93–12.

TOOT Toe-out on turns (TOOT) is a diagnostic angle and is normally not measured as part of a regular alignment, but it is recommended to be performed as part of a total alignment check. TOOT is measured by recording the angle of the front wheels as indicated on the front turn plates. See Figure 93–13.

If, for example, the inside wheel is turned 20 degrees, then the outside wheel should indicate about 18 degrees on the turn plate. The exact angles are usually specified by the vehicle manufacturer. The turning angle should be checked only after the toe is correctly set. *The turning angle for the wheel on the outside of the turn should not vary more than 1 1/2 degrees from specifications.* For example, if the specification calls for the right wheel to be steered into the turn 20 degrees, the outside wheel should measure 18 degrees. This should be within 1 1/2 degrees (16.5 to 19.5 degrees). If the TOOT is not correct, a bent steering arm is the usual cause. If TOOT is not correct, tire squealing noise is usually noticed while cornering and excessive tire wear may occur.

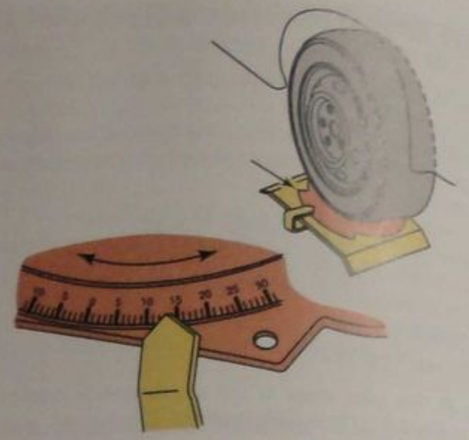


Figure 93–13 The protractor scale on the front turn plates allows the technician to test the turning radius by turning one wheel to an angle specified by the manufacturer and observing the angle of the other front wheel. Most newer alignment machines can display turning angle based on sensor readings, and therefore the protractor scale on the turn plate is not needed or used.

NOTE: Some front-wheel-drive vehicles use a nonsymmetrical (unequal) turning angle design. This design is found on various makes and models of vehicles to assist in controlling torque steer. The test procedure is the same except that the turning angle specifications include left-wheel and right-wheel angles when turned inward and outward.

SPECIFICATIONS VERSUS ALIGNMENT READINGS

Secure both the alignment specifications from the manufacturer and the alignment readings and compare the two. Before starting an alignment, the smart technician checks the SAI, included angle, setback, and toe-out on turns to make sure that there is no hidden damage such as a bent spindle or strut that was not found during the prealignment inspection. *Setback is also a diagnostic angle and should be less than 0.5 in. (13 cm or 1/2 degree).* If setback is greater than 0.5 in. (13 cm or 1/2 degree), check the body, frame, and cradle for accident damage or improper alignment.

NOTE: If the SAI or included angle are unequal, suggesting a possible problem such as a bent strut, check the front and rear toe readings. Some alignment equipment cannot show accurate SAI readings if the front or rear toe readings are not within specifications. If the front and rear toe readings are OK and the alignment readings indicate a bent strut, go ahead with the diagnosis and correction as explained later in this chapter.

CHECKING FOR BENT STRUTS, SPINDLES, OR CONTROL ARMS

Even a minor bump against a curb can bend a spindle or a strut housing.

Before attempting to correct an alignment, check all the angles and use the appropriate diagnostic chart to check for hidden damage that a visual inspection may miss.

DIAGNOSING SAI, CAMBER, AND INCLUDED ANGLE

SLA AND STRUT/SLA SUSPENSIONS

SAI	CAMBER	INCLUDED ANGLE	DIAGNOSIS
CORRECT	LESS THAN SPECS	LESS THAN SPECS OR SPINDLE	BENT STEERING KNUCKLE
LESS THAN SPECS	GREATER THAN SPECS	CORRECT	BENT LOWER CONTROL ARM
LESS THAN SPECS	GREATER THAN SPECS	GREATER THAN SPECS	BENT LOWER CONTROL ARM AND STEERING KNUCKLE OR SPINDLE
GREATER THAN SPECS	LESS THAN SPECS	CORRECT	BENT UPPER CONTROL ARM

STRUT SUSPENSIONS

SAI	CAMBER	INCLUDED ANGLE	DIAGNOSIS
CORRECT	LESS THAN SPECS	LESS THAN SPECS	BENT SPINDLE AND/OR STRUT
CORRECT	GREATER THAN SPECS	GREATER THAN SPECS	BENT SPINDLE AND/OR STRUT
LESS THAN SPECS	GREATER THAN SPECS	CORRECT	BENT CONTROL ARM OR STRUT TOWER OUT AT TOP
LESS THAN SPECS	GREATER THAN SPECS	GREATER THAN SPECS	BENT CONTROL ARM OR STRUT TOWER OUT AT TOP, ALSO BENT SPINDLE AND/OR STRUT
LESS THAN SPECS	LESS THAN SPECS	LESS THAN SPECS	BENT CONTROL ARM OR STRUT TOWER OUT AT TOP, ALSO BENT SPINDLE AND/OR STRUT
GREATER THAN SPECS	LESS THAN SPECS	CORRECT	STRUT TOWER IN AT TOP
GREATER THAN SPECS	GREATER THAN SPECS	GREATER THAN SPECS	STRUT TOWER IN AT TOP AND BENT SPINDLE AND/OR BENT STRUT

KINGPIN TWIN I-BEAM SUSPENSION

SAI (KPI)	CAMBER	INCLUDED ANGLE	DIAGNOSIS
CORRECT	GREATER THAN SPECS	GREATER THAN SPECS	BENT SPINDLE
LESS THAN SPECS	GREATER THAN SPECS	CORRECT	BENT I-BEAM
LESS THAN SPECS	GREATER THAN SPECS	GREATER THAN SPECS	BENT I-BEAM AND SPINDLE
GREATER THAN SPECS	LESS THAN SPECS	CORRECT	BENT I-BEAM

Figure 93–14 By checking the SAI, camber, and included angle, a damaged suspension component can be determined by using this chart.

The chart in Figure 93–14 can be used to determine what is wrong if the alignment angles are known. Simply use the chart that correctly identifies the type of suspension on the problem vehicle.

in spec — The alignment angle is within specifications.

over spec — The alignment angle is greater or higher than specified by the manufacturer.

under spec — The alignment angle is less than or lower than specified by the manufacturer.

CHECKING FRAME ALIGNMENT OF FRONT-WHEEL-DRIVE VEHICLES

Many front-wheel-drive vehicles mount the drive train (engine and transaxle) and lower suspension arms to a subframe or cradle. If the frame is shifted either left or right, this can cause differences in SAI, included angle, and camber. See Figures 93–15 and 93–16. Adjust the frame if SAI and camber angles are different left and right side, yet the included angles are equal.

TYPES OF ALIGNMENTS

There are three types of alignment: geometric centerline, thrust line, and total four-wheel alignment.

Geometric Centerline Until the 1980s, most wheel alignment concerned only the front wheels. Vehicles, such as sports cars, that had independent rear suspensions were often aligned by backing the vehicle onto the alignment rack and adjusting the rear camber and/or toe. This type of alignment is simply an alignment that uses the **geometric centerline** of the vehicle as the basis for all measurements of toe (front or rear). See Figure 93–17.

This method is now considered to be obsolete.

Thrust Line A **thrust line** alignment uses the thrust angle of the rear wheels and sets the front wheels parallel to the thrust line. See Figure 93–18 on page 1189.

TECH TIP ✓ **Ask Yourself These Three Questions**

An older technician told a beginning technician that the key to success in doing a proper alignment is to ask yourself three questions about the alignment angles:

Question 1. **"Is it within specifications?"** For example, if the specification reads 1° ±1/2°, any reading between +1/2° and 1 1/2° is within specifications. All vehicles should be aligned within this range. Individual opinions and experience can assist the technician as to whether the actual setting should be at one extreme or the other or held to the center of the specification range.

Question 2. **"Is it within 1/2° of the other side of the vehicle?"** Not only should the alignment be within specifications, but it should also be as equal as possible from one side to the other. The difference between the camber from one side to the other side is called cross camber. Cross caster is the difference between the caster angle from one side to another. Some manufacturers and technicians recommend that this side-to-side difference be limited to just 1/4 degree!

Question 3. **"If the camber and caster cannot be exactly equal side-to-side in the front, is there more camber on the left and more caster on the right to help compensate for road crown?"** Seldom, if ever, are the alignment angles perfectly equal. Sometimes one side of the vehicle is more difficult to adjust than the other side. Regardless of the reasons, if there *has* to be a difference in front camber and/or caster angle, follow this advice to avoid a possible lead or drift problem even if the answers to the first two questions are "yes."

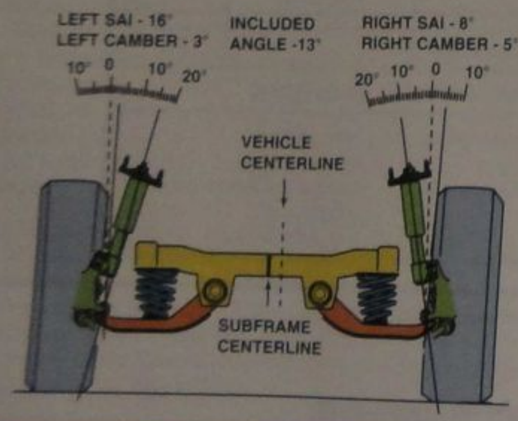


Figure 93–15 In this example, both SAI and camber are far from being equal side-to-side. However, both sides have the same included angle, indicating that the frame may be out of alignment. An attempt to align this vehicle by adjusting the camber on both sides with either factory or aftermarket kits would result in a totally incorrect alignment.

The thrust line is the bisector of rear total toe, or the actual direction in which the rear wheels are pointed. The rear wheels of any vehicle *should* be pointing parallel to the geometric centerline of the vehicle. However, if the rear toe angles of the rear wheels do not total exactly zero (perfectly in a line with the centerline of the vehicle), a thrust condition exists. The front wheels will automatically steer to become parallel to that condition. A crooked steering wheel may also result from an improper thrust condition.

NOTE: It has often been said that while the front wheels steer the vehicle, the rear wheels determine the direction in which the vehicle will travel. Think of the rear wheels as a rudder on a boat. When the rudder is turned, the direction of the boat changes due to the angle change at the rear of the boat.

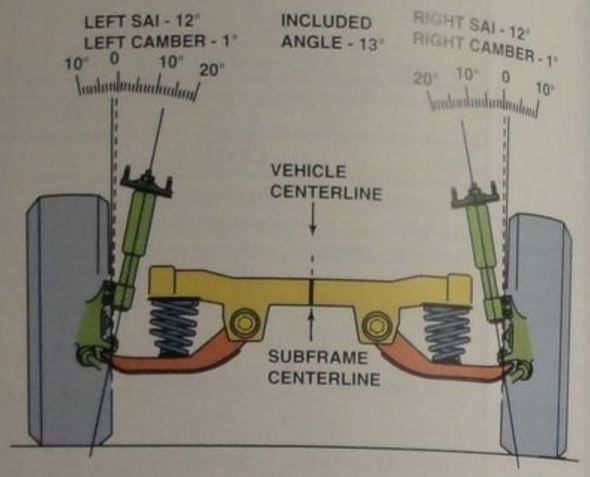


Figure 93–16 This is the same vehicle as shown in Figure 93–15, except now the frame (cradle) has been shifted over and correctly positioned. Notice how both the SAI and camber become equal without any other adjustments necessary.

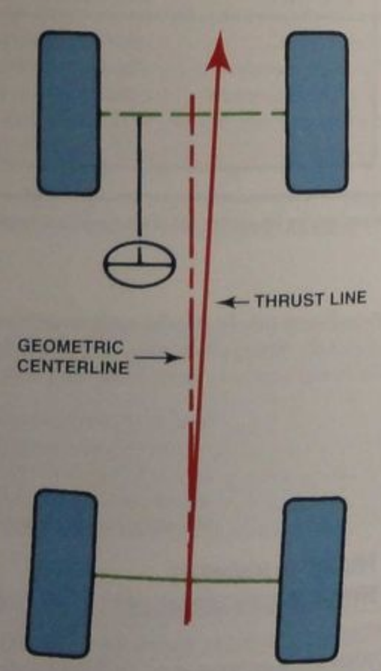


Figure 93–17 Geometric-centerline-type alignment sets the front toe readings based on the geometric centerline of the vehicle and does not consider the thrust line of the rear wheel toe angles. *(Courtesy of Hunter Engineering Company)*

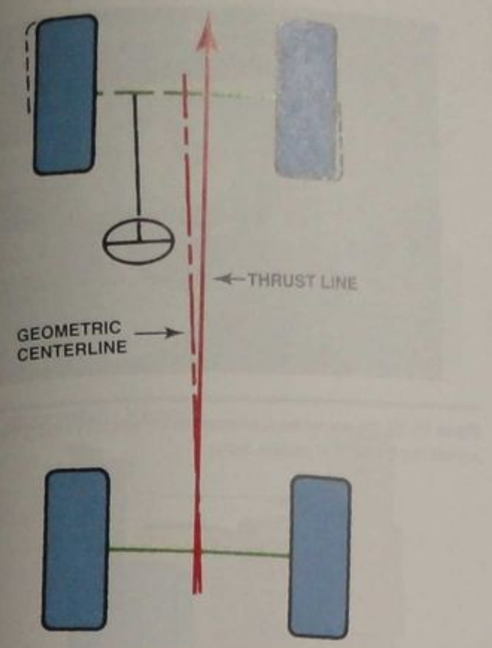


Figure 93–18 Thrust line alignment sets the front toe parallel with the rear-wheel toe. *(Courtesy of Hunter Engineering Company)*

Thrust line alignment is *required* for any vehicle with a nonadjustable rear suspension. If a vehicle has an adjustable rear suspension, then a total four-wheel alignment is necessary to ensure proper tracking.

Total Four-Wheel Alignment A total **four-wheel alignment** is the most accurate alignment method and is necessary to ensure maximum tire wear and vehicle handling. The biggest difference between a thrust-line alignment and a total four-wheel alignment is that the rear toe is adjusted to bring the thrust line to zero. In other words, the rear toe on both rear wheels is adjusted equally so that the actual direction in which the rear wheels are pointed is the same as the geometric centerline of the vehicle. See Figure 93–19.

The procedure for a total four-wheel alignment includes these steps:

1. Adjust the rear camber (if applicable).
2. Adjust the rear toe (this should reduce the thrust angle to near zero).
3. Adjust the front camber and caster.
4. Adjust the front toe, being sure that the steering wheel is in the straight-ahead position.

SAMPLE ALIGNMENT SPECIFICATIONS AND READINGS

The service technician must know not only all of the alignment angles but also the interrelationship that exists among the angles. As an aid toward understanding these relationships, two examples are presented: Example 1 gives the front wheel angles that are acceptable when compared with the specifications; Example 2 gives four-wheel alignment and readings of a vehicle that are not within specifications.

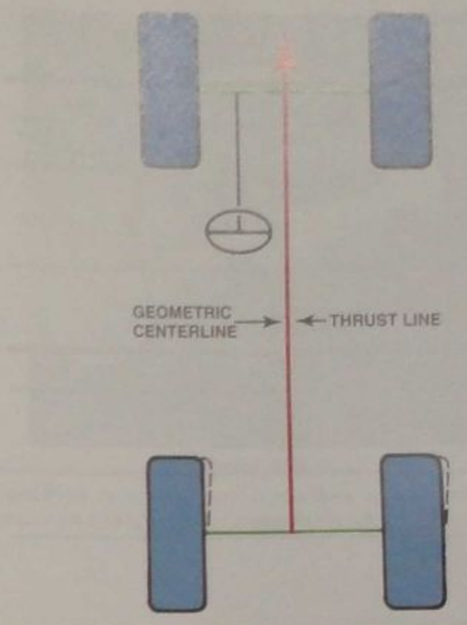


Figure 93–19 Four-wheel alignment corrects for any rear-wheel toe to make the thrust line and the geometric centerline of the vehicle both the same. *(Courtesy of Hunter Engineering Company)*

Example 1: Wheel Alignment

Alignment Specifications

	Left	Right
Camber =	+1/2° ± 1/2°	+1/2° ± 1/2°
Caster =	+1° ± 1/2°	+1° ± 1/2°
Toe (total) =	1/8 in. ± 1/16 in.	

Actual Reading

	Left	Right
Camber =	+1/4°	0°
Caster =	+1°	+1 1/4°
Toe (total) =	1/8 in.	

Answer:

Alignment is perfect:

a. No tire wear
b. No pulling

Explanation:

Camber is within specifications.

Camber is within 1/2-degree difference side-to-side.

Camber is not equal, but there is more camber on the left (1/4 degree) than on the right, thereby helping to compensate for the road crown.

Caster is within specifications.

Caster is within 1/2-degree difference side-to-side.

Caster is not equal, but there is more caster on the right (1/4 degree) than on the left, thereby helping (very slightly) to compensate for road crown.

Toe is within specifications.

Example 2: Four-Wheel Alignment

Specifications

	Left	Right
Front camber =	+1/4° ± 1/2°	0° ± 1/2°
Front caster =	+3° ± 1/2°	+1/2° ± 1/2°
Front toe (total) =	3/16 in. ± 1/16 in.	
Rear camber =	0° ± 1/4°	0° ± 1/4°
Rear toe =	0 in. ± 1/16 in.	

Actual Reading

	Left	Right
Front camber =	−1/2°	−1°
Front caster =	+2 3/4°	+2°
Front toe =	−1/8 in. (toe-out)	
Rear camber =	0°	+1/4°
Rear toe =	1 1/2° (toe-in)	

Answer:

Alignment is incorrect.

a. Left front tire will wear slightly on the inside edge.
b. Right front tire will wear on the inside edge.
c. Vehicle could tend to pull slightly to the left due to the camber difference (may not pull at all due to the pulling effect of the road crown).
d. Vehicle could tend to pull slightly to the right due to the caster difference (3/4 degree more caster on the left).
e. Overall pull could be slight toward the left because it requires four times the caster difference to have the same pulling forces as camber.
f. Tires could wear slightly on both the inside edges due to toe-out.
g. The negative camber of the present alignment puts a heavy load on the outer wheel bearing, if RWD, because the load is being carried by the smaller outer wheel bearing instead of the larger inner wheel bearing.

Conclusion:

The vehicle would wear the inside edges of both front tires.
The vehicle may or may not pull slightly to the left.
The vehicle would not act as stable while driving—possible wander.

ADJUSTING REAR CAMBER

Adjusting rear camber is the first step in the total four-wheel alignment process. Rear camber is rarely made adjustable, but can be corrected by using aftermarket alignment kits or shims. If rear camber is not correct, vehicle handling and tire life are affected. Before attempting to adjust or correct rear camber, carefully check the body and/or frame of the vehicle for accident damage, including the following:

1. Weak springs, torsion bars, or overloading (check ride height)
2. Bowed rear axle, trailing arm, or rear control arm
3. Suspension mount or body dimension not in proper location
4. Incorrectly adjusted camber from a previous repair

The cause of the incorrect rear camber could be accident-related and the body or frame may have to be pulled into correct position. See Figures 93-20 through 93-22 for examples of various methods used to adjust rear camber.

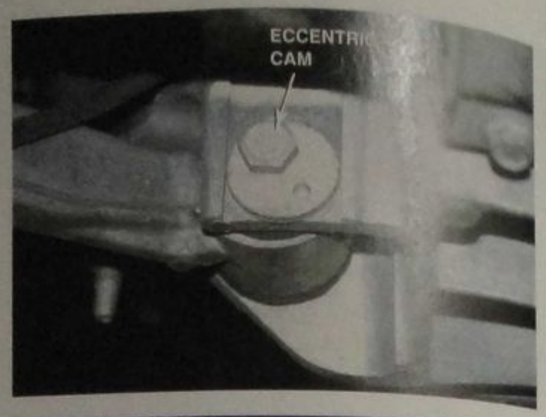


Figure 93–20 The rear camber is adjustable on this vehicle by rotating the eccentric cam and watching the alignment machine display.

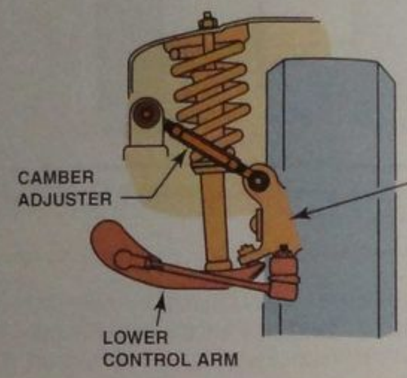


Figure 93–21 Some vehicles use a threaded fastener similar to a tie rod to adjust camber on the rear suspension.

Simple to Use

1. Take alignment readings and determine the change needed.
2. Select proper shims using the easy-to-read chart.
3. Using the template provided, mark and remove tabs to create a proper mounting bolt pattern.
4. Install shim.

TECH TIP ✔ **The Gritty Solution**

Many times it is difficult to loosen a Torx bolt, especially those used to hold the backing plate onto the rear axle on many GM vehicles. See Figure 93–23.

A technique that always seems to work is to place some valve grinding compound on the fastener. The gritty compound keeps the Torx socket from slipping up and out of the fastener, and more force can be exerted to break loose a tight bolt. Valve grinding compound can also be used on Phillips head screws as well as other types of bolts, nuts, and sockets.

Adjusting Rear Toe Many vehicle manufacturers provide adjustment for rear toe on vehicles that use an independent rear suspension. Rear toe adjusts the thrust angle. A thrust angle that exceeds 1/2 degree (0.5 degree) on a vehicle with a solid axle is an indication that a component may be damaged or out of place in the rear of the vehicle. Rear toe is often adjusted using an adjustable tie rod end or an eccentric cam on the lower control arm. Check a service manual for the exact method for the vehicle being aligned. Most solid rear axles do not have a method to adjust rear toe except for aftermarket shims or kits. See Figures 93-24 through 93-26.

NOTE: On vehicles equipped with four-wheel steering, refer to the service manual for the exact procedure to follow to lock or hold the rear wheels in position for a proper alignment check.

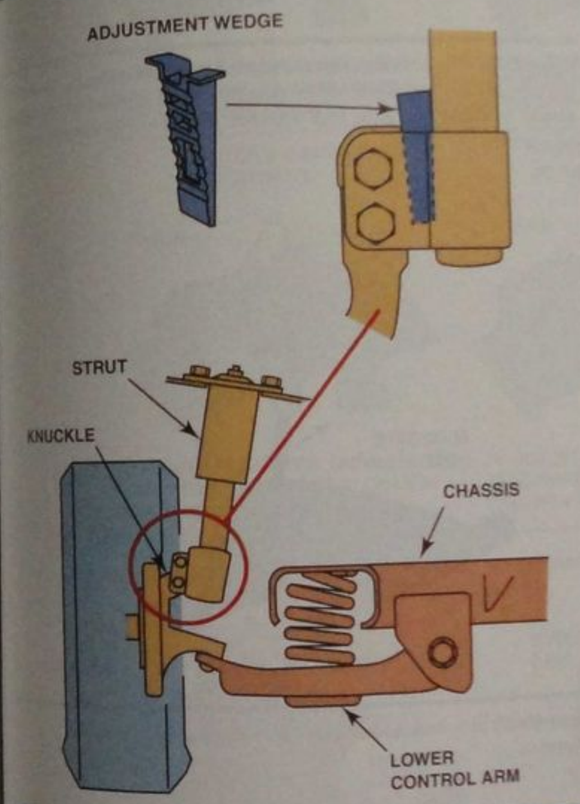


Figure 93–22 Aftermarket alignment parts or kits are available to change the rear camber.

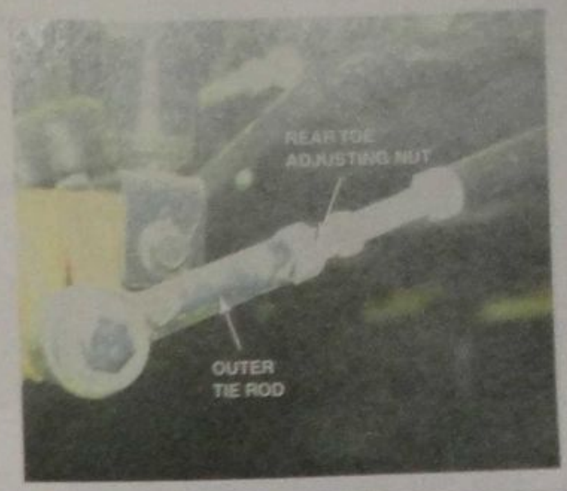


Figure 93–24 The rear toe was easily set on this vehicle. The adjusting nuts were easy to get to and turn. Adjusting rear toe is not this easy on every vehicle.

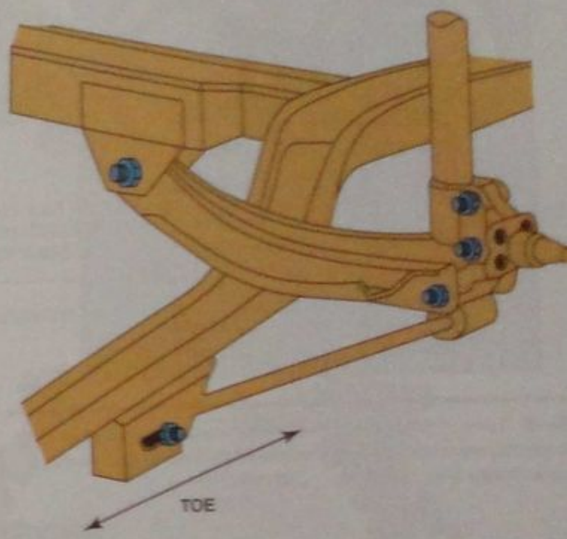


Figure 93–25 By moving various rear suspension members, the rear toe can be chang

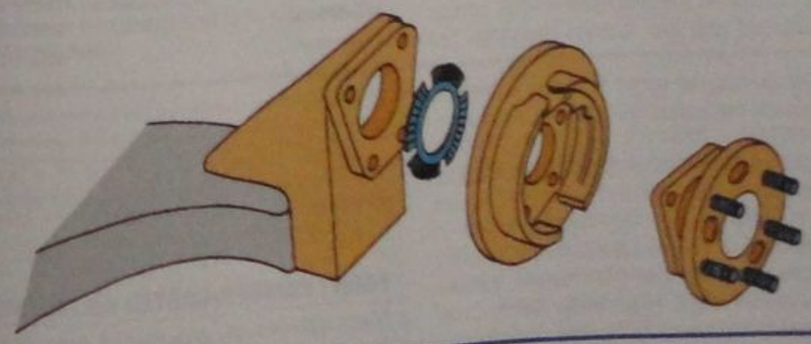


Figure 93–23 Full-contact plastic or metal shims can be placed between the axle housing and the brake backing plate to change rear camber, toe, or both. (Courtesy of Northstar Manufacturing Company, Inc.)

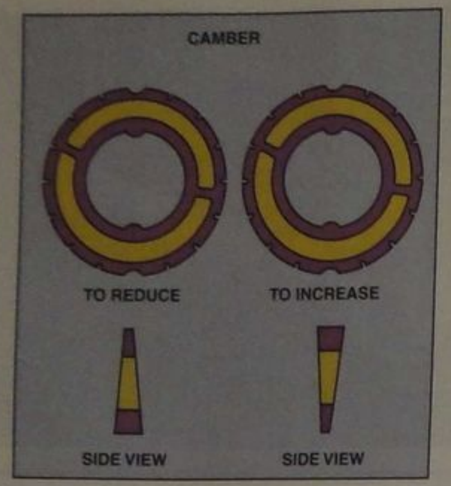


Figure 93–26 The use of these plastic or metal shims requires that the rear wheel as well as the hub assembly and/or backing plate be removed. Proper torque during reassembly is critical to avoid damage to the shims.

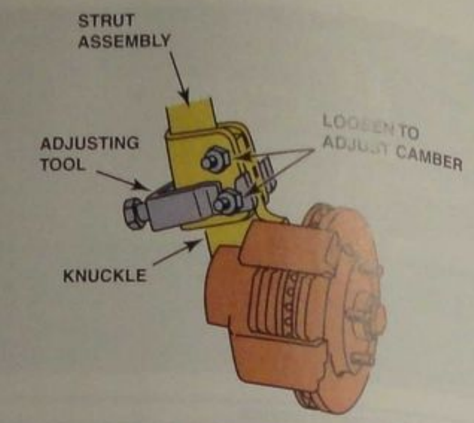


Figure 93–27 Many struts allow camber adjustment at the strut-to-knuckle fasteners. Here a special tool is being used to hold and move the strut into alignment with the fasteners loosened. Once the desired camber angle is achieved, the strut nuts are tightened and the tool is removed.

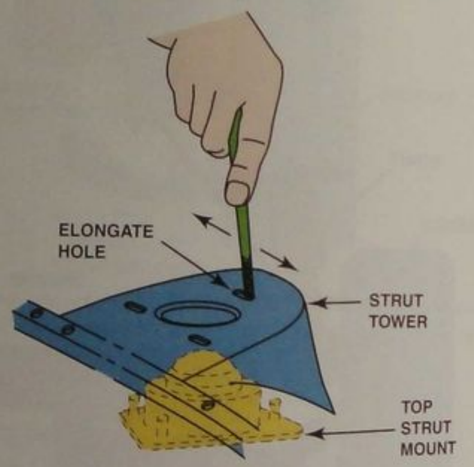


Figure 93–28 Some struts require modification of the upper mount for camber adjustment.

GUIDELINES FOR ADJUSTING FRONT CAMBER/SAI AND INCLUDED ANGLE

If the camber is adjusted at the base of the MacPherson strut, camber and included angle are changed and SAI remains the same. See Figure 93–27.

If camber is adjusted by moving the upper strut mounting location, included angle remains the same, but SAI and camber change. See Figure 93–28.

This is the reason to use the factory alignment methods before using an aftermarket alignment adjustment kit. SAI and included angle should be within 1/2 degree (0.5 degrees) side-to-side. If these angles differ, check the frame mount location before attempting to correct differences in camber. As the frame is changed, camber and SAI change, but the included angle remains the same. Cross camber/caster is the difference between the camber or caster on one side of the vehicle and the camber or caster on the other side of the vehicle.

Alignment Angle	Recommended Maximum Variation
SAI	Within 1/2° (0.5°) side-to-side
Included angle	Within 1/2° (0.5°) side-to-side
Cross camber	Within 1/2° (0.5°) side-to-side
Cross caster	Within 1/2° (0.5°) side-to-side

CAUTION: Do not attempt to correct a pull condition by increasing cross camber or cross caster beyond the amount specified by the vehicle manufacturer.

FRONT CAMBER/CASTER ADJUSTMENT METHODS

Many vehicles are constructed with only limited camber/caster factory adjustment. See Figure 93–29 for a summary of which adjustments are *generally* possible for various types of vehicles and suspension systems.

TOOLS AND ADJUSTMENT DEVICES MAY BE AVAILABLE FROM AFTERMARKET SUPPLIERS TO PERFORM ADJUSTMENTS IN CASES WHERE MANUFACTURERS DO NOT MAKE SUCH PROVISIONS.

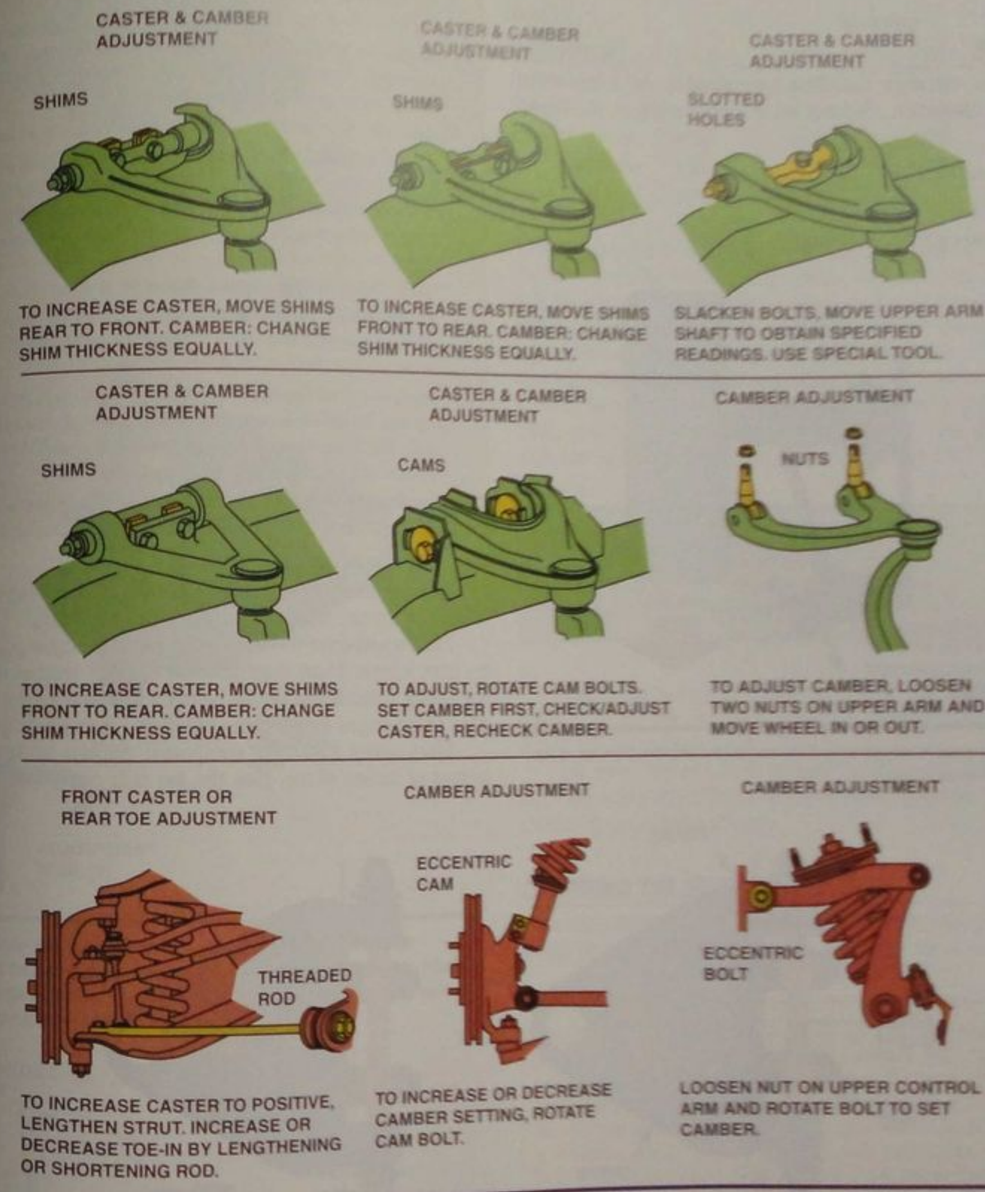


Figure 93–29 An example of the many methods that are commonly used to adjust front caster and camber.

CAUTION: Most vehicle manufacturers warn technicians not to adjust camber by bending the strut assembly. Even though several equipment manufacturers make tools that are designed to bend the strut, most experts agree that it can cause harm to the strut itself.

ADJUSTING FRONT CAMBER/CASTER

Most SLA-type suspensions can be adjusted for caster and camber. Most manufacturers recommend adjusting caster, then camber, before adjusting the toe. As the caster is changed, such as when the strut rod is adjusted as shown in Figure 93–30, the camber and toe also change.

If the camber is then adjusted, the caster is unaffected. Many technicians adjust caster and camber at the same time using shims (Figures 93–31 and 93–32 on page 1195), slots (Figure 93–33 on page 1195), or **eccentric cams** (Figure 93–34 on page 1195).

Always follow the manufacturer's recommended alignment procedure. For example, many manufacturers include a **shim chart** in their service manual that gives the thickness and location of the shim changes based on the alignment reading. Shim charts

are used to set camber and caster at the same time. Shim charts are designed for each model of vehicle. See Figure 93–35 on page 1196.

Regardless of the methods or procedures used, toe is always adjusted after all the angles are set because caster and camber both affect the toe.

SETTING TOE

Front toe is the last angle that should be adjusted and is the most likely to need correction. This has led to many sayings in the alignment field:

"Set the toe and let it go."

"Do a toe and go."

"Set the toe and collect the dough."

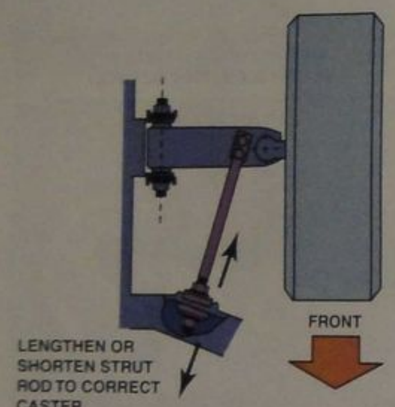


Figure 93–30 If there is a nut on both sides of the strut rod bushing, then the length of the rod can be adjusted to change caster.

TECH TIP ✔ **Race Vehicle Alignment**

Vehicles used in autocrossing (individual timed runs through cones in a parking lot) or road racing usually perform best if the following alignment steps are followed.

1. *Increase caster (+).* Not only will the caster provide a good solid feel for the driver during high speed on a straight section of the course, but it will also provide some lean into the corners due to the camber change during cornering. A setting of 5 to 9 degrees positive caster is typical depending on the type of vehicle and the type of course.
2. *Adjust for 1 to 2 degrees of negative camber.* As a race vehicle corners, the body and chassis lean. As the chassis leans, the top of the tire also leans outward. By setting the camber to 1 to 2 degrees negative, the tires will be neutral while cornering, thereby having as much rubber contacting the road as possible.

NOTE: Though setting negative camber on a street-driven vehicle will decrease tire life, the negative setting on a race vehicle is used to increase cornering speeds, and tire life is not a primary consideration.

3. *Set toe to a slight toe-out position.* When the front toe is set negative (toe-out), the vehicle is more responsive to steering commands from the driver. With a slight toe-out setting, one wheel is already pointed in the direction of a corner or curve. Set the toe-out to −3/8 to −1/2 degree depending on the type of vehicle and the type of race course.

As wear occurs at each steering joint, the forces exerted on the linkage by the tire tend to cause a toe-out condition.

Front-wheel-drive (FWD) vehicles transmit engine power through the front wheels. Many manufacturers of FWD vehicles specify a toe-out setting. This toe-out setting helps compensate for the slight toe-in effect of the engine torque being transferred through the front wheels.

Most newer alignment equipment displays in degrees of toe instead of inches of toe. (See the toe unit conversion chart.) Just

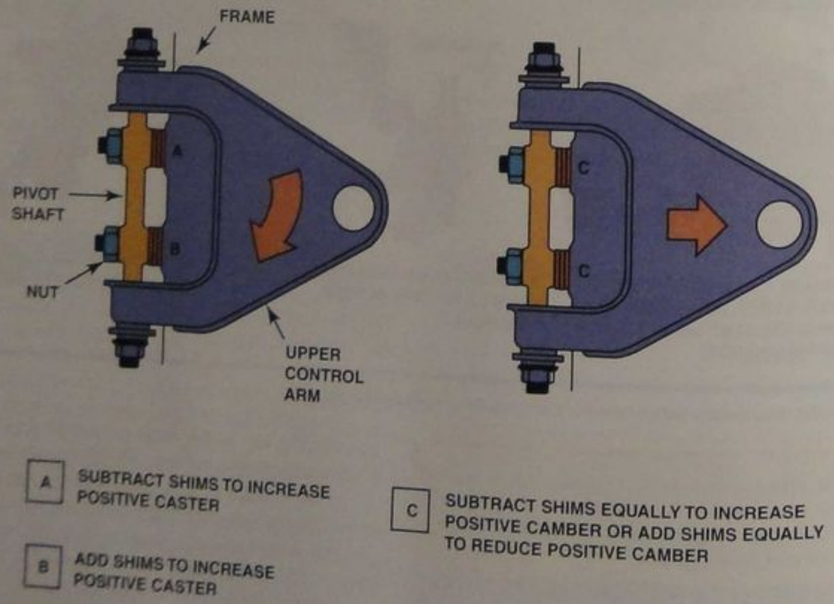


Figure 93–31 Placing shims between the frame and the upper control arm pivot shaft is a popular method of alignment for many SLA suspensions. Both camber and caster can be easily changed by adding or removing shims.

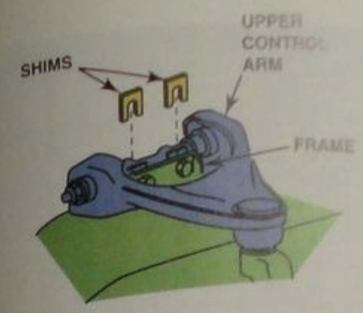


Figure 93–32 The general rule of thumb is that a 1/8-in. shim added or removed from both shim locations changes the camber angle about 1/2 degree. Adding or removing a 1/8-in. shim from one shim location changes the caster by about 1/4 degree.

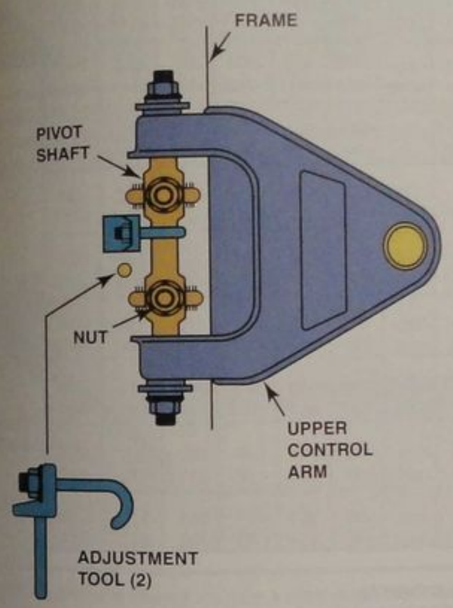


Figure 93–33 Some SLA-type suspensions use slotted holes for alignment angle adjustments. When the pivot shaft bolts are loosened, the pivot shaft is free to move unless held by special clamps as shown. By turning the threaded portion of the clamps, the camber and caster can be set and checked before tightening the pivot shaft bolts.

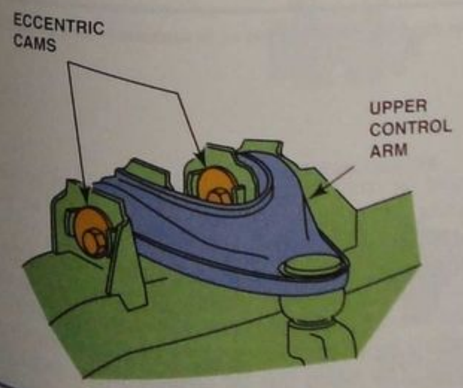


Figure 93–34 When the nut is loosened and the bolt on the eccentric cam is rotated, the upper control arm moves in and out. By adjusting both eccentric cams, both camber and caster can be adjusted.

remember that positive (+) toe means toe-in and negative (−) toe means toe-out.

Toe Unit Conversions

Units	Conversions			
Fractional inches	1/16 in.	1/8 in.	3/16 in.	1/4 in.
Decimal inches	0.062 in.	0.125 in.	0.188 in.	0.250 in.
Millimeters	1.60 mm	3.18 mm	4.76 mm	6.35 mm
Decimal degrees	0.125°	0.25°	0.375°	0.5°
Degrees and minutes	0°8'	0°15'	0°23'	0°30'
Fractional degrees	1/8°	1/4°	3/8°	1/2°

To make sure the steering wheel is straight after setting toe, the steering wheel *must* be locked in the straight-ahead position while the toe is being adjusted. Another term used to describe steering wheel position is **spoke angle.** To lock the steering wheel, always use a steering wheel lock that presses against the seat and the outer rim of the steering wheel. *Do not* use the locking feature of the steering column to hold the steering wheel straight. Always unlock the steering column, straighten the steering wheel, and install the steering wheel lock. See Figures 93–36 through 93–38 on page 1197.

NOTE: If the vehicle is equipped with power steering, the engine must be started and the steering wheel straightened with the engine running to be assured of a straight steering wheel. Lock the steering wheel with the steering lock tool before stopping the engine.

After straightening the steering wheel, turn the tie rod adjustment until the toe for both wheels is within specifications. See Figure 93–39 on page 1198.

Test drive the vehicle for proper handling and centerline steering. *Centerline steering* is a centered steering wheel with the vehicle traveling a straight course.

CENTERING THE STEERING WHEEL

Centerline steering *should* be accomplished by adjusting the tie rod length on both sides of the vehicle while the toe is set.

CAUTION: Do not attempt to straighten the steering wheel by relocating the wheel on the steering column on a vehicle with two tie rod end adjusters. The steering wheel is positioned at the factory in the center of the steering gear, regardless of type. If the steering wheel is not in the center, then the variable ratio section of the gear will not be in the center as it is designed. Another possible problem with moving the steering wheel from its designed straight-ahead position is that the turning radius may be different for right- and left-hand turns.

STEERING WHEEL REMOVAL

If the steering wheel *must* be removed, first disconnect the airbag wire connector at the base of the steering column. This reduces the chance of personal injury and prevents accidental airbag deployment.

CAUTION: Always follow the manufacturer's recommended procedures whenever working on or around the steering column.

DEGREES CASTER

DEGREES CAMBER	BOLT	+4.9°	+4.7°	+4.5°	+4.3°	+4.1°	+3.9°	+3.7°	+3.5K	+3.3°	+3.1°	+2.9°	+2.7°	+2.5°	+2.3°	2.1°
+2.2°	FRONT REAR	+300 +101	+211 +101	+211 +110	+210 +110	+210 +111	+201 +200	+201 +200	+201 +201	+200 +210	+200 +210	+111 +201	+111 +211	+110 +300	+110 +301	110 301
+2.0°	FRONT REAR	+210 +011	+210 +100	+210 +101	+201 +101	+201 +110	+200 +110	+200 +111	+111 +200	+111 +200	+110 +201	+110 +210	+110 +210	+101 +211	+101 +300	+100 300
+1.8°	FRONT REAR	+201 +010	+201 +011	+200 +011	+200 +100	+111 +101	+111 +101	+110 +110	+110 +110	+110 +111	+101 +200	+101 +200	+100 +201	+100 +210	+100 +210	+011 +211
+1.6°	FRONT REAR	+200 +001	+200 +001	+111 +010	+111 +011	+110 +011	+110 +100	+101 +100	+101 +101	+100 +110	+100 +110	+100 +111	+011 +200	+011 +200	+010 +201	+010 +210
+1.4°	FRONT REAR	+111 +000	+110 +000	+110 +001	+101 +001	+101 +010	+100 +011	+100 +011	+100 +100	+011 +100	+011 +101	+010 +110	+010 +110	+010 +111	+001 +200	+001 +200
+1.2°	FRONT REAR	+110 -010	+101 -001	+101 +000	+100 +000	+100 +001	+011 +001	+011 +010	+010 +011	+010 +011	+010 +100	+001 +101	+001 +101	+000 +110	-000 +111	-000 +111
+1.0°	FRONT REAR	+100 -011	+109 -010	+011 -010	+011 -001	+010 -000	+010 +000	+010 +001	+001 +001	+001 +010	+000 +011	-000 +011	-000 +100	-001 +101	-001 +101	-010 +110
+0.8°	FRONT REAR	+011 -100	+011 -100	+010 -011	+010 -010	+001 -010	+001 -001	+000 -001	-000 +000	-000 +001	-001 +001	-001 +010	-010 +011	-010 +011	-010 +100	-011 +101
+0.6°	FRONT REAR	+010 -101	+001 -101	+001 -100	+001 -100	+000 -011	-000 -010	-001 -010	-001 -001	-010 -001	-010 +000	-010 +001	-011 +001	-011 +010	-100 +011	-100 +011
+0.4°	FRONT REAR	+001 -111	+000 -110	+000 -101	-001 -101	-001 -100	-010 -100	-010 -011	-010 -010	-011 -010	-011 -001	-100 -000	-100 +000	-100 +001	-101 +010	-101 +010
+0.2°	FRONT REAR	-001 -200	-001 -111	-001 -111	-010 -110	-010 -101	-011 -101	-011 -100	-100 -100	-100 -011	-101 -010	-101 -010	-101 -001	-110 -000	-110 +000	-110 +001
+0.0°	FRONT REAR	-010 -201	-010 -201	-011 -200	-011 -111	-100 -111	-100 -110	-100 -101	-101 -101	-101 -100	-110 -100	-110 -011	-111 -010	-111 -010	-111 -001	-200 -000
-0.2°	FRONT REAR	-011 -210	-011 -210	-100 -201	-100 -201	-101 -200	-101 -111	-110 -111	-110 -110	-111 -101	-111 -101	-111 -100	-200 -100	-200 -011	-201 -010	-201 -010
-0.4°	FRONT REAR	-100 -300	-101 -211	-101 -210	-110 -210	-110 -201	-110 -201	-111 -200	-111 -111	-200 -111	-200 -110	-201 -101	-201 -101	-201 -100	-210 -011	-210 -011

1. DETERMINE VEHICLE'S CURRENT CASTER AND CAMBER MEASUREMENTS.
2. USING THE CURRENT CASTER READING, READ DOWN THE APPROPRIATE COLUMN TO THE LINES CORRESPONDING TO THE CURRENT CAMBER READING.
3. CORRECTION VALUES WILL BE GIVEN FOR THE FRONT AND REAR BOLTS.
   EXAMPLE: CURRENT READING +1.6° CASTER +0.4° CAMBER. BY READING DOWN THE CHART FROM +1.6° CASTER TO +0.4° CAMBER YOU WILL FIND THAT THE FRONT BOLT REQUIRES AN ADJUSTMENT OF -101 AND THE REAR BOLT REQUIRES AN ADJUSTMENT OF +010.

Figure 93–35 Typical shim alignment chart. As noted, 1/8-in. (0.125) shims can be substituted for the 0.120-in. shims; 1/32-in. (0.0625) shims can be substituted for the 0.060-in. shims, and 1/32-in. (0.03125) shims can be substituted for the 0.030-in. shims.

TECH TIP ✔ **Locking Pliers to the Rescue**

Many vehicles use a jam nut on the tie rod end. This jam nut must be loosened to adjust the toe. Because the end of the tie rod is attached to a tie rod end that is movable, loosening the nut is often difficult. Every time force is applied to the nut, the tie rod end socket moves and prevents the full force of the wrench from being applied to the nut. To prevent this movement, simply attach locking pliers (Vise Grips®) to hold the tie rod. Wedge the pliers against the control arm to prevent any movement of the tie rod. By preventing the tie rod from moving, full force can be put on a wrench to loosen the jam nut without doing any harm to the tie rod end.

Remove the center section of the steering column by removing the retaining screws, including the inflator module on vehicles equipped with an airbag.

After removal of the airbag inflator module, remove the steering wheel retaining nut. Note the locating marks on the steering wheel and steering shaft. See Figure 93–40 on page 1198. These marks indicate the proper position of the steering wheel for centerline steering. This means that the steering wheel spoke angle is straight and in line with the centerline position of the steering gear or rack-and-pinion steering unit.

Most steering wheels are attached to the steering shaft with a spline and a taper. After removing the steering wheel nut, use a



Figure 93–36 Many procedures for setting toe specify that the steering wheel be held in the straight-ahead position using a steering wheel lock, as shown. One method recommended by Hunter Engineering sets toe without using a steering wheel lock.

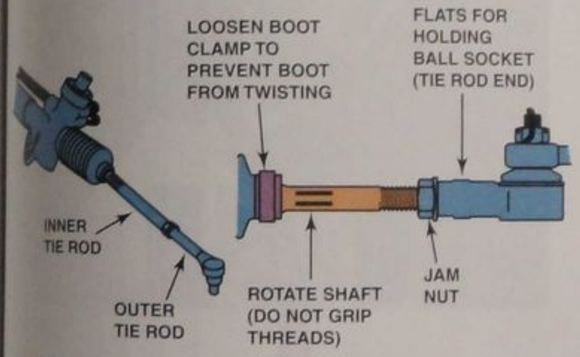


Figure 93–37 Adjusting toe by rotating the tie rod on a vehicle equipped with rack-and-pinion steering.

steering wheel puller to remove the steering wheel from the steering shaft. See Figure 93–41.

NOTE: Because of the taper, it is easier to remove a steering wheel if the steering wheel puller is struck with a dead-blow hammer. The shock often releases the taper and allows the easy removal of the steering wheel. Some technicians simply use their hands and pound the steering wheel from the taper without using a puller.

To reinstall the steering wheel, align the steering wheel in the desired straight-ahead position and slip it down over the splines. Install and tighten the retaining nut to specifications.

REAL WORLD FIX **Left Thrust Line, but a Pull to the Right!**

A new four-door sport sedan had been aligned several times at the dealership in an attempt to solve a pull to the right. The car had front-wheel-drive and four-wheel independent suspension. The dealer rotated the tires, and it made no difference. The alignment angles of all four wheels were in the center of specifications. The dealer even switched all four tires from another car in an attempt to solve the problem.

In frustration, the owner took the car to an alignment shop. Almost immediately the alignment technician discovered that the right rear wheel was slightly toed-in. This caused a pull to the right. See Figure 93–42.

The alignment technician adjusted the toe on the right rear wheel and reset the front toe. The car drove beautifully.

The owner was puzzled about why the new car dealer was unable to correct the problem. It was later discovered that the alignment machine at the dealership was out of calibration by the exact amount that the right rear wheel was out of specification. The car pulled to the right because the independent suspension created a rear steering force toward the left that caused the front to pull to the right. Alignment equipment manufacturers recommend that alignment equipment be calibrated regularly.

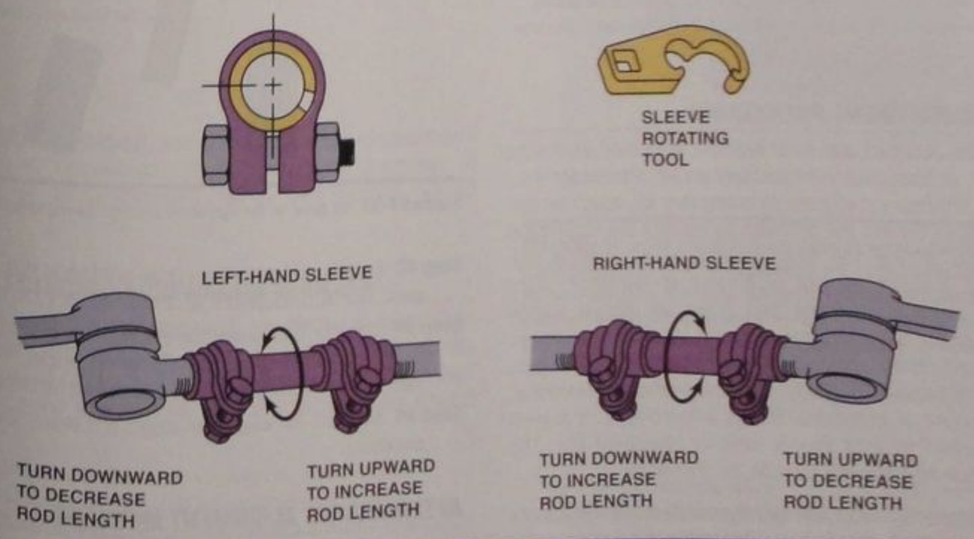


Figure 93–38 Toe is adjusted on a parallelogram-type steering linkage by turning adjustable tie rod sleeves. Special tie rod sleeve adjusting tools should be used that grip the slot in the sleeve and will not crush the sleeve while it is being rotated.

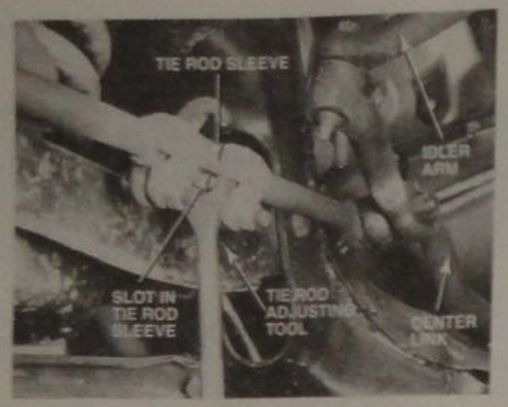


Figure 93–39 Special tie rod adjusting tools should be used to rotate the tie rod adjusting sleeves. The tool grips the slot in the sleeve and allows the service technician to rotate the sleeve without squeezing or damaging the sleeve.

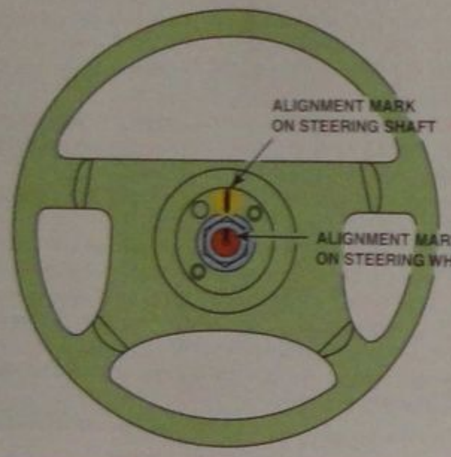


Figure 93–40 Most vehicles have alignment marks made at the factory on the steering shaft and steering wheel to help the service technician keep the steering wheel in the center position.

TOLERANCE ADJUSTMENT PROCEDURE

Many vehicles are designed and built without a method to change caster or camber, or both. (All vehicles have an adjustment for toe.) Before trying an aftermarket alignment correction kit, many technicians first attempt to correct the problem by moving the suspension attachment points within the build tolerance. All vehicles are constructed with a slight amount of leeway or tolerance; slight corrections can be made because bolt holes are almost always slightly larger than the bolt diameter, allowing for slight movement. When several fasteners are involved, such as where the power train cradle (subframe) attaches to the body of the front-wheel-drive vehicle, a measurable amount of alignment change (often over 1/2 degree) can be accomplished without special tools or alignment kits. The steps for **tolerance adjustment** include the following:

Step #1 Determine which way the suspension members have to be moved to accomplish the desired alignment—for example, the right front may require more positive camber to correct a pulling or tire wear problem.

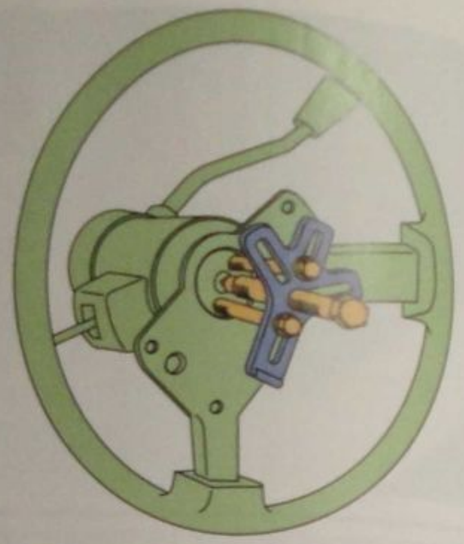


Figure 93–41 A puller being used to remove a steering wheel after the steering wheel retaining nut has been removed.

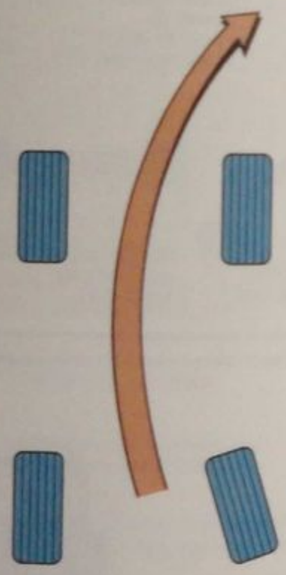


Figure 93–42 The toe-in on the right wheel creates a turning force toward the right.

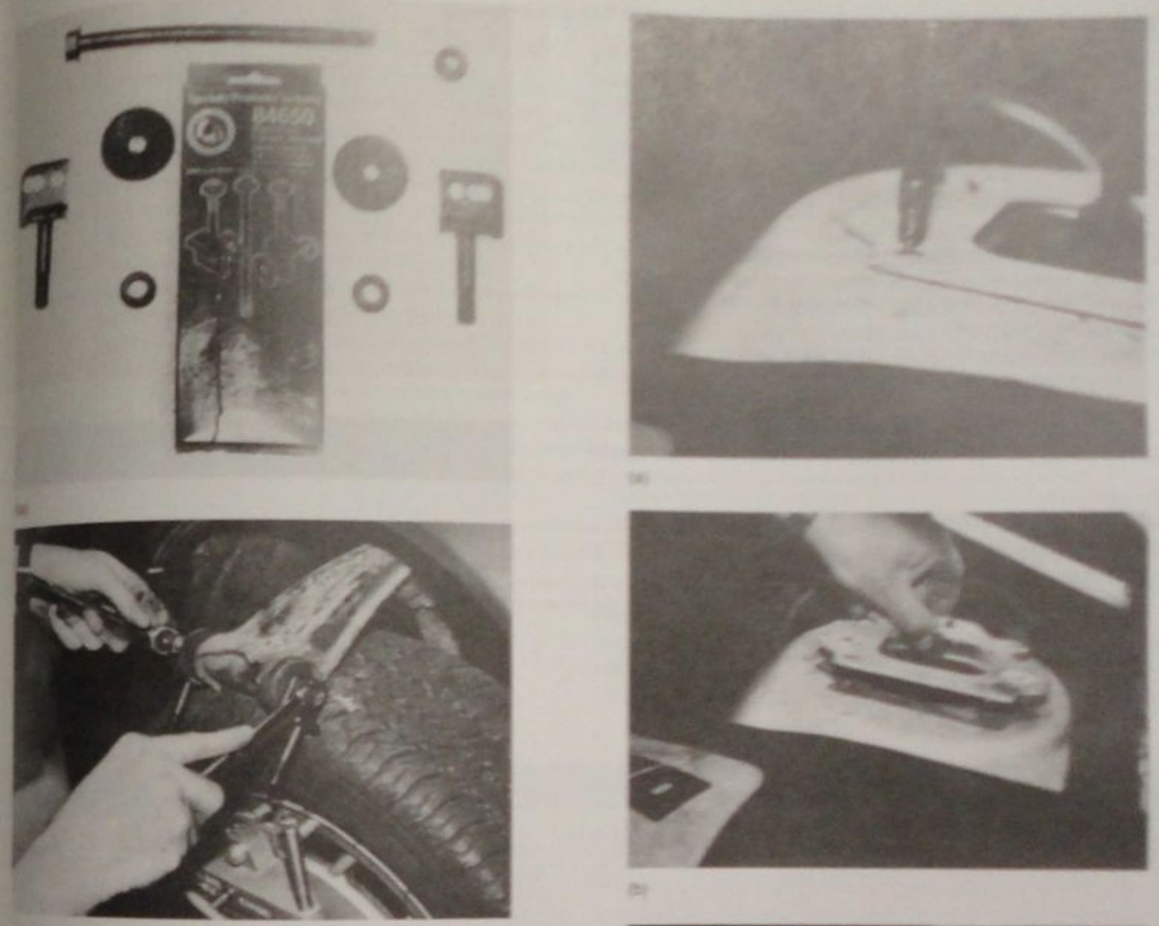
Step #2 Locate and loosen the cradle (subframe) bolts about four turns each. DO NOT REMOVE ANY OF THE BOLTS.

Step #3 Using prybars, move the cradle in the direction that will result in an improvement of the alignment angles. Have an assistant tighten the bolts as pressure is maintained on the cradle.

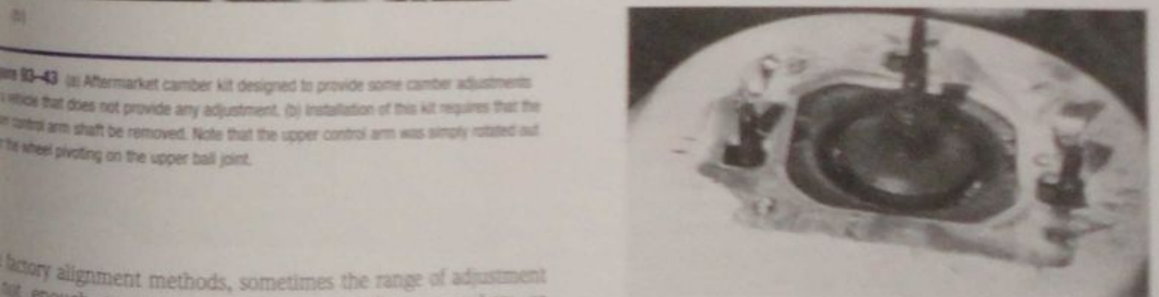
Step #4 Measure the alignment angles and repeat the procedure if necessary.

AFTERMARKET ALIGNMENT METHODS

Accurate alignments are still possible on vehicles without factory methods of adjustment by using alignment kits or parts. Aftermarket alignment kits are available for most vehicles. Even when there



(a)



(b)

Figure 93–43 (a) Aftermarket camber kit designed to provide some camber adjustments for a vehicle that does not provide any adjustment. (b) Installation of this kit requires that the upper control arm shaft be removed. Note that the upper control arm was simply rotated out and the wheel pivoting on the upper ball joint.

are factory alignment methods, sometimes the range of adjustment is not enough to compensate for sagging frame members or other normal or accident-related faults. See Figures 93–43 and 93–44.

ALIGNING ELECTRONIC-SUSPENSION VEHICLES

When aligning a vehicle equipped with an electronic suspension, several additional steps may be required. Always check service information and read carefully all on-screen instructions on the alignment machine. Some examples of the steps that may be needed include:

- Verify the exact type of electronic suspension. This step could include checking the regular production order (RPO) code.
- Check that the ride height (suspension height) is within factory specifications.
- The steering wheel angle, as well as the radar cruise control sensor, will often need to be recalibrated using a scan tool. This is needed

(a)

(b)

(c)

Figure 93–44 (a) The installation of some aftermarket alignment kits requires the use of special tools such as this cutter being used to drill out spot welds on the original alignment plate on a strut tower. (b) Original plate being removed. (c) Note the amount of movement the upper strut bearing mount has around the square openings in the strut tower. An aftermarket plate can now be installed to allow both camber and caster adjustment.

because the steering wheel may be in a different position after the alignment, and the steering wheel position sensor needs to be reset because the rear toe setting was changed. The rear thrust line could also have been changed. The radar cruise control needs to be calibrated to the revised rear thrust angle using a scan tool.

ALIGNING MODIFIED VEHICLES

If different springs were installed which in turn changes the suspension height or if larger or smaller wheels and tires were installed, many alignment shops would reject doing an alignment. If a shop attempted to align a vehicle handling and tire wear problems were common. Because the ride height is changed from stock factory setting, the following can occur:

1. The steering axis inclination (SAI) is now incorrect.
2. Because the steering linkage and the control arms are no longer parallel, bump steer can occur. Bump steer causes the vehicle to dart to one side when a wheel hits a bump.
3. Because the ride height changed, camber and toe also changed. The camber change is often enough to prevent it from being able to be adjusted to within specifications.

Alignment alone will not correct these concerns. To allow for proper handling, the following aftermarket kits and parts are available:

- **Camber kits**—These kits usually include a replacement control arm or offset cam, which provides additional camber adjustment.
- **Bump steer kits**—A bump steer kit can include a modified steering arm or rack-and-pinion steering gear repositioning components.

The kits available can be found listed on the alignment screen of many newer alignment machines, such as the Hunter Engineering Company's WinAlign Tuner Custom Alignment for Modified Vehicles. During part of this alignment, the technician has to select one of two options:

- Maximum tire wear
- Maximum handling

Therefore, the technician has to determine from the customer which of these two parameters are most important. After the alignment, the instructions often state that the vehicle should be driven and then the temperature of the tires measured and recorded. Using a tire pyrometer, be sure to measure the temperature of each tire at the following locations for each tire:

- Approximately 1.5 inches (38 mm) from the outside edge of the tire in the tread rubber
- In the middle of the tread
- Approximately 1.5 inches (38 mm) from the inside edge of the tire in the tread rubber

The temperatures are then typed into the alignment machine, and the program calculates the final alignment settings. See Figure 93–45.

HIDDEN STRUCTURAL DAMAGE DIAGNOSIS

Many accidents result in hidden structural damage that can cause alignment angles to be out of specification. If alignment angles are out of specification tolerances, then accident damage should be suspected. Look for evidence of newly replaced suspension parts, body work, or repainted areas of the body. While a body and/or frame of a vehicle can be straightened, it must be done by a knowledgeable person using body-measuring equipment.

The first thing that must be done is to determine a *datum plane*. Datum means a basis on which other measurements can be based. The datum plane is the horizontal plane.

However, most alignment technicians do not have access to body/frame alignment equipment. The service technician can use a common steel rule to measure several points of the vehicle to determine if the vehicle is or is not damaged or needs to be sent to a frame shop for repair.

TECH TIP ✓ **TSBs Can Save Time**

Technical service bulletins (TSBs) are issued by vehicle and aftermarket manufacturers to inform technicians of a situation or technical problem and give the corrective steps and a list of parts needed to solve the problem.

TSBs are often released by new vehicle manufacturers to the dealership service department. They usually concern the current-year vehicle of a particular model. While many of these TSBs concern minor problems covering few vehicles, many contain very helpful solutions to hard-to-find problems.

Most TSBs can be purchased directly from the manufacturer, but the cost is usually very high. TSBs can also be purchased through aftermarket companies that are licensed to include TSBs on CD-ROM computer discs. Factory TSBs can often save the technician many hours of troubleshooting.

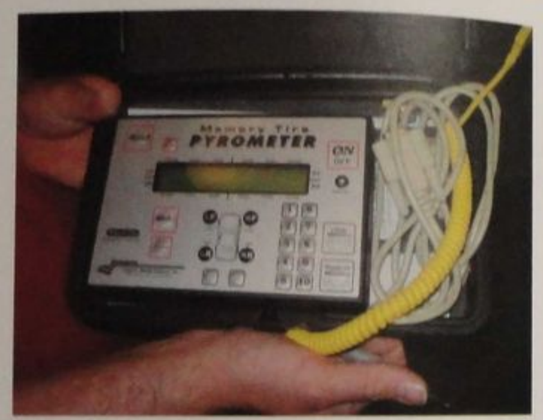


Figure 93–45 A typical tire temperature pyrometer. The probe used is a needle that penetrates about 1/4 inch (7 mm) into the tread of the tire for most accurate readings.

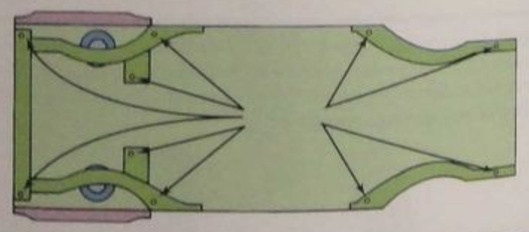


Figure 93–46 Jig holes used at the assembly plant to locate suspension and drive train components.

Frame/Body Diagonals If the frame or body is perfectly square, then the diagonal measurements should be within 1/8 in. (3 mm) of each other. See Figure 93–46.

While there are specified measurement points indicated by the manufacturer, the diagonal measurements can be made from almost any point that is repeated exactly on the other side, such as the center of a bolt in the suspension mounting bracket.

ALIGNMENT TROUBLESHOOTING

The following table lists common alignment problems and their probable causes.

Symptom-Based Alignment Guide

Problem	Probable Causes
Uneven tire pressure, tire rotation, mismatched tires, unequal camber, unequal caster, brake drag, setback, suspension/frame sag, unbalanced power assist, bent spindle, bent strut, worn suspension components (front or rear), rear suspension misalignment
Incorrect individual or total toe, rear wheel misalignment, excessive suspension or steering component play, worn rack-and-pinion attachment bushings, individual toe adjusters not provided
Improper tire pressure, binding steering gear or steering linkage, low P/S fluid, excessive positive caster, lack of lubrication, upper strut mount(s), worn power steering pump, worn P/S belt
Loose wheel bearings, worn steering or suspension components, loose steering gear mount, excessive steering gear play, loose or worn steering coupler
Excessive positive caster, excessive negative camber, improper tire inflation, too wide wheel/tire combination for the vehicle, worn or loose shocks, worn springs
Incorrect camber or caster, bent spindle or strut, binding suspension or steering components, improper tire inflation
Incorrect alignment, defective or improperly inflated tires, worn steering or suspension parts, bent spindle or strut, worn or loose steering gear, loose wheel bearings
Defective or improperly inflated tires, incorrect turning angle (TOOT), bent steering arms, excessive wheel setback, poor driving habits (too fast for conditions), worn suspension or steering parts
Loose or broken stabilizer bar links or bushings, worn shocks or mountings, broken or sagging springs, uneven vehicle load, uneven or improper tire pressure
Binding steering linkage, binding steering gear, binding upper strut mount, ball joint, or kingpin
Misalignment of steering linkage, bent steering arm or frame, defective or sagged springs, uneven load, bent spindle or strut
Bent spindle or strut, bent steering arm, misaligned frame, worn torque strut, defective engine or transaxle mounts, drive axle misalignment, mismatched or unequally inflated tires

PHOTO SEQUENCE Alignment Step-by-Step



P93–1 Begin the alignment procedure by first driving the vehicle onto the alignment rack as straight as possible.



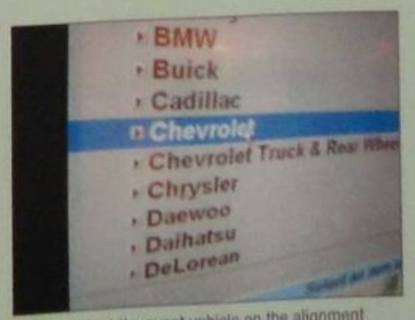
P93–2 Position the front tires in the center of the turn plates. These turn plates can be moved inward and outward to match a vehicle of any width.



P93–3 Raise the vehicle and position the alignment rack following the rack manufacturer's instructions.



P93–4 Check and adjust tire pressures and perform any preliminary checks necessary to be assured of proper alignment.



P93–5 Select the exact vehicle on the alignment machine.



P93–6 Securely mount the alignment heads or target wheels.

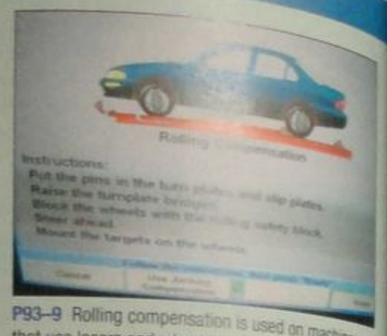
(continued)



P93–7 If mounting a transmitter-type alignment head, be sure to attach the retaining wire to the tire valve.



P93–8 After installation of the heads, follow the specified procedure for compensation, which allows accurate alignment readings.



P93–9 Rolling compensation is used on machines that use lasers and wheel targets.



P93–10 An alignment reading is displayed even though caster has not yet been measured. The readings marked in red indicate that they are not within specifications.



P93–11 Before performing a caster sweep, install a brake pedal depressor to keep the front wheels from rotating when the steering wheel is turned.



P93–12 Perform the caster sweep by turning the front wheels inward, and then outward following the instructions on the screen.



P93–13 Most alignment machines will display where to make the alignment correction and will often include drawings and live-action videos that show the procedure.



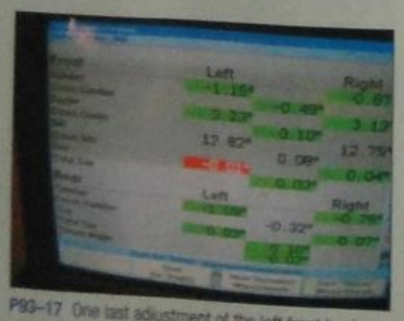
P93–14 The rear toe is being adjusted by rotating the eccentric cam on the lower control arm while watching the display.



P93–15 The alignment machine display indicates that front caster is not a factory-adjustable angle.



P93–16 Adjusting the front toe on this vehicle involves loosening the jam nut (left wrench) and rotating the tie rod using the right wrench.



P93–17 One last adjustment of the left front toe is needed to achieve a perfect alignment. The final alignment reading can be printed and attached to the work order.



P93–18 After disconnecting all of the attachments, reinstalling the valve caps, and removing the steering wheel holder, the vehicle should be test driven to check for proper alignment before returning it to the customer.

SUMMARY

1. Before attempting to align any vehicle, it must be checked for proper ride height (trim height), tire conditions, and tire pressures. A thorough inspection of all steering and suspension components must also be made.
2. Memory steer is a condition that causes the vehicle to lead or pull to the same direction it was last steered. Binding steering or suspension components are the most frequent causes of memory steer.
3. Torque steer is the pull or lead caused by engine torque being applied to the front wheels unevenly on a front-wheel-drive vehicle. Out-of-level drive train, suspension components, or tires are the most common causes of excessive torque steer.
4. Lead/pull diagnosis involves a thorough road test and careful inspection of all tires.
5. There are three types of alignment: geometric centerline, thrust line, and total four-wheel alignment. Only total four-wheel alignment should be used on a vehicle with an adjustable rear suspension.
6. The proper sequence for a complete four-wheel alignment is rear camber, rear toe, front camber and caster, and front toe.

REVIEW QUESTIONS

1. List 10 prealignment checks that should be performed before the wheel alignment is checked and/or adjusted.
2. Describe the difference between a lead (drift) and a pull.
3. Explain the causes and possible corrections for torque steer.
4. Explain the causes and possible corrections for memory steer.
5. List the necessary steps to follow for a four-wheel alignment.

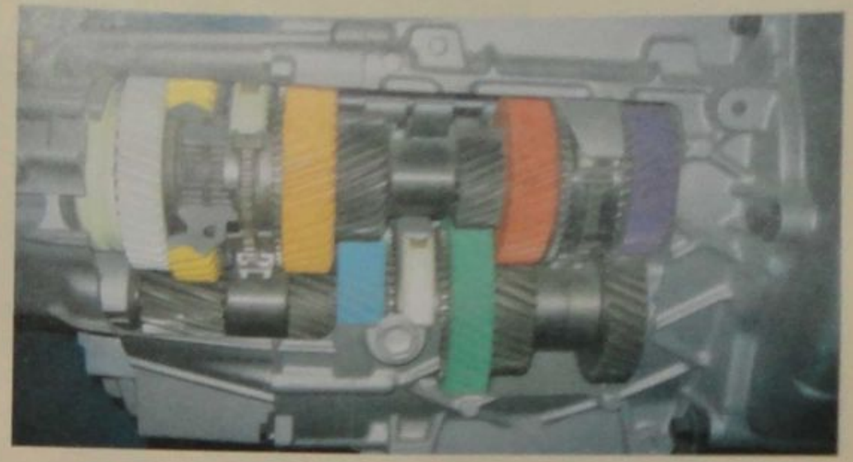
CHAPTER QUIZ

1. When performing an alignment, which angle is the most important for tire wear?
   a. Toe
   b. Camber
   c. Caster
   d. SAI (KPI)
2. Replacement rubber control arm bushings should be _____.
   a. Tightened while the control arm is held in a vise
   b. Torqued with the vehicle on the ground in normal driving position
   c. Tightened with the control arm resting on the frame
   d. Lubricated with engine oil before tightening
3. Which alignment angle is adjustable on all vehicles?
   a. Camber
   b. Caster
   c. Toe
   d. SAI (KPI)
4. Positive (+) toe is _____.
   a. Toe-in
   b. Toe-out
5. If the top of the steering axis is tilted 2 degrees toward the rear of the vehicle, this is _____.
   a. Positive camber
   b. Negative camber
   c. Negative caster
   d. Positive caster
6. Which angle is largest?
   a. 0.55 degrees
   b. 1/4 degree
   c. 45 minutes
   d. 1/2 degree
7. If the turning radius (toe-out on turns, or TOOT) is out of specification, what part or component is defective?
   a. The strut is bent.
   b. The steering arm is bent.
   c. The spindle is bent.
   d. The control arm is bent.
8. Which angle determines the thrust angle?
   a. Front toe
   b. Rear toe
   c. Rear camber
   d. Front caster, SAI, and included angle
9. The proper order in which to perform a four-wheel alignment is _____.
   a. Front camber, caster toe, rear camber, then rear toe
   b. Rear camber, front camber, caster, front toe, then rear toe
   c. Rear camber and toe, front camber, caster, then front toe
   d. Front toe, camber, front caster, rear camber, then rear toe
10. Centerline steering is achieved by correctly adjusting _____.
    a. Rear and front toe
    b. SAI and included angle
    c. Caster and SAI
    d. Rear camber

SECTION XIII

Manual Drive Train and Axles

94 Clutches
95 Manual Transmissions/Transaxles
96 Drive Axle Shafts and CV Joints
97 Drive Axle Shaft and CV Joint Service
98 Differentials
99 Four-Wheel Drive and All-Wheel Drive



CHAPTER 94

Clutches

OBJECTIVES: After studying Chapter 94, the reader will be able to: Prepare for ASE Manual Drive Train and Axles (A3) certification test content area "B" (Clutch Diagnosis and Repair). • List the parts that are included in the clutch system. • Describe how the clutch works. • Explain the importance of proper clutch pedal freeplay. • List the steps necessary to replace a clutch. • Describe the characteristic noise each clutch component part makes when defective.

KEY TERMS: bushing • candlestick • clutch disc • coil spring clutch • cushioning spring • front bearing retainer • lever style (pressure plate) • marcel spring • pilot bearing • pressure plate • quill • quill shaft • release bearing • slave cylinder • throwout bearing • torsional dampers

PURPOSE AND FUNCTION OF A CLUTCH

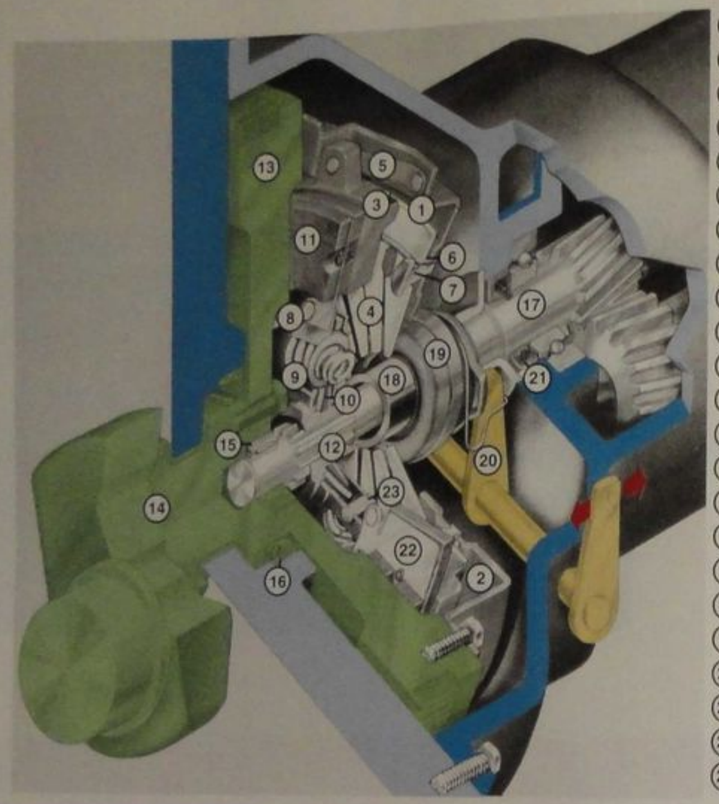
The clutch assembly is located between the engine and the transmission/transaxle. The purpose and function of a clutch include the following:

- To disconnect the engine from the transmission/transaxle to permit the engine to remain running when the vehicle is stopped and to permit the transmission/transaxle to be shifted
- To connect and transmit engine torque to the transmission/transaxle
- To dampen and absorb engine impulses and drive train vibration
- To provide a smooth engagement and disengagement between the engine and the transmission/transaxle

NOTE: The term *transmission* refers to rear-wheel-drive vehicles and the term *transaxle* usually refers to front-wheel-drive vehicles that have a differential built into the unit. A separate differential is used with a transmission.

COMPONENT PARTS AND OPERATION OF A CLUTCH ASSEMBLY

A clutch assembly consists of a **clutch disc** that is splined to the input shaft of the transmission/transaxle. When the driver depresses the clutch pedal, a **throwout bearing (release bearing)** is forced against the fingers of the **pressure plate.** The pressure plate is bolted to and rotates with the flywheel. See Figure 94–1. When force is exerted on the center of the pressure plate, the pressure is released from the clutch disc that has been forced against the engine flywheel. With the pressure removed from the clutch disc, the engine can be operated without transferring torque to the transmission/transaxle. This also permits the transmission/transaxle to be shifted



1. CLUTCH PRESSURE PLATE
2. CLUTCH COVER
3. PRESSURE PLATE
4. DIAPHRAGM SPRING
5. LEAF SPRINGS/STRAPS
6. PIVOT RING
7. DIAPHRAGM RIVET
8. DISC PLATE
9. TORSION DAMPER
10. FRICTION DEVICE
11. CLUTCH FACING
12. HUB
13. FLYWHEEL
14. CRANKSHAFT
15. PILOT BEARING
16. MAIN SEAL (CRANK)
17. TRANSMISSION SHAFT
18. QUILL
19. THROW-OUT BEARING
20. RELEASE FORK
21. SHAFT SEAL
22. CUSHION SEGMENT
23. STOP PIN

Figure 94–1 Typical automotive clutch assembly showing all related parts. *(Courtesy of LUK)*

because a shift cannot be made if the transmission/transaxle is transferring engine torque.

When the driver reduces force on the clutch pedal, the pedal return spring and the pressure plate spring combine to return the clutch pedal to its at-rest position (clutch-engaged position). When the clutch pedal moves up, the pressure on the throwout bearing is released and the force against the pressure plate spring(s) is released allowing the force of the pressure plate to clamp the clutch tightly between the flywheel and the pressure plate. See Figure 94–2.

Additional related parts include the **pilot bearing** (or **bushing**) that supports the front of the transmission input shaft. See Figure 94–3. The throwout bearing is often supported and rides on the transmission/transaxle **front bearing retainer** (also called the **quill**).

NOTE: Most front-wheel-drive transaxles do not use a pilot bearing.

To summarize:

- When the clutch pedal is up, the clutch is engaged.
- When the clutch pedal is down, the clutch is disengaged.

Clutch Pedal Linkage There are three methods of transferring the force of the driver's foot to the throwout (release) bearing, including:

- **Levers and rods.** Through a series of levers and rods, the release fork is forced against the throwout bearing. This method was commonly used on many older vehicles.
- **Cable operation.** A cable is used similar to a brake cable used on a bicycle. See Figure 94–4.
- **Hydraulic.** A small master cylinder and a **slave cylinder** located near the throwout bearing is a very common method of connecting the clutch pedal to the release fork on vehicles equipped with a manual transmission. See Figures 94–5 and 94–6.

Clutch Disc The clutch disc is round with a splined center hole that slips over the splines of the input shaft of the transmission/transaxle. Friction material is riveted to both sides of the clutch disc—one side touches the flywheel of the engine and the other side touches the friction surface of the pressure plate.

Friction material is either woven or molded from a mixture of other materials. Woven materials are softer and help cushion clutch engagement, but they may not last as long as molded materials.

Friction materials operate in high heat and pressure. For many years, asbestos was the most common material used in both clutch and brake linings. However, it is no longer used because inhaling tiny particles of asbestos causes lung damage. Today, clutch friction material may contain paper, cotton, and bits of copper or brass wire with resin holding the mixture together.

CAUTION: Always take precautions when working around clutch lining material and assume that it contains asbestos. These precautions should include wetting the friction disc before removal and preventing any dust from the lining from becoming airborne.

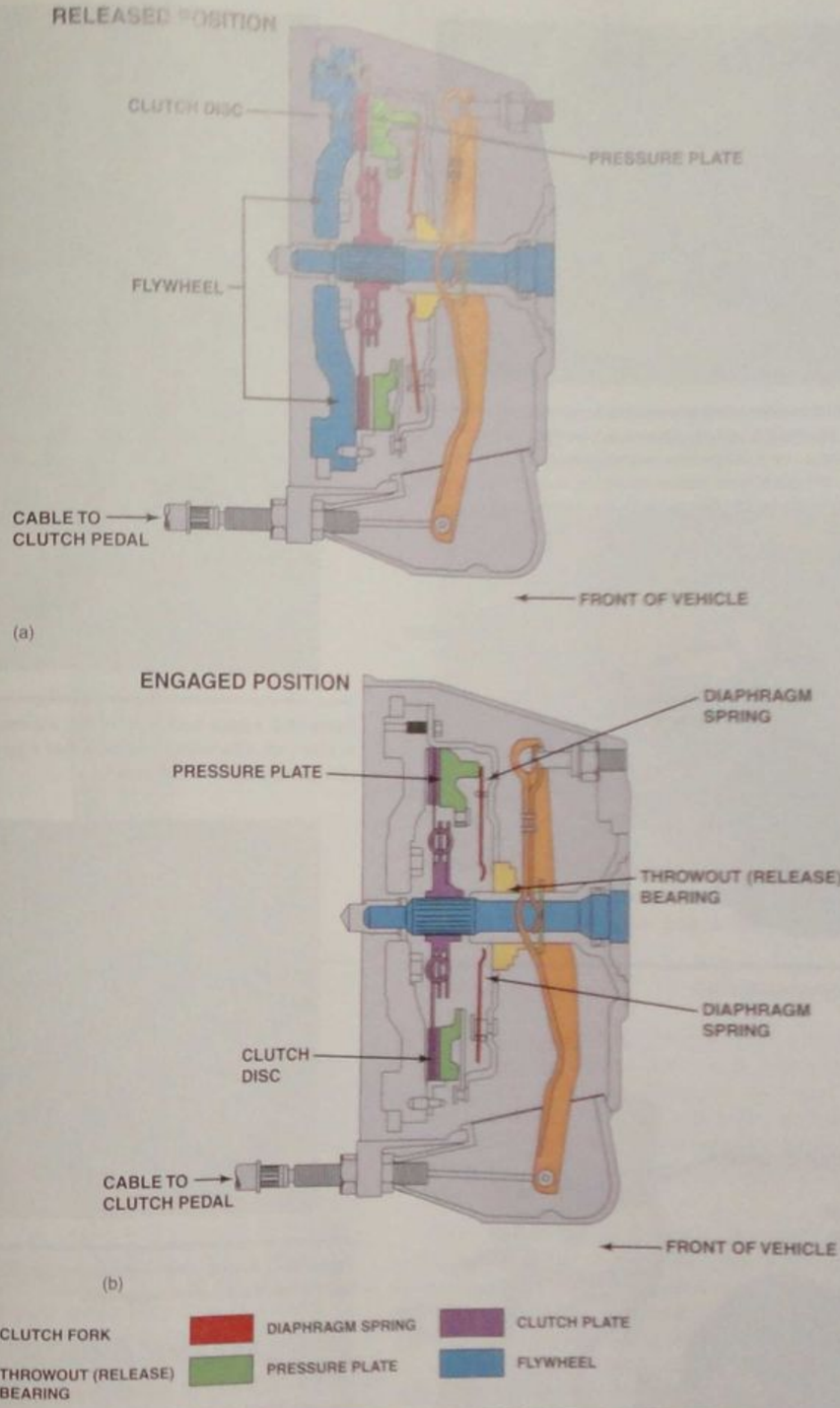


Figure 94–2 (a) When the clutch is in the released position (clutch pedal depressed), the clutch fork is applying a force to the throwout (release) bearing, which pushes on the diaphragm spring, releasing the pressure on the friction disc. (b) When the clutch is in the engaged position (clutch pedal up), the diaphragm spring exerts force on the clutch disc, holding it between the flywheel and the pressure plate.

High-Performance Clutch Disc Another type of friction material is a ceramic and metallic mixture. This creates a hard, long-lasting lining, but is more expensive and does not cushion clutch engagement as much as a softer lining. Instead of a full circle of softer friction material, the disc may have only a few segments or buttons of this ceramic-metallic material. Clutches that use these discs, which are sometimes called "button clutches," are found in racing applications where strength and



Figure 94–3 The transmission has just been removed. Note that this type of transmission incorporates the bell housing, which was therefore removed at the same time as the transmission. The clutch fork and throwout (release) bearing also came off together. All that remained attached to the engine was the flywheel, clutch disc, and pressure plate.

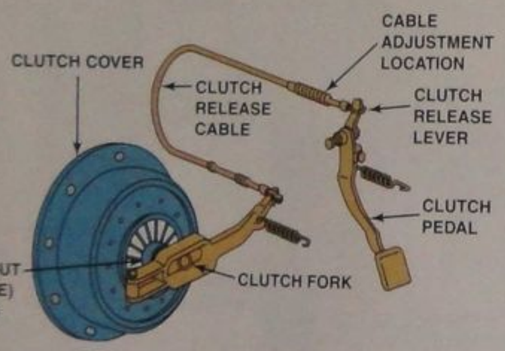


Figure 94–4 A typical cable-operated clutch.

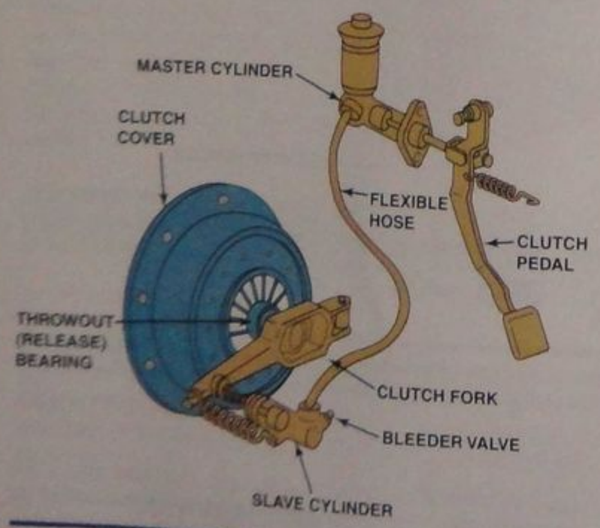


Figure 94–5 A hydraulic clutch linkage uses a master cylinder and a slave cylinder.

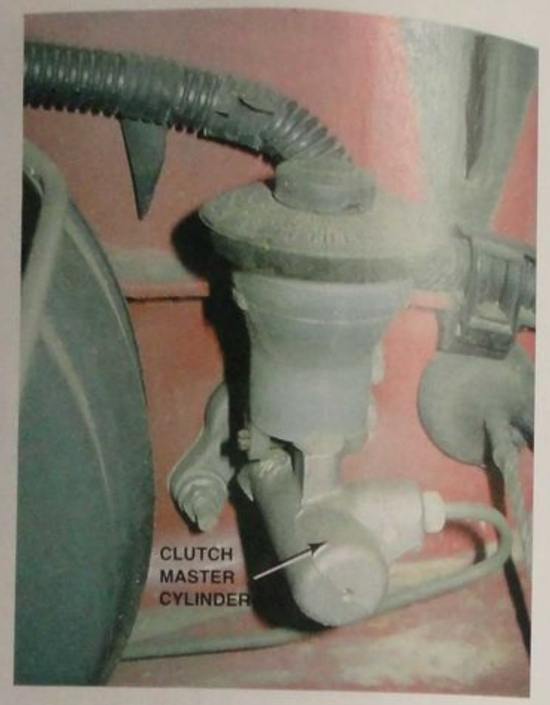


Figure 94–6 A typical clutch master cylinder and reservoir mounted on the bulkhead on the driver's side of the vehicle. Brake fluid is used in the hydraulic system to operate the slave cylinder located on the bell housing.



Figure 94–7 A racing or high-performance clutch disc lacks the features of a stock clutch disc that help provide smooth engagement.

durability are a greater concern than smooth engagement. See Figure 94–7.

Stock Clutch Disc Around the center hub of the clutch disc are **torsional dampers** that absorb the initial shock of engagement and help dampen engine-firing in pulses being transmitted into and through the transmission/transaxle. See Figure 94–8. The torsional dampers are either coil springs or are made of rubber. In the space between the friction surfaces is a wavy spring steel material called a **cushioning spring** or **marcel spring.** See Figure 94–9. The marcel spring also helps to absorb the initial shock of engagement and allows for a smooth engagement of the clutch.



Figure 94–8 A typical stock clutch friction disc that uses coil spring torsional dampers.

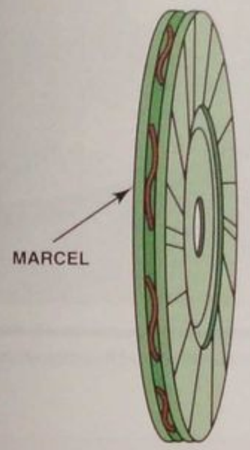


Figure 94–9 A marcel is a wavy spring that is placed between the two friction surfaces to cushion the clutch engagement.

HINT: The larger center hub section of the disc must be installed with the bucket portion facing the pressure plate. See Figure 94–10.

Pressure Plates The purpose of the pressure plate is to exert a force on the clutch disc so that engine torque can be transmitted from the engine to the transmission/transaxle. A strong spring(s) is required to provide adequate clamping force on the clutch disc. However, a strong pressure plate spring force must be released by the force of the driver's foot to disengage the clutch. The pressure plate, like the flywheel, is usually made of nodular cast iron. A smooth, machined area on one side forms the friction disc contact surface. When the clutch engages, spring force pushes the pressure plate toward the flywheel so the friction disc is clamped between the flywheel and the pressure plate. Engine torque flows through the clutch to the transmission input shaft. Three or four drive straps or clips connect the pressure plate to the clutch cover. These spring-steel straps or clips help hold the pressure plate away from the flywheel when the clutch disengages. Several styles of pressure plates have been used, including

- **Coil spring style.** This style of pressure plate uses coil springs and three release arms. A coil-spring-style pressure plate is also called the **lever style** because it uses levers to compress the coil springs. See Figure 94–11.
- **Diaphragm spring style.** This style is the most commonly used pressure plate design. One large, round, spring-steel spring is used to apply even force on the clutch disc. See Figure 94–12. These tend to be smaller assemblies, weigh less, and have fewer parts than coil spring assemblies. The one-piece diaphragm spring does the job of all the release levers and coil springs in a coil spring clutch.



Figure 94–10 Cutaway of the center section of a clutch plate showing the various layers of steel plates used in the construction.



Figure 94–11 A coil spring (lever style) clutch pressure plate.

The driver must push harder on the clutch pedal to disengage a **coil spring clutch** than to disengage a comparable diaphragm spring design. The pedal effort for a coil spring clutch increases the farther down the pedal is pushed. The pedal effort for a diaphragm spring clutch decreases during the second half of pedal travel.

As the friction disc wears, coil springs expand and lose some of their clamping force. In contrast, the design of the diaphragm spring tends to increase its clamping force as the friction disc wears to half its original thickness. Then, as the friction disc continues to wear, the clamping force of the spring gradually returns to its original level. This happens without any obvious change in clutch pedal effort.

In many cases, aftermarket clutch parts manufacturers supply a diaphragm spring pressure plate assembly when an original coil spring assembly must be replaced. If so, carefully compare the new pressure plate to the old one to make sure it is the correct replacement. Physical characteristics, such as dimensions and bolt-hole patterns, must be identical for the assembled clutch to operate



Figure 94–12 Typical diaphragm-style pressure plate that uses a Belleville spring.

properly. Check that the inner edges of the diaphragm spring fingers are the same height as the release levers on the original unit.

Flywheels The engine flywheel serves four basic purposes:

- Smoothes out or dampens engine power pulses.
- Absorbs some of the heat created by clutch operation.
- Provides the connection point for the starter motor to crank the engine.
- Provides the application surface for the clutch friction disc.

A flywheel is heavy, or has a large mass, which creates inertia. This inertia acts upon crankshaft rotation to smooth out or dampen engine power pulses. On a running engine, the crankshaft speeds up as a cylinder fires, then slows due to internal engine friction until the next cylinder fires. The inertia provided by the flywheel mass tends to keep crankshaft speed more constant.

Whenever friction exists between two moving parts, heat is generated. The flywheel absorbs some of the heat created by clutch operation by acting as a heat sink for the clutch friction disc.

An external ring gear is pressed or welded onto the flywheel along its outer circumference. When the starter motor is engaged, the starter-drive gear meshes with the flywheel ring gear. Through gear reduction, the flywheel transfers starter motor rotation to the crankshaft to crank the engine.

The face on the transmission side of the flywheel has a smooth, machined area that creates the application surface for the clutch friction disc. This surface must be properly finished to allow adequate slippage as the clutch engages and disengages, and to prevent slippage when the clutch is engaged. See Figure 94–13.

The flywheel is constructed of cast iron and attaches to the end of the engine crankshaft. The carbon content of the cast iron (about 3%) provides a suitable surface for the clutch disc. The carbon, in the form of graphite, acts as a lubricant to provide a smooth engagement of the clutch. The weight of the flywheel helps to absorb and smooth out engine-firing impulses. A starter ring gear is welded or pressed onto the outside diameter of the flywheel. Often the ring gear can be replaced separately without having to replace the flywheel in the event of a failure, as shown in Figure 94–14. The pilot bearing is often installed in the center of the flywheel (or in the end of the crankshaft) to support the end of the input shaft of the transmission.



Figure 94–13 A flywheel after it has been machined (ground) to provide the correct surface finish for the replacement clutch disc.



Figure 94–14 The starter motor will spin but the engine will not crank if the ring gear on the flywheel is broken.

Dual-Mass Flywheels Some vehicles, especially high-performance vehicles and vehicles equipped with diesel engines, use a dual-mass flywheel. The purpose of a dual-mass flywheel is to dampen engine vibrations and keep them from being transmitted to the passenger compartment through the transmission and shift linkage. A dual-mass flywheel consists of two separate flywheels attached with damper springs, friction material, and ball bearings to allow some movement between the primary and secondary flywheel. By allowing a very slight amount of movement between the two flywheels, the damper absorbs engine torque peaks and normal vibration to provide smoother drive train operation. The damper assembly is completely sealed, because it also contains a fluid or lubricant, typically silicone-based, which also helps absorb vibration and transmit torque. Typically, the two flywheels twist out of phase with each other by up to about 60 degrees to absorb torsional oscillations. The starter ring gear mounts on the primary flywheel. Power from the starter motor does not have to flow through the damper assembly to reach the engine crankshaft. The ring gear and pilot bearing are usually attached to the primary flywheel, and the clutch friction surface is usually the secondary flywheel. See Figure 94–15.

NOTE: If the dual-mass flywheel fails, the symptom is the same as a slipping clutch. The torque-limiting friction material connecting the primary and secondary flywheels can fail. This failure requires the replacement of the flywheel assembly.

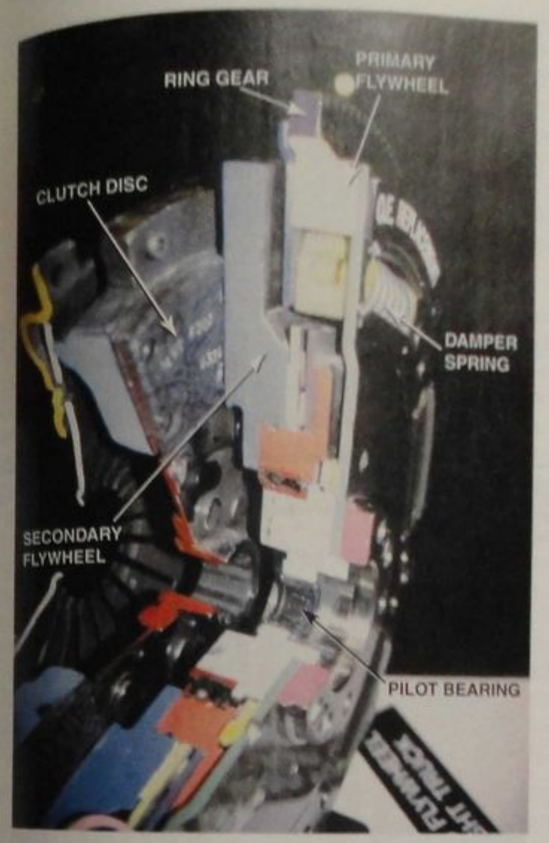


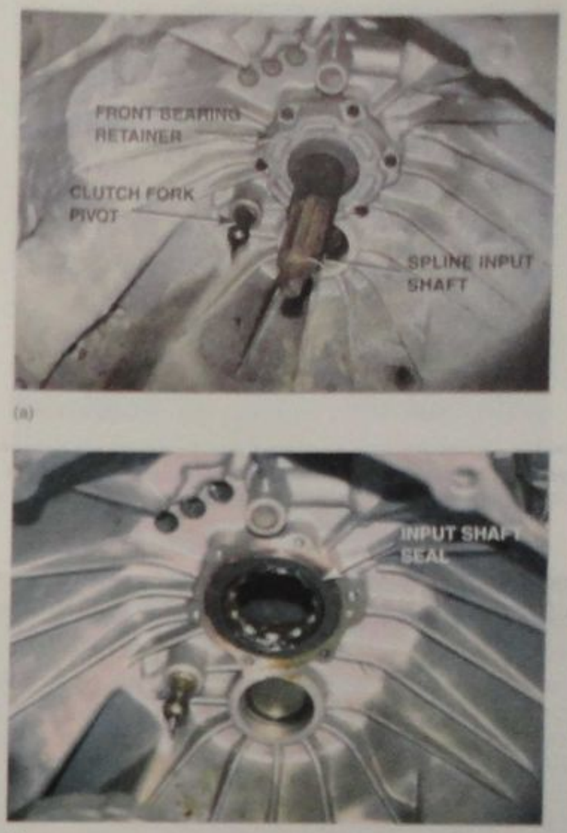
Figure 94–15 A cutaway of a dual-mass flywheel used on a Ford diesel pickup truck.

TECH TIP ✔ **Shim It or Replace It**

Whenever replacing a clutch, most experts agree that the flywheel should be removed from the engine and resurfaced. When material is removed from the surface of the flywheel, the geometry (relationship) of the clutch parts changes because the pressure plate is now closer to the rear of the engine by the amount removed from the flywheel. Ask your parts supplier for a shim equal in thickness to the amount of material removed during resurfacing. Generally, these round shims are available in 0.020" to 0.100" thicknesses. The shim is installed between the crankshaft flange and the flywheel. If a shim is not used, the flywheel may have to be replaced to properly restore proper clutch operation and service life.

TECH TIP ✔ **Repair the Oil Leaks Before Replacing the Clutch**

If engine oil or transmission lube gets onto the friction surface of the clutch, the clutch will chatter when engaged. This grabbing and releasing of the clutch is not only harmful to the drive train (transmission, driveshaft, etc.) but also is disturbing to the driver when the vehicle vibrates and shakes while driving. To avoid the possibility of a chattering clutch, always repair oil leaks as soon as possible. Rocker (valve) cover gaskets, intake manifold gaskets, oil galley plugs, rear main seals, as well as the input shaft seal on the transmission/transaxle itself can all lead to clutch contamination. See Figure 94–16.



(a)

(b)

Figure 94–16 (a) Before replacing the clutch, the bell housing should be cleaned and the clutch fork pivot lightly lubricated. (b) The input shaft seal should also be replaced to prevent the possibility of getting transmission lubricant on the friction surfaces of the clutch.

Pilot Bearing or Bushing The transmission input shaft goes all the way from the transmission, through the clutch assembly, to the engine. Transmission bearings support the transmission end of the shaft. Depending on the length of the input shaft, it may also need a pilot bearing or bushing to support it at the engine end.

A front-wheel-drive vehicle with a stepped flywheel, compact clutch assembly, and a transaxle has a short input shaft that may not reach all the way to the flywheel. This design does not need a pilot bushing or bearing to support the engine end of the input shaft. See Figure 94–17.

Other designs, such as a rear-wheel-drive vehicle with a flat flywheel, have a much longer transmission input shaft. At the engine, the transmission input shaft rests inside a small bore in the flywheel or crankshaft flange. The pilot bearing or bushing, which is pressed into this bore, supports the engine end of the input shaft and provides a low-friction surface for the shaft to ride on. This keeps the shaft and friction disc perfectly aligned with the flywheel and pressure plate.

The pilot bearing or bushing rotates with the crankshaft when the engine is running. At times, the input shaft does not rotate when the engine is running. The pilot bearing or bushing lowers the friction between these two moving parts. Some pilot bearings use ball bearings while other applications use a caged-needle bearing. The outer race of the bearing is pressed into the crankshaft or flywheel. The input shaft slides freely into the inner race. Pilot bushings are usually a sintered metal sleeve pressed into the bore in the crankshaft flange.



Figure 94–17 A transaxle assembly has been removed to replace the clutch. Note the short input shaft. This vehicle did not use a pilot bearing (bushing).

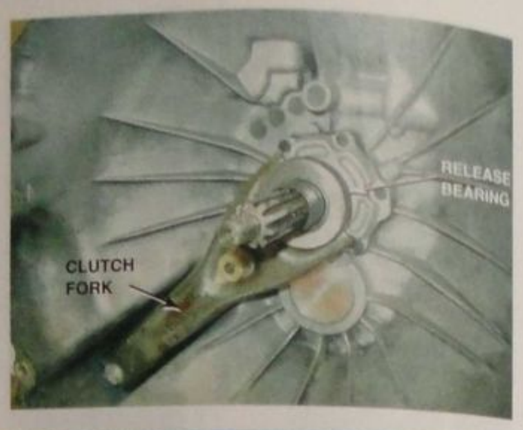


Figure 94–18 The clutch pedal linkage moves the clutch fork, which then applies a force against the release bearing, which then releases the clamping force the pressure plate is exerting on the clutch disc.

REAL WORLD FIX **The Mazda Pickup Truck Story**

The driver of a Mazda pickup truck complained that it was difficult to shift the manual transmission into first gear and reverse. The hydraulic clutch system was checked and bled and seemed to be operating as designed. A defective clutch was not suspected because the clutch did not slip. The problem continued to worsen. Finally, when the driver had trouble shifting into all gears, the technician decided that the transmission had to be removed and the clutch inspected. When the transmission was removed, the clutch assembly including the pressure plate, throwout bearing, and clutch disc all appeared to be worn but not enough to cause any trouble. Then the pilot bearing was inspected. The needle bearings were broken. The input shaft of the transmission is supported by the pilot bearing located in the center of the flywheel. Apparently, what had happened was that the pilot bearing failed and the pieces of the bearing kept the input shaft to the transmission rotating whenever the engine was running whether or not the clutch was depressed or released. The technician replaced the pilot bearing and the other clutch components at the request of the owner and everything worked perfectly.



Figure 94–19 The release bearing rubs against the tips of the diaphragm spring.

Always follow the manufacturer's lubrication instructions. Excess lubricant leaks out onto the clutch friction disc, which causes clutch slippage and early failure. Too little lubricant leads to noisy operation and input shaft damage.

Replacement pilot bearings may need to be packed before installation. Sometimes, the bottom of the bore behind the bearing is also packed with grease. Other pilot bearings are permanently lubricated at the factory. Prelubricated bearings have an oil seal to hold the lubricant. If only one side is sealed, that side faces the transmission when installed.

Some pilot bushings need to be soaked in oil before installation. Others have a permanent lubricant built into the bushing material. With this type, adding another lubricant actually increases friction, by preventing the permanent lubricant from doing its job.

Release Bearing The throwout (release) bearing is attached to the clutch fork and rides on the fingers of the pressure plate. The clutch operating system moves the clutch release bearing when the driver presses or releases the clutch pedal. Most systems move the release bearing toward the flywheel to disengage the clutch. See Figure 94–18. However, some systems have a pull-type mechanism that moves the bearing away from the flywheel to disengage the clutch. The release bearing presses against the diaphragm spring fingers or coil spring levers. This takes spring force off the pressure plate so that it no longer clamps the friction disc against the flywheel.

The diaphragm spring fingers or coil spring levers rotate at crankshaft speed, but the clutch operating system is a part of the vehicle chassis and does not rotate. The release bearing is the point where the fixed, stationary clutch operating system meets the rapidly spinning clutch assembly. See Figure 94–19.

Release Bearing Construction Most clutch release bearings are ball bearings. The bearing absorbs a thrust load when its outer race presses against the diaphragm spring fingers or coil spring levers. When the outer race contacts the spring fingers or levers, it must rotate with them at engine crankshaft speed. The inner bearing race is pressed onto an iron hub, or sleeve. In some designs, the inner bearing race and sleeve are machined as one piece. The inner bearing race and sleeve are stationary and do not spin when the outer race spins.

Release Bearing Installation The transmission front bearing retainer has a long, hollow tube extending toward the engine. The release bearing sleeve slides on the outer surface of this tube, which is commonly called the quill, **quill shaft**, or **candlestick**.

In a typical system, the outside of the release bearing sleeve has grooves or raised flat surfaces that fit into the clutch release fork. A snap ring, spring clips, or lock pins secure the release bearing to the release fork. The clutch operating system pivots the release fork back and forth when the driver presses and releases the clutch pedal. The pivoting motion of the fork slides the release bearing away from or toward the engine to engage or disengage the clutch.

Types of Release Bearings If the clutch operating system self-adjusts, then there is no clearance between the release bearing outer race and the diaphragm spring fingers or coil spring levers. The release bearing outer race constantly turns at engine crankshaft speed. This is called a constant-running release bearing. In some self-adjusting systems, a snap ring holds the outer race to the spring fingers. This design is typical of pull-type clutch operating systems that move away from the flywheel to disengage the clutch.

If the clutch operating system does not self-adjust, then there must be some clearance between the release bearing outer race and the spring fingers when the clutch is engaged. The outer race does not contact the spring fingers and so it does not turn. As the driver depresses the clutch pedal, the release bearing moves into contact with the fingers and the outer race begins to rotate with them. This type of release bearing is not designed to rotate constantly. If the clutch is not adjusted properly and there is no clearance, the release bearing spins constantly and wears out quickly.

Release Bearing Lubrication The ball bearing portion of the release bearing is usually permanently lubricated and sealed during manufacture. This part of the bearing should not be lubricated during service.

The sleeve, or quill shaft, often needs lubrication during clutch service. Typically, a thin film of high-temperature grease coats the sliding surfaces. Always follow the manufacturer's recommendations for release bearing lubrication, and avoid overlubricating. As with pilot bearings, too much lubricant here can lead to early clutch failure.

CLUTCH PROBLEM DIAGNOSIS

If the clutch is slipping, it cannot transfer engine torque to the transmission or drive wheels. A common method used to check for a slipping clutch is the following:

1. Drive the vehicle to a safe location where it can be accelerated safely.
2. Rapidly accelerate the vehicle in first or second gear and rapidly shift the transmission into a higher gear.

The engine speed should drop as the clutch is released after selecting a higher gear. If the clutch is slipping, the engine speed will either rise or not drop after the clutch pedal is released (clutch is engaged).

Another common problem with a clutch is that it sometimes will not fully disengage. The following symptoms will occur if there is a fault in the clutch or in the linkage or hydraulic system that could prevent the clutch from being fully disengaged:

- The transmission will be difficult (or impossible) to shift into reverse.
- The transmission will be difficult (or impossible) to shift.

See Figures 94–20 through 94–28 for examples of worn clutch components.



Figure 94–20 Heavy chatter marks on the pressure plate indicate that oil or grease has gotten onto the clutch facing. (Courtesy of LUK)

FREQUENTLY ASKED QUESTION ???

What Part Causes What Noise and When?

Many service technicians try to determine which part causes noise before the clutch assembly is removed from the vehicle. Start your noise analysis by starting the engine with the manual transmission in neutral and the clutch engaged (foot off the clutch pedal). If you hear a growl or grinding sound, the cause is the input shaft bearing in the transmission.

If you are hearing a chirping noise, slowly depress the clutch pedal. If the noise stops, the problem is lack of lubrication at the fork and pivot. If the noise gets louder as you depress the clutch, the throwout (release) bearing is the problem.

The pilot bearing is the cause of a squealing noise if the sound changes as the clutch pedal is depressed or released. The sound will be loudest when the difference in speed between the engine and the input shaft is greatest.

REAL WORLD FIX **Best to Double-Check Your Parts Before Installation**

A beginning technician installed a new clutch in a Chevrolet S-10 pickup truck. After the transmission was installed and the driveshaft connected, the technician started the engine to check the operation of the clutch with the truck still on the lift and off the ground. The drive wheels never turned even though the clutch was released. It was almost as if the clutch disc was left out completely although the clutch pedal felt normal.

The transmission was removed and the clutch parts inspected. Everything looked okay until the technician slid the clutch disc over the splines of the transmission input shaft. The diameter of the hole in the clutch disc was a bit larger than the diameter of the shaft. The clutch also simply revolved without even touching the input shaft. Obviously, the technician received the wrong clutch disc from the parts department. The experienced technician explained that not only should all parts be carefully inspected before installation but that the clutch disc should have been slid over the splines of the input shaft to check for any possible burrs that could prevent the clutch disc from disengaging.



Figure 94–21 Hot spots on the pressure plate indicate that this clutch has been slipping or that oil/grease has gotten onto the clutch facing. *(Courtesy of LUK)*



Figure 94–23 Friction material (facing) only makes contact with the flywheel on the inner and outer edge. The likely cause is that the flywheel was not resurfaced or replaced during a previous repair. *(Courtesy of LUK)*



Figure 94–22 Friction material (facing) worn down to the rivets. Normal wear can cause this or improper clamping force from a defective pressure plate. *(Courtesy of LUK)*



Figure 94–24 Deep scoring in the friction material (facing) on the flywheel side indicates that the flywheel was not resurfaced or replaced during a previous repair. *(Courtesy of LUK)*

SAFETY TIP **Disconnect the Battery Before Work Begins**

It is always a safe idea to disconnect the negative (−) battery cable before performing major work to the vehicle as a safety precaution.

CLUTCH REPLACEMENT

The clutch replacement for a typical rear-wheel-drive vehicle includes the following steps.

1. Hoist the vehicle safely and mark and remove the driveshaft. This step ensures that the driveshaft will be reinstalled correctly and in phase.
2. Disconnect the shift linkage, speedometer connections, and reverse light switch connection.
3. Support the transmission with a transmission jack and then remove the rear crossmember and bell housing bolts.
4. Carefully move the transmission toward the rear. Try to keep the transmission level to avoid causing damage to the pilot bearing or clutch components. A slight wiggling of the transmission is usually necessary to allow the input shaft to slide over the spline of the clutch disc.
5. After the transmission has cleared the clutch, it can be lowered and inspected before being reinstalled after the clutch assembly has been replaced.



Figure 94–25 A broken cushion segment caused by movement between the engine and transmission. The most likely cause is a missing or defective pilot bearing. *(Courtesy of LUK)*



Figure 94–27 A worn down or broken diaphragm is often caused by a faulty release bearing or a linkage problem that keeps the clutch from fully releasing. *(Courtesy of LUK)*



Figure 94–26 A destroyed torsional damper is usually caused by driving at too low an engine speed, which would cause too much strain on the torsional damper. *(Courtesy of LUK)*



Figure 94–28 Rusting hub splines indicate that the transmission shaft was not lubricated, which can cause the clutch to not disengage correctly. *(Courtesy of LUK)*

6. Mark the pressure plate and flywheel if they are to be reused to allow them to be reinstalled in the same location to maintain assembly balance.
7. Remove the clutch pressure plate retaining bolts, and remove the clutch assembly including the release bearing, pressure plate, and clutch disc.
8. Clean and inspect the flywheel.

NOTE: Most experts recommend that the flywheel be removed and resurfaced. Always use new flywheel bolts and torque to factory specifications.

9. Replace or lightly lubricate the pilot bearing/bushing.
10. Install the clutch disc and pressure plate using an aligning tool to center the clutch disc and then torque the pressure plate bolts to factory specifications. See Figure 94–29.
11. Inspect the clutch release lever and replace if necessary.
12. Attach the replacement release bearing and install the transmission and torque the retaining bolts to factory specifications.

13. Reconnect the clutch linkage and place the transmission into high gear and have an assistant depress the clutch pedal. Grasp the output shaft and turn it with your hand.
    a. The transmission output shaft should be easy to rotate if the clutch is fully disengaged with the clutch pedal held down. See Figure 94–30.
    b. If the output shaft cannot be rotated, double-check that the clutch linkage and clutch is correctly installed.
14. Reinstall the rear crossmember and torque the retaining bolts to factory specifications.
15. Reconnect the shift linkage, speedometer, and reverse light connections.
16. Install the driveshaft and torque the U-joint retaining fastener to factory specifications.
17. Lower the vehicle and test-drive it to verify correct clutch operation.



Figure 94–29 A clutch alignment tool is inserted into the pilot bearing and over the splines of the clutch disc to keep the disc properly centered before installing the pressure plate. After the pressure plate has been installed and torqued to factory specifications, the alignment tool can be removed because the pressure plate spring force holds the friction disc tightly against the flywheel.



Figure 94–30 To check that the clutch is properly installed before replacing all of the components, try to turn the output shaft with the transmission in gear and the clutch pedal depressed by an assistant.

CLUTCH PEDAL ADJUSTMENT

As the clutch disc wears, the pressure plate moves closer to the flywheel. This causes the clutch to engage when the clutch pedal is higher and higher. Eventually, the clutch will start to slip if the linkage is not adjusted to compensate for the normal wear. Most hydraulic clutch linkage is self-adjusting and does not require any adjustment in normal service. Some cable-operated clutches are either self-adjusting or are adjusted easily. For example, one style of clutch linkage is adjusted by simply pulling upward on the clutch pedal until it stops. Some cable-operated clutch linkage is adjusted either at the bulkhead (firewall) where the cable exits the passenger compartment or at the clutch fork. Follow the adjustment procedures specified for the exact vehicle being serviced.

Most adjustment procedures specify a clutch pedal freeplay of 0.5 to 1.0 inch. Freeplay is the distance the clutch pedal can be depressed without encountering any noticeable resistance. This slight amount of freeplay assures that the clutch is fully engaged and not partially engaged as could occur if there is no freeplay in the pedal linkage.

TECH TIP ✔ **Check for Bulkhead Flex**

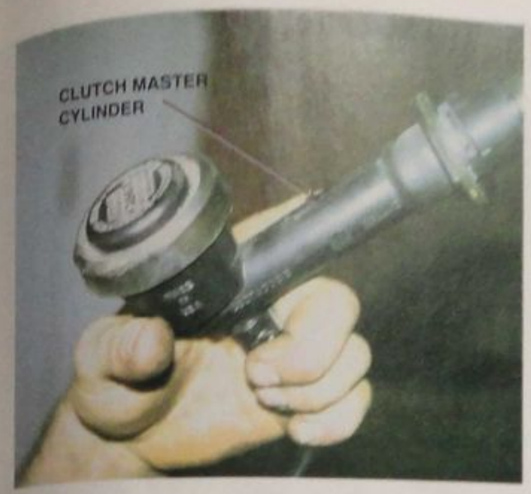
Many cable-operated clutch linkage problems are caused by flexing of the bulkhead (firewall) as the clutch pedal is depressed. This movement of the bulkhead can cause the clutch to slip. To prevent unnecessary clutch repairs, have an assistant observe the bulkhead near the clutch cable while the clutch pedal is depressed. If there is movement of the sheet metal bulkhead, add reinforcing steel plate to the area.

BLEEDING THE HYDRAULIC CLUTCH

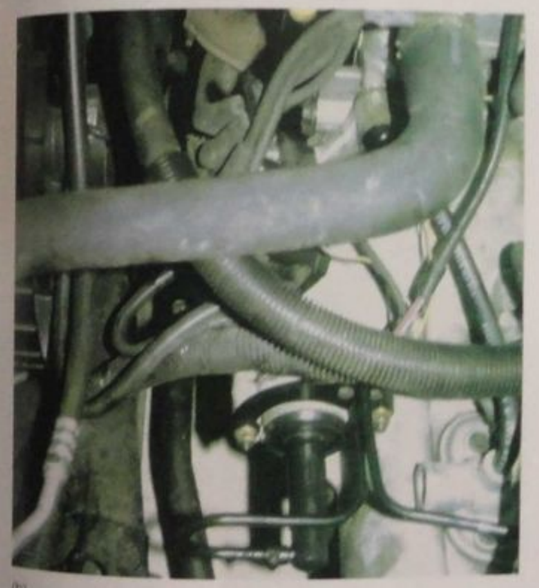
If the hydraulic system has been opened to replace either a clutch slave cylinder or master cylinder or both, air has to be bled from the system. See Figures 94–31 and 94–32. Fill the master cylinder with DOT 3 brake fluid and open the bleeder valve at the slave cylinder. Gravity should force the brake fluid to flow downward, expelling any trapped air that may be in the system. When brake fluid starts to drip from the bleeder valve, close the bleeder valve and check the clutch for normal operation. Sometimes depressing the clutch pedal slowly as an assistant opens the bleeder valve at



Figure 94–31 The clutch slave cylinder is often corroded because of moisture absorbed by the brake fluid used in the hydraulic clutch. This slave cylinder was disassembled to see if it could be overhauled rather than replaced.



(a)



(b)

Figure 94–32 (a) The replacement hydraulic clutch for a Saturn includes the master cylinder (shown) with the line and the slave cylinder as an assembly. The assembly is even filled with brake fluid! Do not open the master cylinder cap on this unit because Saturn did not provide any method of bleeding air out of the ignition. (b) The slave cylinder attaches to the bell housing of the transaxle.

the slave cylinder will force any trapped air out of the system. This is called *manual bleeding* and should be repeated as necessary until the normal operation of the clutch returns.

CLUTCH SYMPTOM GUIDE

Clutch Slips Possible causes:

1. Clutch is worn.
2. Clutch disc has oil on the surface.
3. Flywheel height is out-of-specifications.

Clutch Grabs Possible causes:

1. Clutch disc has oil on the surface.
2. Clutch linkage is binding.

Clutch Noises Possible causes:

1. Pilot bearing is defective or worn.
2. Release bearing is defective or worn.

SUMMARY

1. The clutch not only transmits engine torque from the flywheel to the transmission/transaxle it also absorbs engine-firing impulses to reduce the vibration felt by the driver through the shift linkage.
2. The clutch has to be depressed (clutch disengaged) to keep the engine running with the transmission in gear and to shift from one gear to another.
3. The clutch disc has friction material on both sides and is clamped between the engine flywheel and the pressure plate.
4. The pressure plate bolts to and revolves with the flywheel.
5. A throwout (release) bearing is used to disengage the clutch by depressing a lever or spring, which removes the clamping force from the clutch disc.
6. The pilot bearing is supported by the front bearing retainer of the transmission.
7. The linkage between the clutch pedal and the clutch fork can be levers and rods, a cable, or a hydraulic connection.
8. The flywheel attaches to the engine and not only provides the friction surface for one side of the clutch disc but also dampens engine-firing impulses.
9. A dual-mass flywheel is used on many import, luxury, and diesel vehicles to help dampen engine and driveline vibrations.
10. The clutch linkage can be adjusted on some vehicles to provide about 1/2 inch to 1 inch of clutch pedal freeplay.
11. It is a normal service procedure to replace the clutch disc, pressure plate, and throwout bearing as well as the pilot bearing every time the clutch is replaced. The flywheel should also be removed from the engine and resurfaced or replaced.

PHOTO SEQUENCE Clutch Replacement Step-by-Step



P94–1 The first step in the process of replacing the clutch on this Chevrolet S-10 pickup truck is to remove the negative battery cable.



P94–2 Remove the shifter mechanism inside the vehicle. This step may involve removing the center console and other components.



P94–3 Mark and then remove the driveshaft.

(continued)

PHOTO SEQUENCE Clutch Replacement Step-by-Step—continued



P94–4 Remove the exhaust pipe if needed. It was needed in this case, according to service information.



P94–5 Remove the transmission mount fasteners.



P94–6 Using a transmission jack, support the transmission and remove the bell housing bolts.



P94–7 A view of the bell housing and throwout bearing as the transmission assembly is removed from the engine.



P94–8 Removing the fasteners holding the pressure plate to the flywheel.



P94–9 Removing the pressure plate and clutch disc.



P94–10 Using a special puller, remove the pilot bearing.



P94–11 The flywheel is being removed to be refinished or replaced as needed.



P94–12 With the flywheel removed, check to see if the rear main seal is leaking and replace if needed.



P94–13 Installing a reconditioned flywheel and torquing new bolts to factory specifications.



P94–14 Using a pilot tool to align the clutch disc with the pilot bearing through the center opening of the pressure plate.



P94–15 Installing a new pilot bearing and lubricate as per instructions in service information.

PHOTO SEQUENCE Clutch Replacement Step-by-Step—continued



P94–16 Installing the transmission assembly with a new throwout bearing.



P94–17 Bleeding the air from the hydraulic clutch circuit.



P94–18 Finish the clutch replacement by reinstalling all components removed and check for proper operation.

REVIEW QUESTIONS

1. List the parts of a typical clutch assembly.
2. Describe what happens when the driver depresses the clutch pedal.
3. Describe how to determine which of the following is the cause of a noise: pilot bearing, throwout (release) bearing, and input shaft bearing.
4. Explain why a dual-mass flywheel is used on some vehicles.
5. What is meant by clutch pedal freeplay?

CHAPTER QUIZ

1. Technician A says that too much clutch pedal freeplay can cause the clutch to slip during acceleration. Technician B says that too little clutch pedal freeplay can cause the clutch to slip. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. The engine speed increases when the driver depresses the accelerator pedal and releases the clutch pedal, but the vehicle does not move. Technician A says the clutch may be defective. Technician B says the dual-mass flywheel may be defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. A growling noise is heard only when the driver exerts force on the clutch pedal. No noise is heard when the clutch pedal is up. Technician A says the pilot bearing is defective. Technician B says the input shaft bearing is defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Which part does *not* rotate when the engine is running and the clutch is depressed?
   a. Clutch disc
   b. Pilot bearing
   c. Pressure plate
   d. Flywheel
5. The clutch pedal freeplay is less than specifications. Technician A says that the clutch may slip during hard acceleration. Technician B says that the clutch will "grab" when the clutch pedal is close to the floor when the clutch is engaged. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. What part is often *not* used on a front-wheel-drive vehicle with a manual transaxle?
   a. Flywheel
   b. Throwout (release bearing)
   c. Clutch fork
   d. Pilot bearing
7. Most hydraulic clutch systems use what hydraulic fluid?
   a. Mineral (hydraulic) oil
   b. SAE 80W-90
   c. DOT 3
   d. ATF
8. A clutch is chattering when engaged. Technician A says that too much clutch freeplay is the cause. Technician B says that oil or grease may be on the friction disc. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. A manual transmission is difficult to shift or get into gear, especially reverse. Technician A says that the clutch may not be fully releasing. Technician B says that too much clutch pedal freeplay could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Two technicians are discussing bleeding a hydraulic clutch. Technician A says to open the bleeder and allow the fluid to gravity bleed. Technician B says to have an assistant slowly depress the clutch pedal as the bleeder valve is opened at the slave cylinder to bleed the air out of the system. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 95

Manual Transmissions/ Transaxles

OBJECTIVES: After studying Chapter 95, the reader will be able to: Prepare for the ASE Manual Drive Train and Axles (A3) certification test content area "B" (Transmission Diagnosis and Repair) and content area "C" (Transaxle Diagnosis and Repair). • Explain how to calculate gear ratios. • Name the parts of a typical manually shifted transmission/transaxle. • Describe how the synchronizer assembly allows for smooth, clash-free shifting. • Describe the different types of lubricants that may be used in a manual transmission/transaxle. • Diagnose a difficult-to-shift manual transmission/transaxle.

KEY TERMS: axis • back taper • bell housing • bevel gear • blocker ring • cluster gears • cluster shaft • clutch • constant-mesh gear • counter gears • countershaft • direct drive • drive gear • driven gear • extension housing • external gears • fifth gear • final drive assembly • first gear • fourth gear • front bearing retainers • gear reduction • helical gear • hypoid gear set • input shaft • internal ring gears • keys • lay shaft • main drive pinion assembly • main gear • main shaft • neutral • output shaft • overdrive • pinion gear • quill • reverse • second gear • sliding reverse gear • sliding sleeve • springs • spur gear • stop ring • synchronizer assemblies • synchronizer keys • synchronizer ring • third gear • transmission case

THE NEED FOR A TRANSMISSION

A vehicle requires a lot of torque to start off and to climb hills, yet it does not require as much torque to move on level ground. The source of the torque is the engine. Torque is a twisting or turning force that is exerted on the input shaft of a transmission/transaxle. An engine produces increasing torque as its speed increases up to a certain point where the torque output starts to decrease. Therefore, to get a vehicle moving or to accelerate up a hill, it is desirable to use a transmission that allows the engine speed to be increased even though the vehicle speed may be low. Using gears allows the engine speed to increase at low vehicle speeds yet still permits it to drop at higher speeds to save fuel and reduce exhaust emissions.

For example,

First gear: Vehicle speed is low, engine speed is high.

Second gear: Vehicle speed increases, engine speed decreases as shift is made.

Third gear: Vehicle speed continues to increase, engine speed is kept in a narrow range.

Fourth gear: Again, the vehicle speed is increasing, yet engine speed is about the same as in third gear.

FREQUENTLY ASKED QUESTION ???

What Is the Difference Between a Transmission and a Transaxle?

A transmission is used on rear-wheel-drive vehicles, whereas a transaxle is usually used on front-wheel-drive vehicles. A vehicle equipped with a transmission uses a separate differential to split the torque equally to the drive wheels. A transaxle includes a differential assembly. In a transaxle, the differential, sometimes called the *final drive unit*, is incorporated in the construction of the transmission.

GEAR TYPES

The simplest type of gear is the **spur gear.** See Figure 95–1. A spur gear consists of a gear blank with straight-cut teeth around its entire circumference. All gear teeth lie parallel to the centerline, or **axis,** of the gear. The teeth are shaped so they can mesh without slippage with a second spur gear's teeth positioned along a parallel axis.



Figure 95–1 Spur gears have straight-cut teeth.

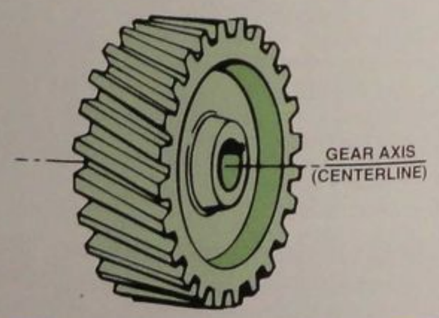


Figure 95–2 The teeth of a helical gear are cut at an angle to the gear axis.

Spur gear design permits 1.5 to 2.5 gear teeth to mesh at a time. The gear teeth make contact with each other over their full width at the same instant. The fact that the gear teeth are in full contact increases the strength of the gear, but also causes spur gear operation to be noisy. Due to their strength, most heavy-duty truck transmissions use spur gears.

A **helical gear,** although similar to a spur gear, has its teeth cut at an angle to the axis of the gear. See Figure 95–2. This enables more teeth, 2.5 to 3.5, to mesh at a time than the spur gear. Additionally, the angle allows the teeth to mesh gradually, rather than all at once. As a result, helical gears run quieter than spur gears.

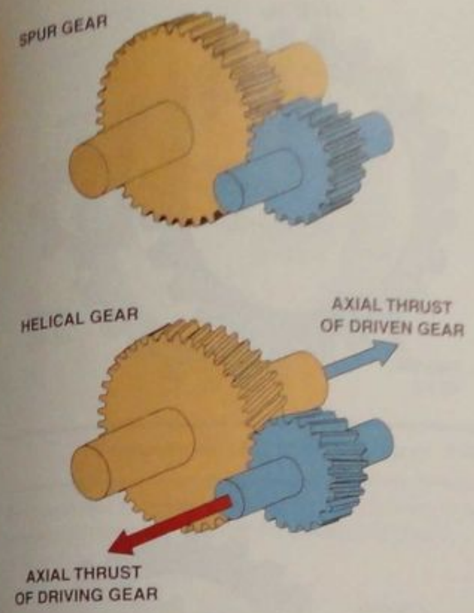


Figure 95–3 A spur gear has straight-cut teeth. This design is very strong and is used where strength is important. Spur gears are noisy during operation. Helical-cut gears, on the other hand, operate quietly but create a force in line with the axis of the gears due to the angle of the gear teeth.

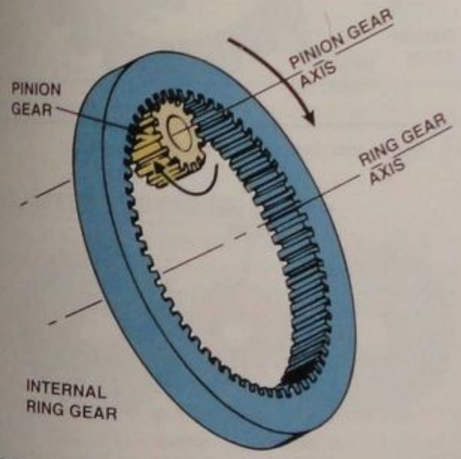


Figure 95–4 A pinion gear meshed with an internal ring gear rotates in the same direction around a parallel axis of rotation.

Helical gears, however, have two disadvantages. Each gear pushes against its shaft parallel to its axis. Special bearings are needed to protect the gearbox from this type of axial, or thrust, loading. Furthermore, because of the increased contact area, helical gears create more friction than spur gears. See Figure 95–3.

Spur and helical gears have gear teeth on their outside circumference and, for this reason, are called **external gears.** This type of gear is the most commonly used in manual transmissions and transaxles.

Gears having teeth along the inside circumference are called **internal ring gears.** See Figure 95–4. The teeth of an internal ring gear may be spur or helical teeth. An internal ring gear may



Figure 95–5 When two external gears mesh, they rotate in opposite directions.

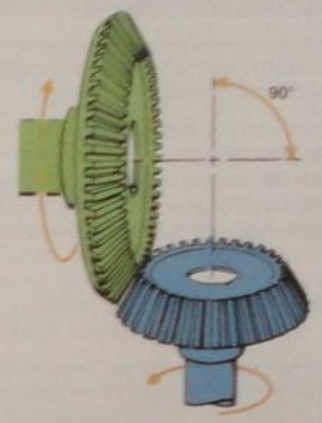


Figure 95–6 Bevel gears are often used to change the direction of rotation and are typically used in differentials.

mesh with a smaller external gear designed to rotate as it travels around the inside of the internal ring gear. This type of external gear is called a **pinion gear** because of its smaller diameter.

When an external gear meshes with an internal ring gear, both gears rotate in the same direction, but when an external gear meshes with another external gear, the gears rotate in opposite directions as shown in Figure 95–5.

Bevel Gears The teeth of a **bevel gear** are cut at an angle to the outside gear surface. Simple bevel gears have straight-cut teeth similar to those on a spur gear. See Figure 95–6. Special gears used in a differential, called spider gears, are a common example of the simple bevel gear.

Hypoid Gears **Hypoid gear sets** have gear teeth that are curved much like the teeth of a spiral bevel gear. The pinion gear is offset below the centerline of the ring gear as shown in Figure 95–7. This design provides maximum gear tooth contact for strength, gradual tooth engagement, and quiet operation. Hypoid gears are generally available only as a matched set.

Hypoid gears are commonly used as the final drive gears in rear axles where load-carrying ability and low noise are important. The offset pinion allows the driveshaft to be positioned lower in the vehicle, reducing the size of the hump in the vehicle's interior.

GEAR RATIOS

When one gear turns another, the speed that the two gears turn in relation to each other is the gear ratio. Gear ratio is expressed as



Figure 95–7 A differential uses a hypoid gear set to provide a change in the direction of torque and for gear reduction (torque increases) to the drive wheels.

the number of rotations the **drive gear** must make in order to rotate the **driven gear** through one revolution. To obtain a gear ratio, simply divide the number of teeth on the driven gear by the number of teeth on the drive gear. Gear ratios, which are expressed relative to the number one, fall into three categories:

- Direct drive
- Gear reduction
- Overdrive

Direct Drive If two meshed gears are the same size and have the same number of teeth, they will turn at the same speed. Since the drive gear turns once for each revolution of the driven gear, the gear ratio is 1:1; this is called a **direct drive.** When a transmission is in direct drive, the engine and transmission turn at the same speed.

Gear Reduction If one gear drives a second gear that has three times the number of teeth, the smaller drive gear must travel three complete revolutions in order to drive the larger gear through one rotation. See Figure 95–8. Divide the number of teeth on the driven gear by the number of teeth on the drive gear and you get a 3:1 gear ratio (pronounced three to one). This type of gear arrangement, where driven gear speed is slower than drive gear speed, provides **gear reduction.** Gear reduction may also be called underdrive as drive speed is less than, or under, driven speed. Both terms mean the same thing and use is a matter of preference.

Gear reduction is used for the lower gears in a transmission. First gear in a transmission is called "low" gear because output speed, not gear ratio, is low. Low gears have numerically high gear ratios. That is, a 3:1 gear ratio is a lower gear than those with a 2:1 or 1:1 gear ratio. These three ratios taken in order represent a typical upshift pattern from low gear (3:1), to second gear (2:1), to drive gear (1:1).

Overdrive **Overdrive** is the opposite of a gear reduction condition and occurs when a driven gear turns faster than its drive gear. For the gears shown in Figure 95–9, the driven gear turns three times for each turn of the drive gear. The driven gear is said to overdrive the drive gear. For this example, the gear ratio is 0.33:1. Overdrive ratios of 0.65:1 and 0.70:1 are typical of those used in automotive applications.

NOTE: Ratios always end in one with a colon in between. Therefore, the first number is less than one if it is an overdrive ratio and greater than one if it is a gear reduction ratio.

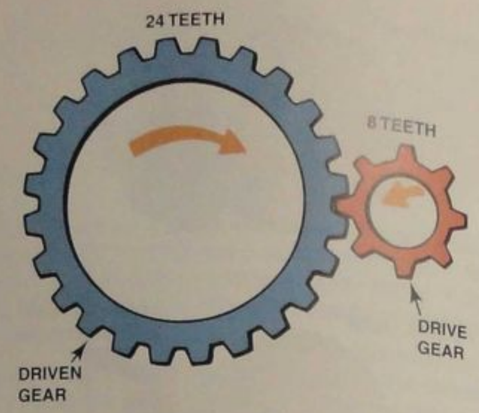


Figure 95–8 This gear combination provides a gear reduction of 3:1.

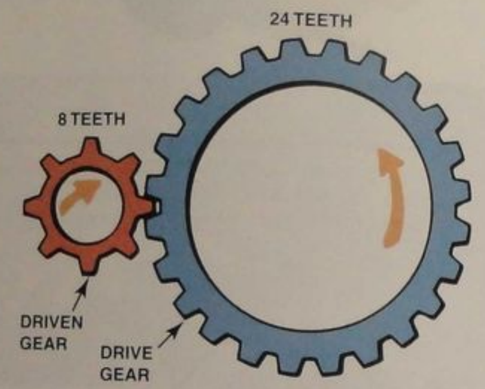


Figure 95–9 This gear combination provides an overdrive ratio of 0.33:1.

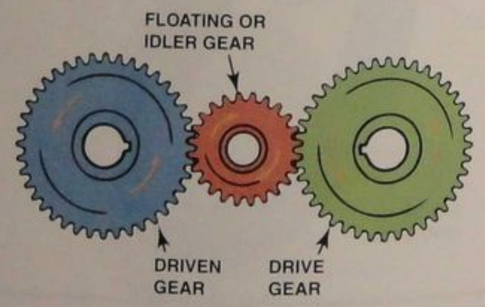


Figure 95–10 Idler gears affect the direction of rotation in a gear train, but not the final drive ratio.

Idler Gears In a gear train, a gear that operates between the drive and driven gears is called a floating gear, or idler gear. See Figure 95–10. Idler gears do not affect the speed relationship between the drive and driven gears, although they do affect the direction of rotation. Reverse gear on an automatic transmission often uses an idler gear to change the direction of rotation.

When a drive and driven gear mesh directly, they rotate in opposite directions. When an idler gear is installed between the drive and driven gears, both gears rotate in the same direction. The presence of idler gears in the gear train does not affect the gear ratio.

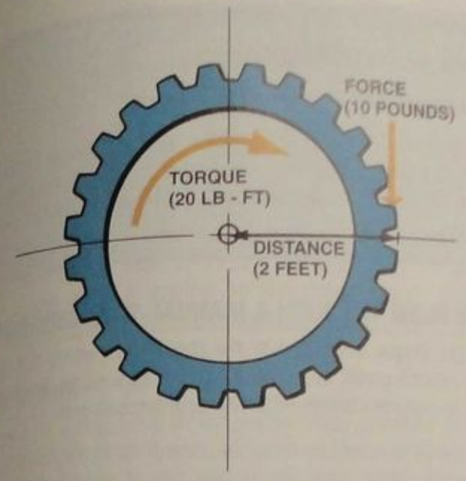


Figure 95–11 Gears apply torque in the same way a wrench applies torque—the force applied multiplied by the distance from the center of the gear equals the torque.

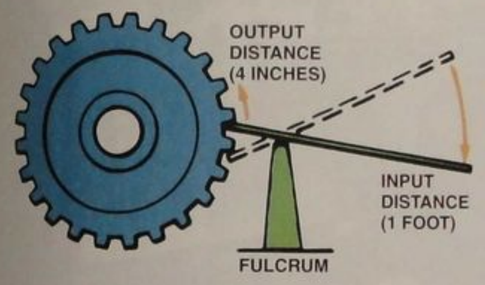


Figure 95–12 A lever can be used to multiply torque, but it does so at the expense of distance or speed.

TORQUE, SPEED, AND POWER

Torque is a twisting force commonly expressed in pound-feet (lb-ft) or Newton-meters (N-m). Gears apply torque much like a wrench does; each tooth of a gear is actually a lever. On a gear with a 2-foot radius, applying a force of 10 pounds to one gear tooth exerts 20 lb-ft of torque on the center of the shaft to which the gear attaches. See Figure 95–11.

Torque and Speed Relationship Torque and speed have an inverse relationship: as one goes up, the other goes down. With a constant input speed, transmission torque decreases as output speed increases. The opposite also applies assuming a constant input speed, transmission torque increases as output speed decreases.

Torque Multiplication Levers can be used to increase or multiply torque. For example, a wheel that is too heavy for a person to turn by muscle power alone turns easily when that same person uses a lever and fulcrum to multiply the applied force. See Figure 95–12. The force, or torque, increases at one end, but the lever must be moved a greater distance at the opposite end to obtain the increase in force. Either distance or speed must always be given up in order to increase, or multiply, torque.

Gears can be used in the same way as levers to multiply torque. When two gears of the same diameter are meshed, the driven gear will turn at the same speed as the drive gear. Since there is no difference in speed, there is no difference in torque between the two gears.

If the drive gear is one-third the diameter of the driven gear, it must rotate three times for each rotation of the larger gear. This means that the larger gear will turn three times slower than the smaller gear. At the same time, the larger gear will exert three times the torque of the smaller gear. When speed decreases, torque increases. Torque multiplication and gear ratios are directly related. When a gear system is in reduction, there is more torque available at the driven gear, but less speed. When the gear system is in overdrive, there is less torque available at the driven gear, but greater speed.

Engine Torque Characteristics The torque curve of an engine shows how much torque is available at different points within a range of engine speeds.

Because of these characteristics, torque multiplication must be provided between the crankshaft and drive axles to enable a vehicle to begin moving from a standstill and to accelerate at low speeds. Once engine RPM rises beyond the torque peak, a change in gear ratio brings engine speed back within the most efficient torque producing range.

POWER TRAIN GEAR RATIOS

A transmission enables a vehicle to maximize engine torque, allowing the vehicle to move more efficiently. The transmission is aided in this task by the final drive gearing. These components work together to provide select gear ratios that take maximum advantage of engine torque available through various speed ranges.

A gear ratio, to repeat, is determined by dividing the number of teeth on the driven gear (output) by the number of teeth on the driving gear (input). See Figure 95–13.

$$\frac{\text{Number of teeth on the driven gear (24)}}{\text{Number of teeth on the driving gear (12)}} = 2{:}1$$

The gear ratio represents the number of turns of the input gear to one turn of the output gear. A transmission/transaxle usually uses two pairs of gears to achieve each gear ratio, and there may be four, five, or six forward gears plus reverse. When two pairs of gears are used to create a gear, simply multiply the two ratios together to get the gear ratio.



Figure 95–13 Gear ratio is determined by dividing the number of teeth of the driven (output) gear (24 teeth) by the number of teeth on the driving (input) gear (12 teeth). The ratio illustrated is 2:1.

A low first-gear (high numerical) ratio creates a high amount of torque applied to the drive wheels to get the vehicle moving. To summarize what is occurring if the engine speed is constant:

First gear:

- Output shaft speed is a lot lower than engine speed.
- Output torque is a lot higher than the engine is producing.

Fifth gear:

- Output shaft speed is faster than the engine speed.
- Output torque is lower than the engine is producing.

TRANSMISSION CONSTRUCTION

A transmission is usually constructed of cast aluminum machined to accept the internal parts and strong enough to be a structural member of the drive train. The front of the transmission attaches to a separate **bell housing** or includes the bell housing as part of the casting of the transmission itself at the front of the transmission (toward the engine) in the **front bearing retainer** (sometimes called the **quill**) that supports the clutch throwout (release) bearing and usually houses the front grease seal. The rear of the transmission usually includes a separate casting called the **extension housing.** The center housing is usually referred to as the **transmission case.** See Figure 95–14.

The **input shaft** is splined to the clutch disc and is also referred to as the **main gear, clutch gear,** or **main drive pinion assembly.** See Figure 95–15. The **main shaft,** also called the **output shaft,** is splined at the end and transmits engine torque to the drive shaft (propeller shaft) through a yoke and universal joint.

All manual transmissions/transaxles use a **countershaft** (also called a **lay shaft** or **cluster shaft**) to provide the other set of gears necessary to achieve the changes in gear ratios. The gears on the countershaft are called **cluster gears** or **counter gears.**

FREQUENTLY ASKED QUESTION ???

What Is Meant by a 77 mm Transmission?

The size (77 mm or about 3 inches) is the distance between the center of the input shaft and the center of the countershaft. The greater this distance, the larger the transmission and the more torque it is capable of handling due to the larger gears.

TORQUE FLOW THROUGH A MANUAL TRANSMISSION

The engine torque is applied to the input shaft when the clutch is engaged (clutch pedal up). This torque is applied to the main gear, which is in constant mesh with the countershaft gear.

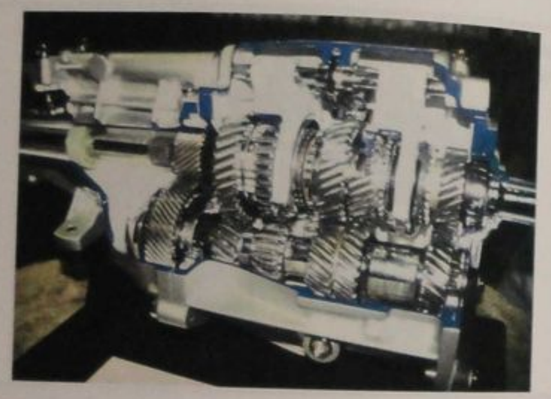


Figure 95–15 Cutaway of a six-speed manual transmission showing all of its internal parts.

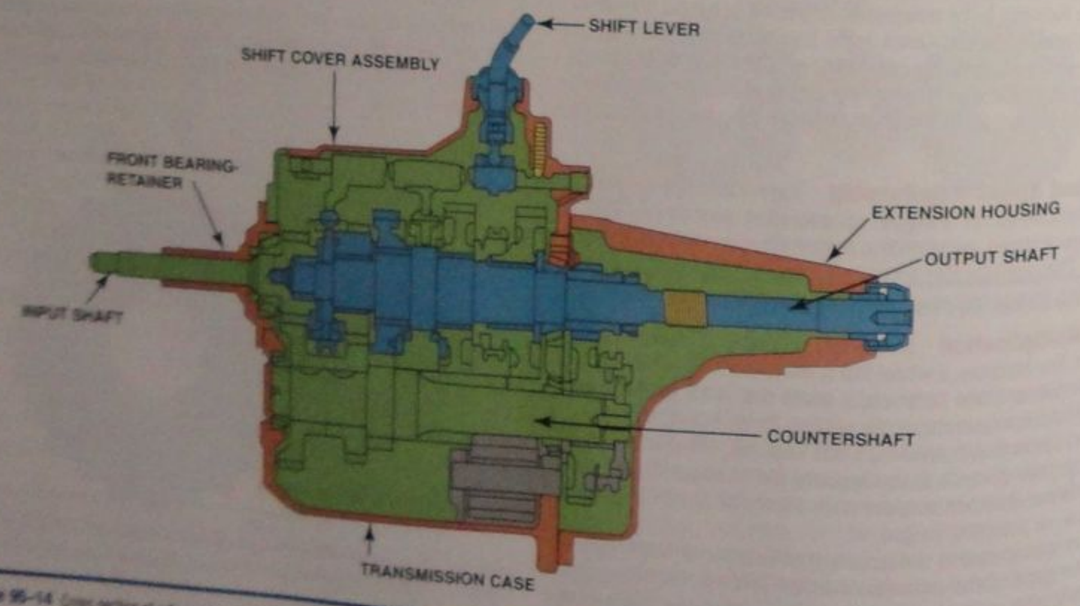


Figure 95–14 Cross section of a five-speed manual transmission showing the main parts.

NOTE: The fact that the countershaft is revolving any time the clutch is engaged makes transmission noise diagnosis easier.

The engine torque is multiplied by the ratio difference between the main gear and the cluster gear. The engine torque is then transferred and multiplied again when first gear is in mesh with the corresponding first gear on the main (output) shaft. Again, the torque is multiplied by the ratio difference between the two gears. The engine torque then is applied to the drive wheels through the driveshaft, differential, and drive axles.

SPEED GEARS

All gears on the countershaft are permanently attached to the shaft. When the countershaft rotates, all gears on the countershaft rotate. The input shaft gear is also part of the input shaft. However, the gears on the main shaft are free to move on the shaft and are connected to the main shaft through the synchronizer hub when a shift is made. All speed gears use bearings that allow the speed gears to move independently of the main shaft.

NOTE: When assembling the main shaft and the countershaft, just remember that each shaft should look like a Christmas tree (tapered downward from the top). When installed in the transmission, these two "Christmas trees" are meshed together with the small gear end of one shaft meshing with the large gear end of the other shaft. See Figure 95–16.

SYNCHRONIZER PARTS AND OPERATION

Most vehicles today in a manually shifted transmission use a floor-mounted shifter to change gears. The shifting lever either moves cables that transfer the shifting motion to the transmission or transaxle or move the shift forks directly. Inside the transmission/transaxle are shift forks that control shifts between two gears, such as first and second or second and third. Interlocks either in the shifter linkage itself or inside the transmission/transaxle prevent the accidental selection of reverse except when shifting from neutral and also prevent selecting two gears at the same time. See Figure 95–17.

Synchronizers are used in manual transmissions/transaxles to make shifting easier. To synchronize means to make two or more events occur at the same time. When the driver depresses the clutch pedal, torque is no longer being transmitted to the input shaft and the drive wheels are "driving" the main shaft of the transmission/transaxle. To achieve a clash-free (no grinding sound) shift, the shift speed must match the speed of the rotating gears. The detents and interlocks hold the shift mechanism in position.

The real "shifting" in a synchromesh transmission takes place in the **synchronizer assemblies,** not the gears. Most synchronizer assemblies ride on the output shaft between two gears. A synchronizer assembly is named for the gears on either side of it, which are the two speeds that it engages. For example, a five-speed transmission with constant-mesh reverse uses a 1–2 synchronizer, 3–4 synchronizer, and a 5-reverse synchronizer.

Synchronizer Construction Although there are number of design variations, all are similar and include a hub, a **sliding sleeve,** a stop ring, (or **blocker rings** or **synchronizer ring**), **keys,** and **springs.** In addition, the tapered cone and coupling teeth machined on the speed gear are part of the synchronizer assembly. See Figure 95–18. In a typical synchronizer:

- Splines attach the center hub of the synchronizer to the output shaft, so the hub and output shaft rotate together. There are also splines machined on the outer circumference of the hub.
- An outer sleeve rides on the external hub splines with enough clearance so that it slides freely. The splines on the sleeve also match the small coupling teeth of the stop ring and speed gear. Coupling teeth are also called engagement or clutch teeth. The sleeve is splined to the hub, so it rotates with the output shaft.
- A **stop ring** sits between the speed gear and the sleeve. The coupling teeth on the stop ring match those on both the sleeve and



Figure 95–16 Notice that the countershaft and the main shaft both use gears of increasing size that mesh together.

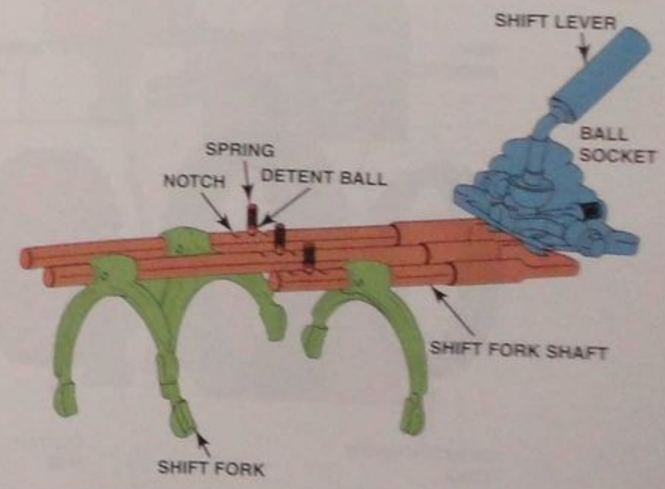


Figure 95–17 A typical shift mechanism showing the shift detents designed to not only give the driver a solid feel when shifting but also to prevent two gears from being selected at the same time.

the speed gear. The stop ring also has a tapered cone to match the cone machined on the speed gear.

- Small, spring-loaded detent keys, also called **synchronizer keys** or **struts**, ride in slots on the outer sleeve. The stop ring has slots to match these keys. This allows the stop ring to rotate slightly, relative to the sleeve, before the keys hit the sides of their slots and stop the stop ring. As the sleeve moves, the synchronizer keys move with it, which pushes the blocking ring onto the tapered cone of the speed gear.

Synchronizer Operation When the outer sleeve is centered on the hub, the synchronizer is in its neutral position—it does not contact either of the speed gears. See Figure 95–19. To shift into gear, the driver disengages the clutch and moves the shift linkage. The shift linkage, which is described later in this chapter, pushes the sleeve toward one of the speed gears. As the sleeve moves, the detent keys push the stop ring toward the speed gear. This causes the ring cone to slide onto the tapered cone of the speed gear.

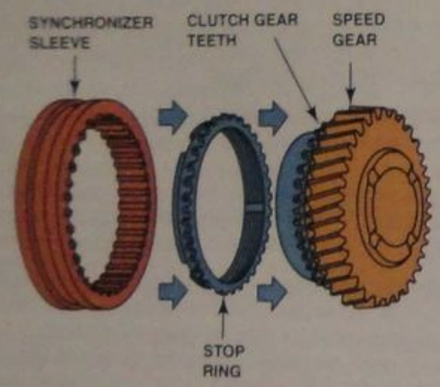


Figure 95–18 The shifter fork fits into the groove of the synchronizer sleeve. When a shift is made, the sleeve is moved toward the speed gear. The sleeve presses the stop ring (synchronizer ring) against the cone area of the speed gear. The friction between the stop ring and the speed gear causes the speed of the two to become equal, permitting the sleeve to engage the gear clutch teeth of the speed gear. When this engagement occurs, the shift is complete.

The speed gear is turning because it is in constant mesh with a countershaft gear. However, the gear may not be turning at the same speed as the synchronizer assembly even though both are on the same shaft. When the clutch is disengaged, the engine is no longer driving the transmission, so there is no torque applied to the input shaft, and the countershaft, or cluster gear, simply free-wheels. As the shift is made, the stop ring acts as a brake to slow down the gear so that its speed matches the speed of the synchronizer assembly. That is, it synchronizes the shift. This matched speed allows the internal hub splines to easily engage the coupling teeth on the stop ring and speed gear. When the clutch disengages, the crankshaft drives the input shaft, which drives the countershaft, which drives the output shaft through the selected gear.

The synchronizer goes through three stages during a shift:

1. The tapered surface, or cone, of the stop ring touches the speed gear first. As the two conical surfaces begin riding against each other, friction is created. See Figure 95–20. This causes the stop ring to move with the speed gear, but it moves only slightly until the detent keys hit the sides of their slots. This aligns the



Figure 95–19 Typical synchronizer assembly.

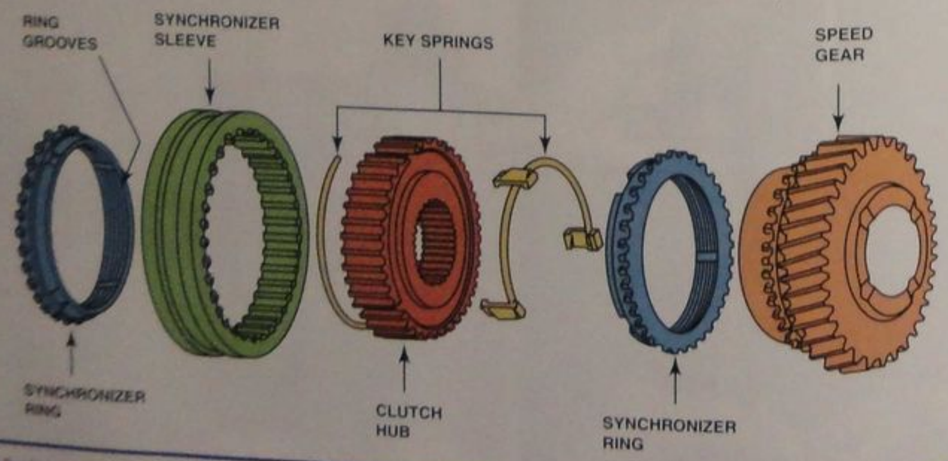


Figure 95–20 Synchronizer keys are attached to the clutch hub and push against the synchronizer ring when the sleeve is being moved during a shift. Notice the grooves on the synchronizer ring. These grooves prevent lubricating oil from becoming trapped between the ring and the cone surface of the speed gear. The grooves also help the ring release from the cone surface when a shift is made out of a gear.

coupling teeth on the stop ring with the sleeve splines. Friction between the stop ring and cone slows the gear.

2. The sleeve overcomes the force of the detent key springs as the shift linkage continues to move it toward the gear. This allows the stop ring to relax and move slightly so that the sleeve splines begin to engage the coupling teeth on the stop ring. At this point, the coupling teeth on the stop ring and the speed gear may not line up with each other. However, friction continues to build between the ring and the cone, so the gear continues to slow down.
3. Once the sleeve, stop ring, and gear are all turning at the same speed, it takes just a small movement between the stop ring and gear to align the coupling teeth and allow the sleeve to slip completely over both sets. The speed gear is now locked to the output shaft through the synchronizer stop ring and sleeve. See Figure 95–21.

Synchronizer stop rings are a simple type of clutch, called a cone clutch for the shape of the mating surfaces. Some manufacturers refer to the synchronizer action as "clutching."

Synchronizer sleeves and hubs are gear-quality steel. Stop rings are a softer metal—usually brass, copper, or a sintered metal—to absorb the friction of synchronizer operation. The tapered cone is relieved, that is grooves are machined into its contact surface. These grooves serve two purposes; they

- Channel excess lubricant out from between the two pieces for better contact.
- Retain a small amount of lubricant. This decreases wear when the cone clutch must slip slightly during coupling tooth alignment.

The internal splines on the synchronizer sleeve and the coupling gear teeth on stop rings and speed gears have a special shape that works to hold the gear engaged once the driver releases the shift lever. The ends of the gear teeth are chamfered, giving them a triangular shape. These pointed ends allow easier sleeve-to-gear alignment as the angles tend to center the splines between the teeth. Once aligned, a back taper machined behind the chamfered end of the teeth and splines tends to keep the sleeve in place until the linkage pushes the sleeve away for another shift. **Back taper** is an angle cut opposite to the chamfer so that spline or tooth narrows just behind the chamfered end. See Figure 95–22. The back taper creates resistance to motion to keep the splines from sliding off the coupling teeth. This is especially important when there is no torque load, such as coasting, to help keep the parts meshed. Worn back taper may cause the transmission to jump out of gear, usually when the throttle is released.

Some synchronizer stop rings have friction material on the cone surface. This paper friction material is the same as used on automatic transmission clutch plates, and provides a smoother synchronizing action than metal-to-metal contact. A manual transmission with

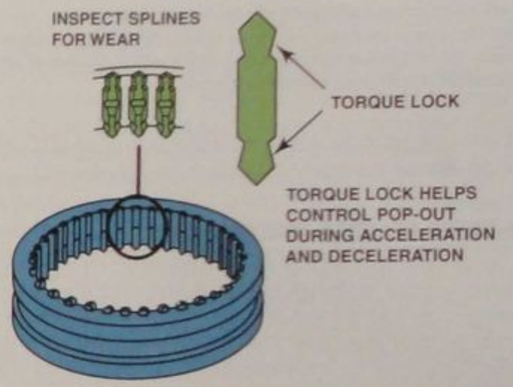


Figure 95–22 Before reassembling the transmission/transaxle, carefully inspect the splines on the synchronizer sleeves for wear. The shape of the splines helps prevent the transmission/transaxle from jumping out of gear during acceleration and deceleration.

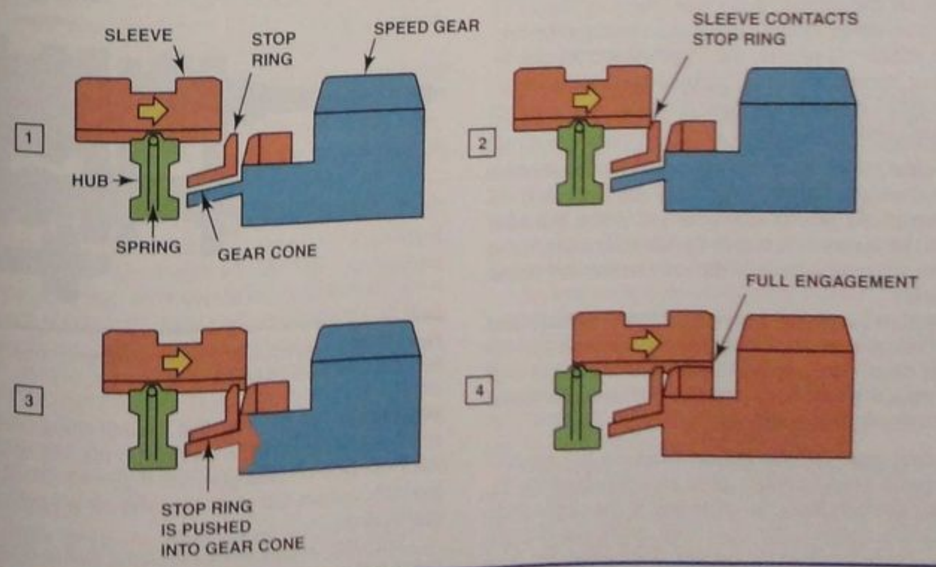


Figure 95–21 A shift sequence starts when the shift fork is moved by the driver, (1) applying a force on the sleeve that moves it toward the speed gear. (2) The sleeve and the inserts contact the stop ring (blocking ring). (3) The synchronizer ring (stop ring) engages the cone on the speed gear, causing both assemblies to reach the same speed. (4) The shift is completed when the internal teeth of the sleeve mesh with the gear clutch teeth of the speed gear.



Figure 95–23 A three-piece synchronizer assembly. This type of synchronizer uses two cones, which helps achieve a smooth shift with less driver effort. Many newer transmissions/transaxles use a paper lining similar to that of the clutches in an automatic transmission. The transmissions/transaxles that have these paper linings must use automatic transmission fluid (ATF) for proper operation and long life.

paper stop rings must use automatic transmission fluid (ATF). Other lubricants damage the paper ring surface. See Figure 95–23.

FIVE-SPEED GEARBOX TORQUE FLOW

This section describes how power is transmitted through a typical five-speed gearbox. Although minor differences exist among different designs, the basic pattern of torque flow, also called power flow, is similar for most gearboxes. The concept of torque flow, or torque transfer, is the same for any transmission, regardless of the number of gear ratios available. The differences are in how the parts assemble and where they are located in the transmission.

Five-Speed Transmission A five-speed transmission has six gear sets that provide five forward speeds and one reverse speed. Either a sliding gear or constant-mesh gears may be used for reverse. All forward gears are the constant-mesh type. The Borg-Warner T5 manual transmission serves as an example of a contemporary five-speed design. In addition to reverse, the T5 provides three gear reduction ratios (first, second, and third), direct drive (fourth), and an overdrive ratio (fifth). A sliding idler gear is used to change output shaft direction and provide reverse.

Neutral In **neutral,** all of the synchronizer sleeves are centered on their hubs as shown in Figure 95–24. Note that in this and the following illustrations the reverse idler shaft and sliding gear have been repositioned for clarity. In actuality, the assembly is positioned so it meshes with the reverse gears of the countershaft and output shaft simultaneously.

With the clutch engaged, the drive gear of the input shaft turns the cluster gear, or countershaft. The speed gears are driven by the cluster gears, but rotate freely on the output shaft. The output shaft may turn if the vehicle is moving or coasting, but no engine torque is being transferred through the transmission.

First Gear In **first gear,** the shift linkage slides the 1–2 synchronizer sleeve rearward toward the first speed gear. See Figure 95–25. The synchronizer assembly locks the speed gear to the output shaft.

With the clutch engaged, the input shaft drives the countershaft, delivering engine torque to the gearbox. Torque transfers from the first counter gear to the first speed gear, which drives the output shaft through the 1–2 synchronizer hub splines. Torque flows through the transmission in gear reduction at the first gear ratio.

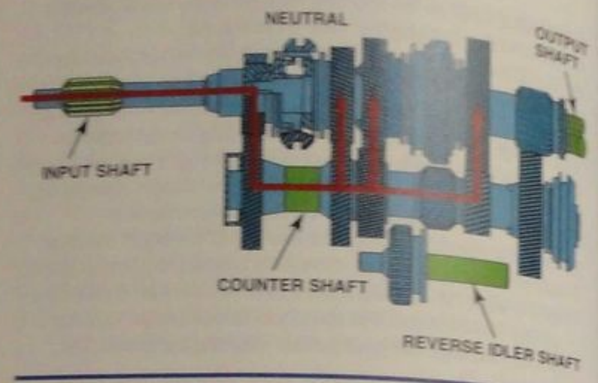


Figure 95–24 In neutral, the input shaft and the countershaft are rotating if the clutch is engaged (clutch pedal up), but no torque is being transmitted through the transmission.

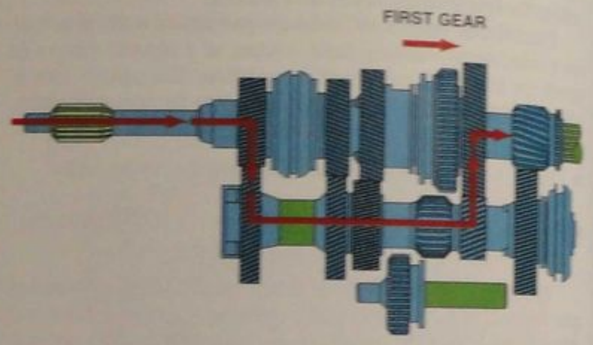


Figure 95–25 In first gear, the 1–2 synchronizer sleeve is moved rearward, locking the speed gear to the output shaft. Torque is transmitted from the input shaft to the countershaft and then to the output shaft.

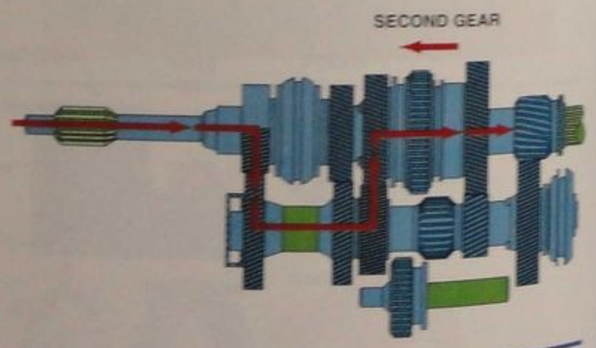


Figure 95–26 In second gear, the 1–2 synchronizer sleeve is moved forward, which locks the second speed gear to the output shaft.

Second Gear In **second gear,** the shift linkage slides the 1–2 synchronizer sleeve forward, away from the first speed gear and toward the second speed gear. See Figure 95–26. The synchronizer assembly releases first gear, then locks the second speed gear to the output shaft.

With the clutch engaged, the input shaft is driven at crankshaft speed and turns the countershaft. Engine torque transfers from the second counter gear to the second speed gear, which drives the output shaft through the 1–2 synchronizer hub splines. Torque flows through the transmission in gear reduction at the second gear ratio.

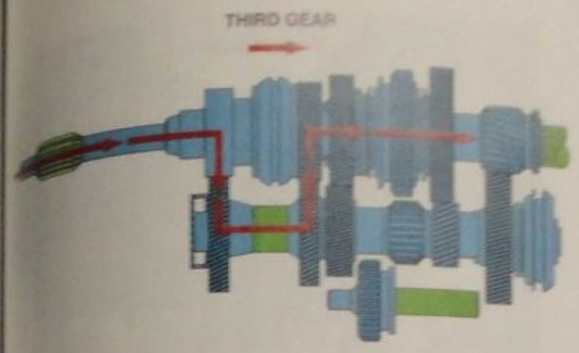


Figure 95–27 To achieve third gear, the shaft linkage first centers the 1–2 synchronizer sleeve and then moves the 3–4 synchronizer sleeve rearward, locking third gear to the output shaft.

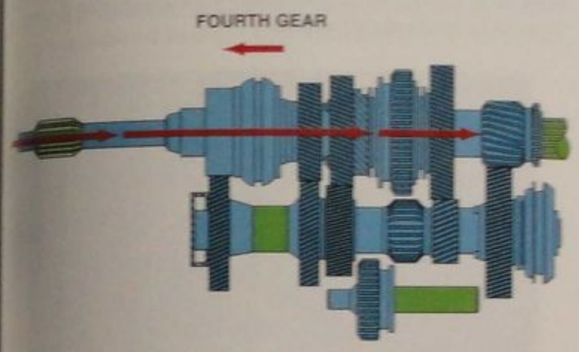


Figure 95–28 In fourth gear, the 3–4 synchronizer sleeve is moved forward, which locks the fourth speed gear to the output shaft.

Third Gear In **third gear,** the shift linkage centers the 1–2 synchronizer sleeve and moves the 3–4 synchronizer sleeve back toward the third speed gear. See Figure 95–27. The synchronizer assembly locks the third speed gear to the output shaft.

With the clutch engaged and the input shaft driving the countershaft, the third counter gear transfers torque to the third speed gear. The speed gear drives the output shaft through the 3–4 synchronizer hub splines. Torque flows through the transmission in gear reduction at the third gear ratio.

Fourth Gear In **fourth gear,** the shift linkage moves the 3–4 synchronizer sleeve forward, away from the third speed gear and toward the input shaft drive gear. See Figure 95–28. The synchronizer assembly locks the input shaft drive gear to the output shaft.

With the clutch engaged, the input shaft drives the output shaft through the 3–4 synchronizer hub splines and both shafts rotate at crankshaft speed. Torque flows straight through the transmission at a 1:1 ratio, delivering engine torque to the drive shaft. This is called direct drive because there is no gear reduction through the transmission. The counter gears also turn because they are in constant mesh, but they do not affect torque flow because all of the speed gears are freewheeling on the output shaft.

Fifth Gear In **fifth gear,** the shift linkage centers the 3–4 synchronizer sleeve and moves the fifth synchronizer sleeve toward the fifth speed gear. See Figure 95–29. Note that on the T5 transmission the synchronizer assembly locks the fifth speed gear to the countershaft. The speed gear drives a fixed gear on the output shaft.



Figure 95–29 To achieve fifth gear, the shaft linkage first centers the 3–4 synchronizer sleeve and then moves the fifth synchronizer sleeve toward the fifth speed gear, locking it to the output shaft.

With the clutch engaged, the input shaft drives the countershaft. The fifth synchronizer hub is splined to the countershaft, so it is driven and driving the speed gear when fifth gear is engaged. This transfers engine torque to the output shaft through the fixed fifth gear. Note the countershaft gear is larger than the output shaft gear. Therefore, fifth gear is overdriven. Torque flows through the transmission at the fifth gear, or overdrive, ratio. Typical overdrive gear ratios are between 0.6:1 and 0.8:1. This lowers engine speed for economical highway cruising.

On some five-speed transmissions, the fifth speed gear is on the output shaft with the other speed gears. This type of arrangement is typically used with constant-mesh reverse gears. In these designs, fifth and reverse gears share a synchronizer assembly. The fixed countershaft gear drives the speed gear, which drives the output shaft through the hub splines when the sliding sleeve is engaged. Torque flow through the transmission is similar to any of the gear reduction forward speeds detailed above, but the speed gear is generally overdriven.

Reverse There are two common **reverse** gear designs used on transmissions:

1. Sliding gear
2. Constant-mesh gear.

With a **sliding reverse gear** design, such as on the T5, the shift linkage slides the reverse idler gear on its shaft until it engages the reverse gears on the countershaft and output shaft gear. Both gears are fixed to their respective shafts. This design uses spur gears for reverse, not helical gears, because the gear teeth must move into and out of mesh. On some gearboxes, the sliding gear splines to the output shaft. The linkage moves the gear along the output shaft splines to engage the reverse idler gear.

An unusual feature of the Borg-Warner T5 is that it does not have a separate reverse output shaft gear. See Figure 95–30. Instead, spur teeth machined around the outside of the 1–2 synchronizer sleeve act as the reverse output gear. When the T5 is shifted into reverse, the linkage moves the reverse idler gear rearward so it simultaneously meshes with the countershaft reverse gear and the gear on the synchronizer sleeve.

When the clutch is engaged, the countershaft is driven and the reverse gear drives the idler gear, which rotates in the opposite direction of the countershaft. The idler gear drives the 1–2 synchronizer sleeve, so there is another directional change in rotation. Although the sleeve is not engaged to a speed gear, it remains splined to the output shaft, so the sleeve drives the output shaft when the idler gear is engaged. The output shaft rotates in the opposite direction of the input shaft because the idler gear is between them.

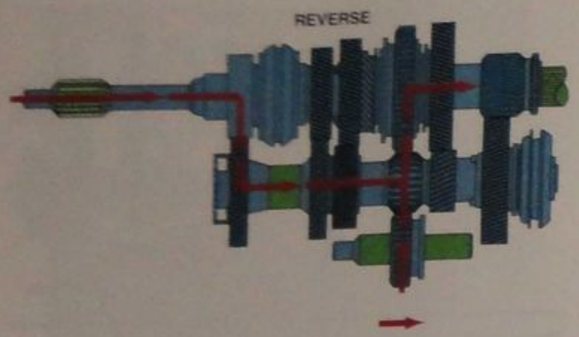


Figure 95–30 Torque flows through the transmission in reverse gear. Note that the idler gear drives the 1–2 synchronizer sleeve gear, which is splined to the output shaft.

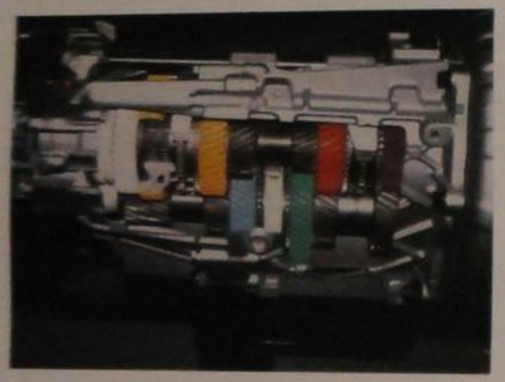


Figure 95–31 Cutaway of a T5 five-speed transmission showing all of its internal parts.

With **constant-mesh gears,** the shift linkage moves the 5-reverse synchronizer sleeve away from the fifth speed gear and toward the reverse speed gear when reverse is selected. Typically, no stop ring is used between the synchronizer sleeve and the reverse gear, so the output shaft must be stopped to engage reverse without grinding the sleeve splines against the coupling teeth of the reverse gear. The synchronizer assembly locks the reverse speed gear to the output shaft.

With the clutch engaged, the input shaft drives the countershaft. The reverse counter gear drives the reverse idler gear, which drives the reverse speed gear in the direction opposite normal rotation. The reverse speed gear drives the output shaft through the 5-reverse synchronizer hub splines. Torque flows through the transmission in gear reduction at the reverse gear ratio. The output shaft turns opposite its normal direction of rotation, so the vehicle moves to the rear. See Figure 95–31.

MANUAL TRANSAXLE CONSTRUCTION

A manually shifted transaxle includes an input shaft, an output shaft, and a differential assembly all in one case. The input shaft is attached to the clutch, which transfers engine torque from the engine flywheel to the input shaft when the clutch is engaged. Most transaxles use speed gears and synchronizers on both the input and output shafts, as shown in Figure 95–32. The differential assembly, also called a **final drive assembly,** attaches to the output shaft and splits the torque to both front drive axles. See Figure 95–33.

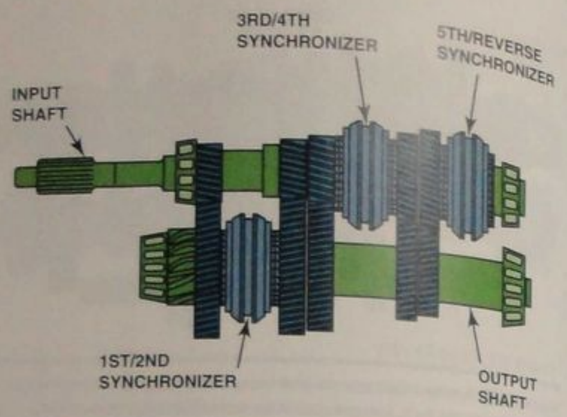


Figure 95–32 Notice that this five-speed transaxle from a Dodge/Plymouth Neon uses synchronizers on both the input and output shafts.

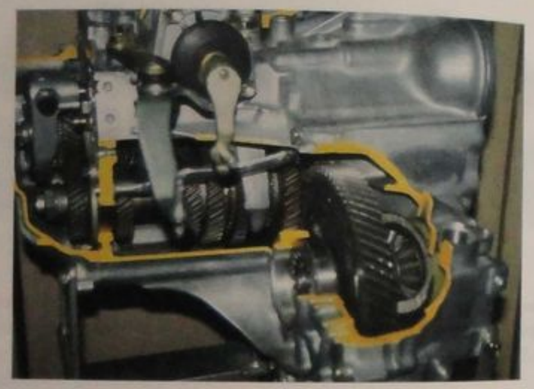


Figure 95–33 Cutaway of a typical manual transaxle showing all of its internal parts including the final drive assembly.

TRANSMISSION/TRANSAXLE REMOVAL

Before removing the transmission/transaxle for service, double-check that the problem is not due to any malfunction of the clutch or shift linkage. To remove a transmission or transaxle, always follow the procedure in the service manual to be assured of doing no harm to either the vehicle or to yourself. Steps typically involved in the removal and disassembly include

- Disconnecting the negative battery cable
- Safely hoisting and supporting the vehicle
- Supporting the engine with a holding fixture or other support (front-wheel-drive). See Figure 95–34.
- Removing the drive axle shafts or drive shaft (rear-wheel-drive)
- Removing the clutch linkage and shift linkage. See Figures 95–35 and 95–36.
- Disconnecting the vehicle speed sensor and reverse (backup) light connectors
- Removing the attaching bolts/nuts from the engine and transmission/transaxle mounts and then removing the unit from the vehicle

Sometimes it is easier to remove the entire power train (engine and transaxle as an assembly) from the vehicle, as shown in Figure 95–37. When the entire assembly has been removed from the vehicle, often the transaxle can then be removed from the engine.



Figure 95–34 When the transmission/transaxle is removed from the vehicle, the engine must be supported. In this case, the engine oil pan is supported with a block of wood to spread the load across the entire oil pan to prevent damage. The block of wood is placed on top of a tall safety stand that allows room for the service technician to work while standing.



Figure 95–35 A transmission from a restored muscle car from the 1970s. Notice the use of internal control rod shift linkage.



Figure 95–36 Typical cable-operated shift linkage used on a front-wheel-drive transaxle.



(a)



(b)

Figure 95–37 (a) Saturn drive train is removed as an assembly along with the cradle. (b) The transaxle can now be easily removed from the cradle and the engine.

TRANSMISSION/TRANSAXLE DISASSEMBLY

Before disassembling the transmission/transaxle, drain any remaining gear lubricant from the unit and dispose of it properly.

CAUTION: Most extreme pressure (EP) lubricants contain sulfur compounds that can cause skin irritation. Either wear protective gloves or wash your hands thoroughly using soap and water after exposure to used gear lubricant.

Mount the transmission/transaxle on a holding fixture or place it on a large, clean work surface. Many vehicle manufacturers recommend removing the shift housing before further disassembly.

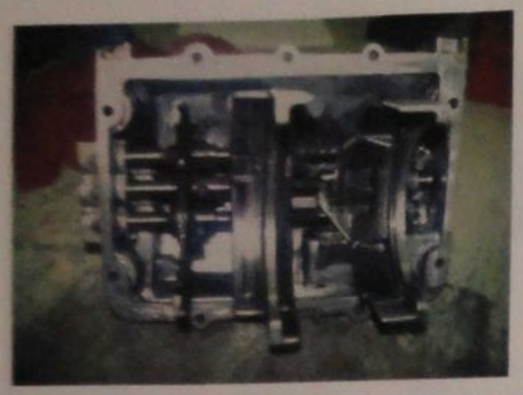


Figure 95–38 The shift forks should be inspected for wear.



Figure 95–39 The cost to replace these gears may exceed the cost of a replacement transmission.



Figure 95–40 It often requires two people to assemble a transaxle because the shaft with the shifter forks needs to be placed into the case as an assembly, as on this unit.

The removal of the shifter housing allows the technician to see any obvious damage as well as providing the opportunity to check the shift forks, which are frequently worn in manually-shifted transmissions/transaxles. See Figures 95–38 and 95–39.

The disassembly and reassembly of a manual transaxle is similar to that for a manual transmission except for the addition of the final drive unit. Some transaxles require two people for disassembly and reassembly because often the shift linkage has to be held in



(a)



(b)



(c)

Figure 95–41 (a) During the disassembly of any manual transmission/transaxle, carefully check for the location of the snap rings. Often they are hidden. Consult the factory service manual or unit repair manual for information and procedures for the unit being serviced. (b) Using snap-ring pliers to remove a snap ring. Many snap rings have an "up" side. Be sure to reinstall any snap rings in the correct direction. (c) After the snap ring is removed, some components can be simply lifted off the main shaft, while other gears may require the use of a press.

place while assembled components are placed into the case, as shown in Figure 95–40.

Check the service manual for the exact disassembly procedures to follow for the unit being serviced. Sometimes the main shaft is removed through the rear of the transmission and sometimes it is removed through the top of the case. Also look for hidden snap rings. See Figures 95–41 and 95–42. Also see the Tech Tip titled "Manual Transmission Service Tips."



(a)



(b)



(c)

Figure 95–42 (a) Many gears require that a hydraulic press be used to separate the gears from the shaft. After double-checking that all snap ring retainers have been removed and after checking in the service manual to see which gear needs to be pressed off, carefully position the "bearing splitter" as far inward as possible to avoid damaging the teeth during the pressing operation. (b) For safety, place an old brake drum over the gear(s) being pressed off. If the gear were to shatter, the parts will be trapped inside the brake drum. (c) Some transmission disassembly and reassembly procedures require the use of special pullers, such as this tool being used on a NV 4500 transmission.

TECH TIP ✓ **Manual Transmission Service Tips**

A wise technician once told a beginning technician to remember these items when working with transmissions:

- Always use a *brass* or *plastic* hammer when pounding on a steel or aluminum component.
- If using a steel hammer, always use a *brass* or *aluminum* punch or place wood between the steel components and the hammer.
- Many parts can be installed in either direction but usually only one way is correct.
- If you are exerting a lot of force, you are probably doing something wrong.
- Many drive train parts are pulled or pressed off and pressed or driven on.

HARD-TO-SHIFT PROBLEM DIAGNOSIS

Several items that could be worn or defective can cause a manual transmission/transaxle to be difficult to shift, including

- **Clutch not fully disengaging.** If the clutch linkage is not properly adjusted or if there is a leak in the hydraulic clutch linkage, the clutch may not be fully disengaged. A shift is very difficult, if not impossible, if engine torque is being transferred through the transmission/transaxle as a shift is being attempted.
- **Worn synchronizer.** If the synchronizer rings are worn, the rings will be unable to properly match the speed gear speed, making the shift difficult and/or creating gear clash (noise) when shifting.
- **Worn, cracked, or loose shift forks.** If there is any problem with the shift forks, the synchronizer cannot be properly moved during a shift attempt, making shifting difficult, if not impossible. If only one fork is worn or defective, usually engaging two gears instead of one is likely.
- **Excessive input- or main-shaft end play.** Excessive end play in the input or main shaft will cause the gears to move away from the synchronizer assembly, resulting in grinding during shifts or shifts that are difficult or impossible to complete.
- **Improper lubrication.** Many of today's manual transmissions use synchronizer rings (blocking rings) that are lined with compounds, paper, or other friction material. All of these transmissions/transaxles must be filled with the proper fluid formulated for proper shifting.

REAL WORLD FIX **The Worn Shift Fork Mystery**

A vehicle equipped with a manual transmission had to be repaired several times for worn shift forks. Even though the vehicle warranty paid for the repair, both the customer and the service department personnel were concerned about the repeated failures. All technical service bulletins (TSBs) were checked to see if there was an updated, improved shift fork. No luck. Even the manufacturer's technical assistance personnel were unable to determine why the shift forks were wearing out. After the third repair, the service technician rode with the customer to see if the cause could be determined. As the woman driver got into the driver's seat, she placed the handle of her purse over the shifter on the floor and allowed the purse to hang from the shifter. The technician asked the owner if she always placed her purse on the shifter and when she said yes, the technician knew immediately the cause of the worn shift forks. The purse exerted a force on the shifter all the time. This force pushed the shift forks against the synchronizer sleeve. Because the sleeve rotates all the time the vehicle is in motion, the shift forks were quickly worn. The service technician should have determined the root cause of the problem after the *first* repair. The customer agreed to find another location for her purse so that the transmission problem would not reoccur.

NOTE: A worn synchronizer sleeve and/or blocking ring can cause the transmission/transaxle to pop out of gear while accelerating or decelerating.

MANUAL TRANSMISSION INSTALLATION

When installing a repaired or replacement transmission/transaxle, the clutch should be carefully inspected and replaced as necessary. The clutch friction disk must be held in position using an alignment tool (sometimes called a *dummy shaft*) that is secured in the pilot bearing. This holds the disk in position while the pressure plate is being installed. Finally, the engine bell housing is put on the engine, if it was not installed before. The alignment of this type of bell housing is then checked.

CAUTION: Perfectly round cylinders can be distorted whenever another part of the engine is bolted and torqued to the engine block. For example, it has been determined that after the cylinders are machined, the rear cylinder bore can be distorted as much as 0.006 inch (0.15 millimeter) out-of-round after the bell housing is bolted onto the block! To help prevent this distortion, always apply the specified torque to all fasteners going into the engine block and tighten in the recommended sequence.

The clutch release yoke should be checked for free movement. Usually, the clutch release bearing is replaced, ensuring that the new bearing is securely attached to the clutch release yoke. The transmission can then be installed.

The transmission clutch shaft must be guided straight into the clutch disk and pilot bearing. See the Tech Tip "The Headless Bolt Trick." The transmission clutch shaft is rotated, as required, to engage in the splines of the clutch disk. The assembly bolts are secured when the transmission fully mates with the bell housing.

CAUTION: Always adjust the clutch free play *before* starting the engine to help prevent thrust bearing damage.

Complete the installation by attaching the transmission/transaxle mount, driveshaft (drive axle shafts), vehicle speed sensor, and reverse (backup) light switch.

GEAR LUBRICATION

After the installation of the transmission/transaxle, the unit should be filled with the correct lubricant. The various lubricants, their general use, and their American Petroleum Institute (API) rating include

GL-1 Straight mineral oil

GL-2 Worm-type gear lubricant

GL-3 Mild-type EP lubricant (will not protect hypoid gears)

GL-4 EP-type lubricant (okay for manual transmissions/transaxles)

GL-5 EP-type okay for hypoid gears and for Mil-L2150B (military)

Manual transmissions/transaxles require one of the following lubricants:

- SAE 80W-90 (GL-4) gear lube
- STF (synchromesh transmission fluid), but with friction characteristics designed for manual transmissions. See Figure 95–43.
- ATF (automatic transmission fluid)
- Engine oil (usually SAE 5W-30)

CAUTION: Failure to use the specified manual transmission/transaxle lubricant could cause hard shifting and possible severe transmission damage.

TECH TIP ✔ The Headless Bolt Trick

Sometimes parts do not seem to line up correctly. Try this tip the next time. Cut the head off extra-long bolts that are of the same diameter and thread as those being used to retain the part, such as a transmission. See Figure 95–44. Use a hacksaw to cut a slot in the end of these guide bolts for a screwdriver slot. Install the guide bolts; then install the transmission. Use a straight-blade screwdriver to remove the guide bolts after securing the transmission with the retaining bolts.



Figure 95–43 Some manual transmissions/transaxles require synchromesh transmission fluid.

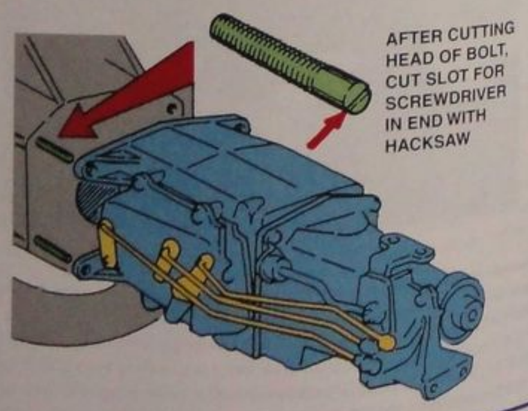


Figure 95–44 Headless, long bolts can be used to help install a transmission to the engine.

PHOTO SEQUENCE NV-1500 Manual Transmission Service



P95–1 A NV-1500 five-speed manual transmission is used in two-wheel drive applications only.



P95–2 The shifter assembly has been removed. Not the roll pin in the center of the shift lever socket.



P95–3 Snap-ring pliers are being used to remove the snap ring retaining the input shift bearing.



P95–4 The upside down case is being separated from the countershaft (top) and shift forks.



P95–5 Before further disassembly can be accomplished, the shift lever socket roll pin must be driven out using a punch and a hammer.



P95–6 The shift shaft and forks can now be removed.



P95–7 The reverse idle gear is unbolted from the case and removed.



P95–8 A special tool is required to be bolted to the case of the output shaft bearing retainer before the output shaft. The output shaft assembly fifth gear (far left) and the synchronizer assemblies.



P95–9 The bearing is being removed using a bearing splitter and a hydraulic press.



P95–10 A speed gear (bottom) along with the double row needle bearing used between the shaft and the splined gear. The hub (center) is splined and rotates with the output shaft.



P95–11 A synchronizer assembly being reassembled. It often takes several hands to hold the hub (center) and the sleeve (outer ring).



P95–12 A hydraulic press is used to reassemble output shaft and bearing.

(continued)



P95–13 The assembled output shaft is held against the countershaft to double check that all of the gears have been correctly assembled.



P95–14 The assembled output shaft and counter are being reinstalled in the transmission case.



P95–15 The case halves are bolted together.



P95–16 The roll pin is reinstalled in the shift lever socket. The last component in the installation of countershaft bearing cup (background on the tab which also provides the countershaft bearing press.

NV-350 Transaxle Service



P95–17 After the transaxle has been removed from the stand and the fluid drained, place the transaxle on a work surface.



P95–18 The bell housing case half containing the large output shaft front bearing (center) and the input shaft front bearing (smaller bearing on the left).



P95–19 The differential assembly is simply lifted out of half of the case.



P95–20 The input and output shafts are a press fit into the bearings and are also retained with a snap ring, which must be removed.



P95–21 Using a special tool, the input and output shafts are pressed out of the housing using a hydraulic press.



P95–22 The input shaft can be disassembled using a bearing splitter and a press, or two screwdrivers to pry the gears off the shaft.



P95–23 This transaxle uses both brass and sintered metal synchronizer rings with a fiber insert inner cone surface.



P95–24 Synchronizer ring gaps are being measured using a feeler (thickness) gauge. The factory specifications are usually 0.040 in. to 0.089 in.



P95–25 The gear clutch teeth should be inspected for wear.



P95–26 An assembled synchronizer assembly showing a sleeve, struts, springs, and detent.



P95–27 The input shaft (left) and the output shaft (right) are checked for proper assembly before being installed into the case.



P95–28 The differential bearing preload is determined by measuring for zero end play; then adding the thickness shim under the bearing cup.



P95–29 The bearing cup is being installed using an installation tool and a hammer.



P95–30 All of the shift forks and shift arms must be aligned properly before installing the components into the case.



P95–31 All of the components, including the differential (right), the output shaft (center), and the input shaft (left), plus the shift linkage are installed and checked for proper positioning.



P95–32 The case halves being reinstalled. The bearings (top) must be pressed back onto the input and output shafts using a press.



P95–33 The bell housing case being reattached.



P95–34 The completed assembly. Notice the bearing cover (top) has already been installed.

SUMMARY

1. A transmission is required both to provide the torque necessary to the drive wheels to get the vehicle moving from a stop and to provide economical cruising on the highway.
2. A gear ratio is determined by dividing the number of teeth on the driven gear (output) by the number of teeth on the driving gear (input). A ratio is always expressed as a number relative to one rotation of the output gear.
3. An overdrive ratio is a ratio that results in the output gear rotating faster than the input gear; the first number of this ratio is less than one.
4. A spur gear is a gear with straight teeth, and a helical-cut gear is a gear with angled teeth.
5. The input shaft is splined to the clutch disc. The output shaft is also called the main shaft.
6. A countershaft is another shaft inside a transmission/transaxle which provides another set of gears to produce the necessary gear ratios.
7. Care should be taken to not damage the parts of the transmission/transaxle during disassembly. Always consult the factory service manual for the exact procedures to follow, especially regarding using a hydraulic press to press gears off or on the shafts.
8. A synchronizer assembly permits a shift to be made without gear clash. The parts of a typical synchronizer include the synchronizer sleeve, hub, and ring.
9. A transaxle includes a final drive unit that splits the torque to the two front drive wheels and allows the drive wheels to rotate at different speeds while traveling around a corner or over bumpy roads.
10. A manual transmission/transaxle may use one of four possible lubricants including gear lube, synchromesh transmission fluid (STF), automatic transmission fluid (ATF), or engine oil.

REVIEW QUESTIONS

1. Calculate the gear ratio if the driven gear has 36 teeth and the driving gear has 12 teeth.
2. Explain what is meant by an overdrive ratio.
3. List the parts of a manual transmission.
4. Explain how a synchronizer assembly is able to allow a clash-free shift.
5. List four possible causes for a manual transmission/transaxle being difficult to shift.
6. List the possible lubricants that a manual transmission/transaxle may require.

CHAPTER QUIZ

1. Technician A says that the torque available at the output shaft is greater in second gear than when the transmission/transaxle is in third gear at the same engine speed. Technician B says that the output shaft is rotating faster when the transmission/transaxle is in second gear compared to third gear when the engine is at the same speed. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. The driving gear has 15 teeth and the driven gear has 29 teeth. Technician A says that the output gear will be going faster than the input gear. Technician B says the ratio is 1.86:1. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Which part is splined to the clutch disc?
   a. Main shaft
   b. Countershaft (lay shaft)
   c. Cluster shaft
   d. Main gear
4. Two technicians are discussing how torque is increased inside a manual transmission/transaxle. Technician A says that the gear ratio in first gear between the main shaft and the countershaft should be *multiplied* by the ratio of the corresponding countershaft gear and output shaft gear. Technician B says that the two ratios should be added together. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Which component cannot be removed before removing the transmission/transaxle from the vehicle?
   a. Vehicle speed sensor
   b. Reverse (backup) light connector
   c. Front bearing retainer (quill)
   d. Drive axle shaft(s)
6. Technician A says that snap-rings are used to hold many components of a manual transmission/transaxle. Technician B says that snap rings have a "right side" that should always face up so that the snap-ring pliers can be applied. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. A customer complained of hard shifting particularly into first gear and reverse. Technician A says that the blocking ring may be worn. Technician B says that the clutch may be defective or out of adjustment. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. Which part of a synchronizer is splined to a shaft?
   a. Synchronizer sleeve
   b. Hub
   c. Synchronizer ring (blocking ring)
   d. Speed gear
9. A manual transmission is difficult to shift but only when the outside temperature is below freezing (32°F or 0°C). Technician A says that the brass blocking ring could be defective. Technician B says that incorrect gear lubricant could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Which type of lubricant is usually *not* used in a manual transmission/transaxle?
    a. Automatic transmission fluid (ATF)
    b. High-temperature chassis grease
    c. SAE 80W-90 gear lube
    d. Engine oil

CHAPTER 96

Drive Axle Shafts and CV Joints

OBJECTIVES: **After studying Chapter 96, the reader will be able to:** Prepare for ASE Suspension and Steering (A4) certification test content area "C" (Related Suspension and Steering Service). • Name driveshaft and U-joint parts, and describe their function and operation. • Describe how CV joints work. • Explain how the working angles of the U-joints are determined. • List the various types of CV joints and their applications.

KEY TERMS: cardan joints • center support bearing • CV joint boot • CV joints • double-cardan joints • drive axle shaft • driveshaft • fixed joint • half shaft • plunge joint • propeller shaft • Rzeppa joint • spider • trunnions • universal joints

A drive axle shaft transmits engine torque from the transmission or transaxle (if front wheel drive) to the rear axle assembly or drive wheels. See Figures 96–1 and 96–2.

Driveshaft is the term used by the Society of Automotive Engineers (SAE) to describe the shaft between the transmission and the rear axle assembly on a rear-wheel-drive vehicle. General Motors and some other manufacturers use the term **propeller shaft** or *prop shaft* to describe this same part. The SAE term will be used throughout this textbook.

A typical driveshaft is a hollow steel tube. A splined end yoke is welded onto one end that slips over the splines of the output shaft of the transmission. See Figure 96–3. An end yoke is welded onto the other end of the driveshaft. Some driveshafts use a center support bearing.

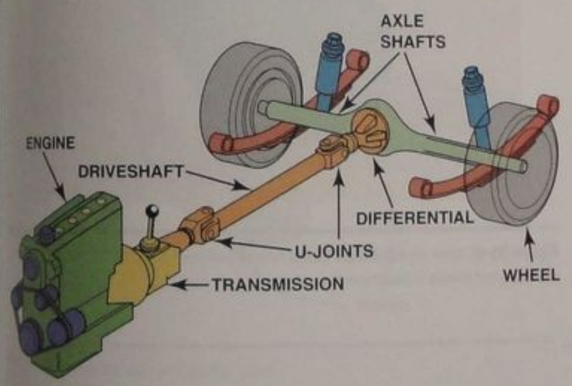


Figure 96–1 Typical rear-wheel-drive power train arrangement. The engine is mounted longitudinal (lengthwise).

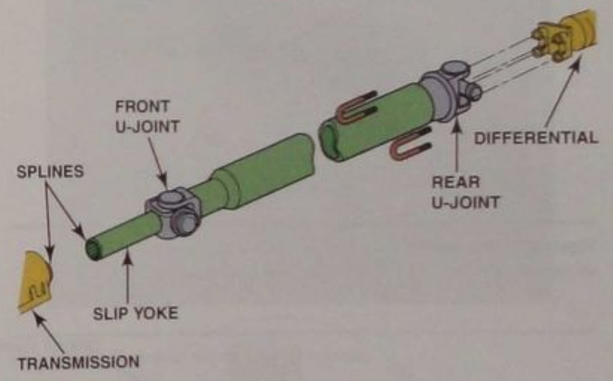


Figure 96–3 Typical driveshaft (also called a *propeller shaft*). The drivershaft transfers engine power from the transmission to the differential.

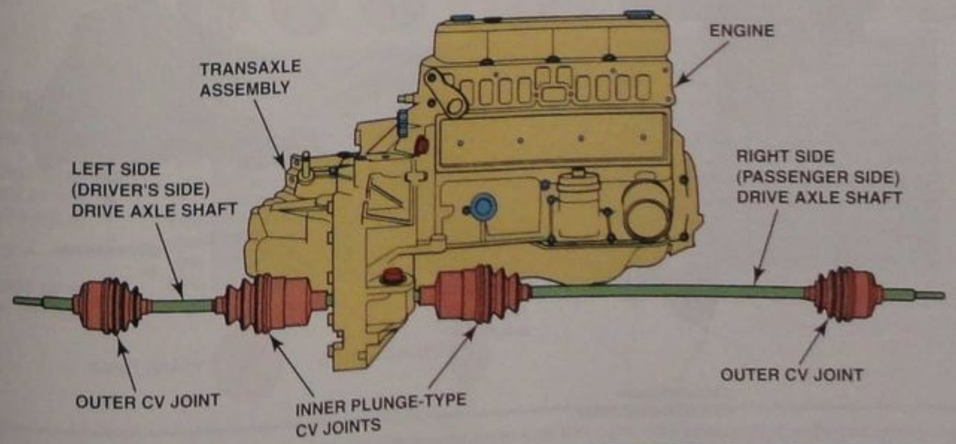


Figure 96–2 Typical front-wheel-drive power train arrangement. The engine is usually mounted transversely (sideways).

DRIVESHAFT DESIGN

Most driveshafts are constructed of hollow steel tubing. *The forces are transmitted through the surface of the driveshaft tubing.* The surface is therefore in tension, and cracks can develop on the outside surface of the driveshaft due to metal fatigue. Driveshaft tubing can bend and, if dented, can collapse. See Figure 96–4.

Most rear-wheel-drive cars and light trucks use a one- or two-piece driveshaft. A steel tube driveshaft has a maximum *length of about 65 in. (165 cm).* Beyond this critical length, a **center support bearing** must be used, as shown in Figure 96–5. A center support bearing is also called a steady bearing or hanger bearing.

Some vehicle manufacturers use aluminum driveshafts; these can be as long as 90 in. (230 cm) with no problem. Many extended-cab pickup trucks and certain vans use aluminum driveshafts to eliminate the need (and expense) of a center support bearing. Composite-material driveshafts are also used in some vehicles. These carbon-fiber-plastic driveshafts are very strong yet lightweight, and can be made in extended lengths without the need for a center support bearing.



Figure 96–4 This driveshaft failed because it had a slight dent caused by a rock. When engine torque was applied, the driveshaft collapsed, twisted, and then broke.

To dampen driveshaft noise, it is common to line the inside of the hollow driveshaft with cardboard. This helps eliminate the tinny sound whenever shifting between drive and reverse in a vehicle equipped with an automatic transmission. See Figure 96–6.

DRIVESHAFT BALANCE

All driveshafts are balanced. Generally, any driveshaft whose rotational speed is greater than 1000 RPM must be balanced. Driveshaft balance should be within 0.5% of the driveshaft weight. (This is one of the biggest reasons why aluminum or composite driveshafts can be longer because of their light weight.)

Driveshafts are often not available by make, model, and year of the vehicle. There are too many variations at the factory, such as transmission type, differential, or U-joint type. To get a replacement driveshaft, it is usually necessary to know the series of U-joints (type or style of U-joint) and the center-to-center distance between the U-joints.

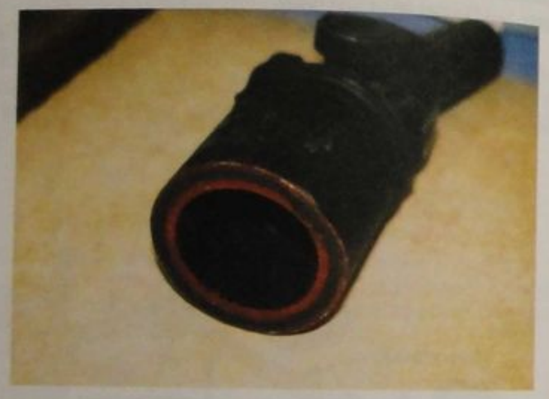


Figure 96–6 Some driveshafts use rubber between an inner and outer housing to absorb vibrations and shocks to the driveline.

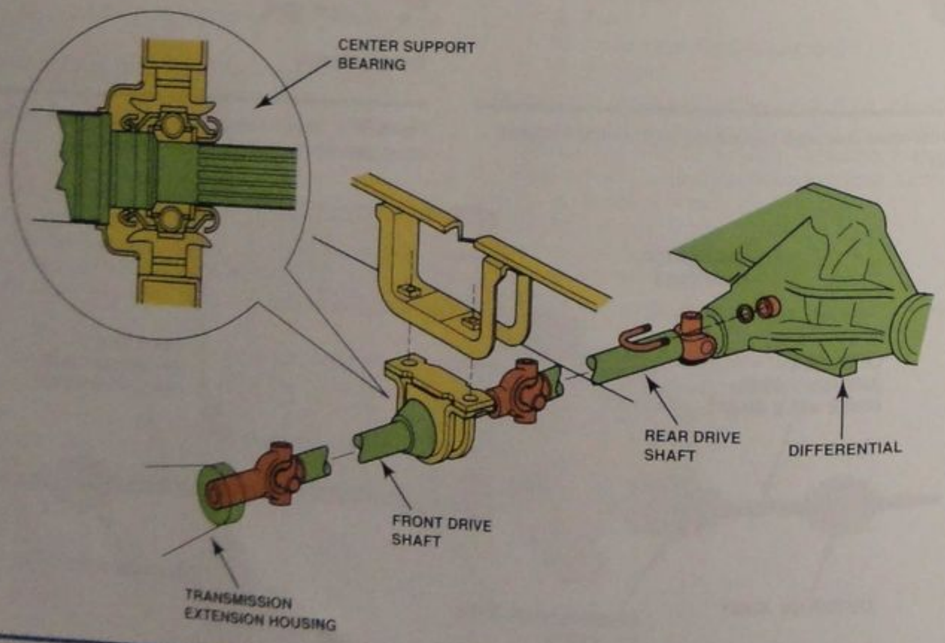


Figure 96–5 A center support bearing is used on many vehicles with long driveshafts.

U-JOINT DESIGN AND OPERATION

Universal joints (U-joints) are used at both ends of a driveshaft. U-joints allow the wheels and the rear axle to move up and down, remain flexible, and still transfer torque to the drive wheels. A simple universal joint can be made from two Y-shaped yokes connected by a crossmember called a cross or **spider.** The four arms of the cross are called **trunnions.** See Figure 96–7 for a line drawing of a simple U-joint with all part names identified. A similar design is the common U-joint used with a socket wrench set.

Most U-joints are called cross-yoke joints or **Cardan joints.** Cardan is named for a sixteenth-century Italian mathematician who worked with objects that moved freely in any direction. Torque from the engine is transferred through the U-joint. The engine drives the U-joint at a constant speed, but the output speed of the U-joint changes because of the angle of the joint. The speed changes twice per revolution. *The greater the angle, the greater the change in speed (velocity).* See Figure 96–8.

If only one U-joint were used in a driveline, this change in speed of the driven side (output end) would generate vibrations in the driveline. To help reduce vibration, another U-joint is used at the other end of the driveshaft. If the angles of both joints are nearly equal, the acceleration and deceleration of one joint is offset by the alternate deceleration and acceleration of the second joint. *It is very important that both U-joints operate at about the same angle to prevent excessive driveline vibration.* See Figure 96–9.

Acceptable Working Angles Universal joints used in a typical driveshaft should have a *working angle* of 1/2 to 3 degrees. See Figure 96–10. The working angle is the angle between the driving end and the driven end of the joint. If the driveshaft is perfectly

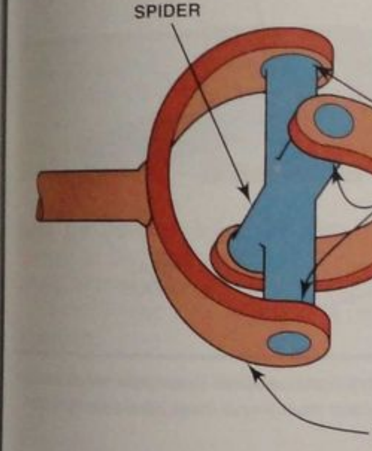


Figure 96–7 A simple universal joint (U-joint).

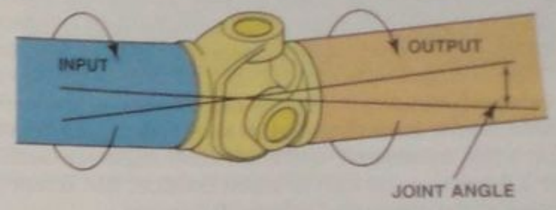


Figure 96–9 The joint angle is the difference between the angles of the joint. *(Courtesy of Dana Corporation)*



Figure 96–10 The angle of this rear U-joint is noticeable.

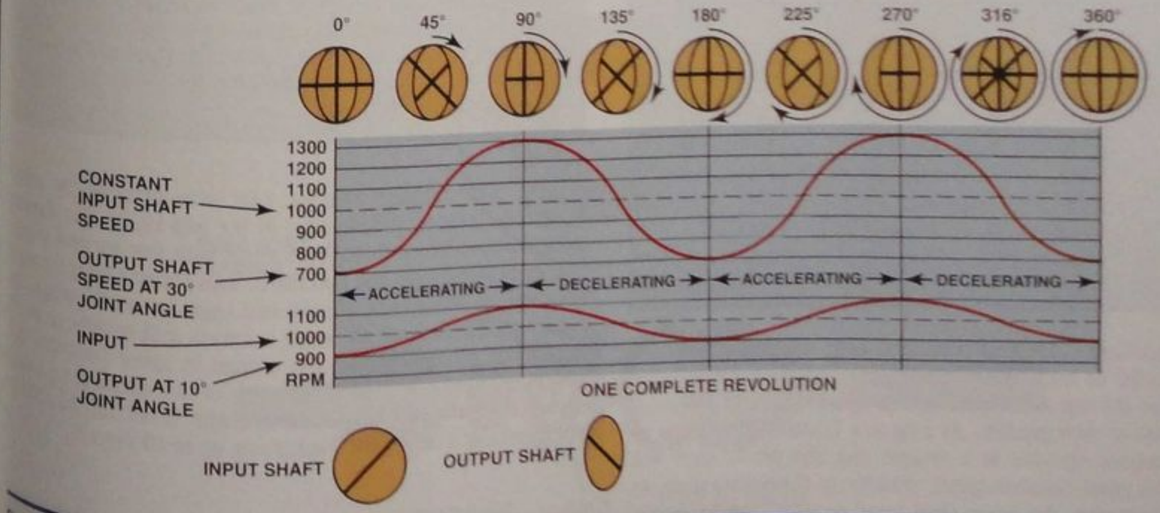


Figure 96–8 How the speed difference on the output of a typical U-joint varies with the speed and the angle of the U-joint. At the bottom of the chart, the input speed is a constant 1000 RPM, while the output speed varies from 900 RPM to 1100 RPM when the angle difference in the joint is only 10°. At the top part of the chart, the input speed is a constant 1000 RPM, yet the output speed varies from 700 to 1200 RPM when the angle difference in the joint is changed to 30°. *(Courtesy of Dana Corporation)*

straight (0-degree working angle), then the needle bearings inside the bearing cap are not revolving because there is no force (no difference in angles) to cause the rotation of the needle bearings. If the needle bearings do not rotate, they can exert a constant pressure in one place and damage the bearing journal. If a two-piece driveshaft is used, one U-joint (usually the front) runs at a small working angle of about 1/2 degree, just enough to keep the needle bearings rotating. The other two U-joints (from the center support bearing and rear U-joint at the differential) operate at typical working angles of a single-piece driveshaft.

If the U-joint working angles differ by more than 1/2 degree, a vibration is usually produced that is *torque sensitive*. As the vehicle is first accelerated from a stop, engine torque can create unequal driveshaft angles by causing the differential to rotate on its suspension support arms. This vibration is most noticeable when the vehicle is heavily loaded and being accelerated at lower speeds. The vibration usually diminishes at higher speeds due to decrease in the torque being transmitted. If the driveshaft angles are excessive (over 3 degrees), a vibration is usually produced that increases as the speed of the vehicle (and driveshaft) increases.

CONSTANT VELOCITY JOINTS

Constant velocity joints, commonly called **CV joints,** are designed to rotate without changing speed. Regular U-joints are usually designed to work up to 12 degrees of angularity. If two Cardan-style U-joints are joined together, the angle at which this **double-Cardan joint** can function is about 18 to 20 degrees. See Figure 96–11.

FREQUENTLY ASKED QUESTION ???

What Is a 1350-Series U-Joint?

Most universal joints are available in sizes to best match the torque that they transmit. The larger the U-joint, the higher the amount of torque. Most U-joints are sized and rated by series numbers. See the accompanying chart for series numbers and sizes.

Series Number	Cap Diameter (inches)	Overall Length (inches)	Trunnion Diameter (inches)
1000	15/16	2 5/64	1/2
1100	15/16	2 13/64	1/2
1280/1310	1 1/16	2 31/32	19/32
1350	1 1/16	2 31/32	39/64
1310	1 1/16	2 31/32	21/32
1330	1 1/16	3 3/8	21/32
1300	1 3/16	3 3/8	49/64
1410	1 3/16	3 15/16	49/64
1480	1 3/8	3 7/8	57/64

Double-Cardan U-joints were first used on large rear-wheel-drive vehicles to help reduce drive-line-induced vibrations, especially when the rear of the vehicle was fully loaded and driveshaft angles were at their greatest. As long as a U-joint (either single or double Cardan) operates in a straight line, the driven shaft will rotate at the same constant speed (velocity) as the driving shaft. As the angle increases, the driven shaft speed or velocity varies during each revolution. This produces pulsations and a noticeable vibration or surge. The higher the shaft speed and the greater the angle of the joint, the greater the pulsations.

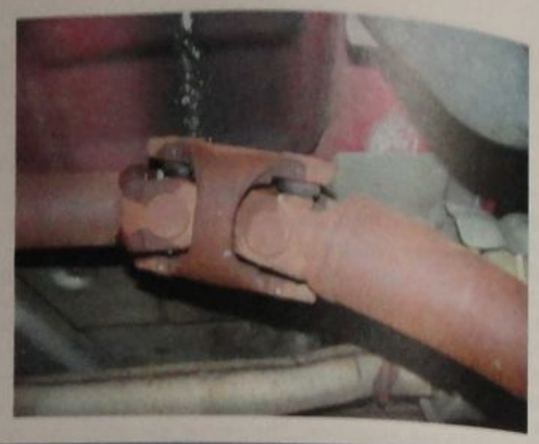


Figure 96–11 A double-Cardan U-joint.

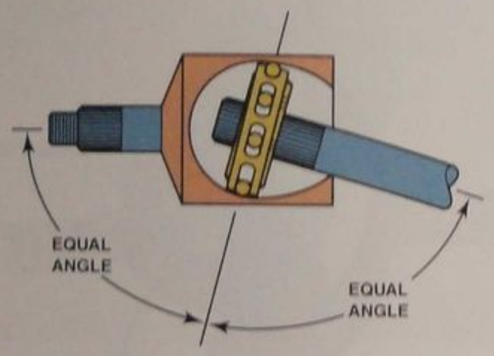


Figure 96–12 A constant velocity (CV) joint can operate at high angles without a change in velocity (speed) because the joint design results in equal angles between input and output.

NOTE: Many four-wheel-drive light trucks use standard Cardan-style U-joints in the front drive axles. If the front wheels are turned sharply and then accelerated, the entire truck often shakes due to the pulsations created by the speed variations through the U-joints. This vibration is normal and cannot be corrected. It is characteristic of this type of design and is usually not noticeable in normal driving.

The first constant velocity joint was designed by Alfred H. Rzeppa (pronounced shep'pa) in the mid-1920s. The **Rzeppa joint** transfers torque through six round balls that are held in position midway between the two shafts. This design causes the angle between the shafts to be equally split regardless of the angle. See Figure 96–12. Because the angle is always split equally, torque is transferred equally without the change in speed (velocity) that occurs in Cardan-style U-joints. This style of joint results in a constant velocity between driving and driven shafts. It can also function at angles greater than simple U-joints can, up to 40 degrees.

NOTE: CV joints are also called LOBRO joints, the brand name of an original equipment manufacturer.

While commonly used today in all front-wheel-drive vehicles and many four-wheel-drive vehicles, its first use was on the front-wheel-drive 1929 Cord. Built in Auburn, Indiana, the Cord was the first front-wheel-drive car to use a CV-type drive axle joint.

Outer CV Joints The Rzeppa-type CV joint is most commonly used as an outer joint on most front-wheel-drive vehicles. See Figure 96–13. The outer joint must do the following:

1. Allow up to 40 degrees or more of movement to allow the front wheels to turn
2. Allow the front wheels to move up and down through normal suspension travel in order to provide a smooth ride over rough surfaces
3. Be able to transmit engine torque to drive the front wheels

Outer CV joints are called **fixed joints.** The outer joints are also attached to the front wheels. They are more likely to suffer from road hazards that often can cut through the protective outer flexible boot. See Figure 96–14. Once this boot has been split open, the special high-quality grease is thrown out and contaminants such as dirt and water can enter. Some joints cannot be replaced individually but as a worn. See Figure 96–15.

NOTE: Research has shown that in as few as eight hours of driving time, a CV joint can be destroyed by dirt, moisture, and a lack of lubrication if the boot is torn. The technician should warn the owner as to the possible cost involved in replacing the CV joint itself whenever a torn CV boot is found.

Inner CV Joints Inner CV joints attach the output of the transaxle to the drive axle shaft. Inner CV joints are therefore inboard, or toward the center of the vehicle. See Figure 96–16.

Inner CV joints have to be able to perform two very important movements:

1. Allow the drive axle shaft to move up and down as the wheels travel over bumps.

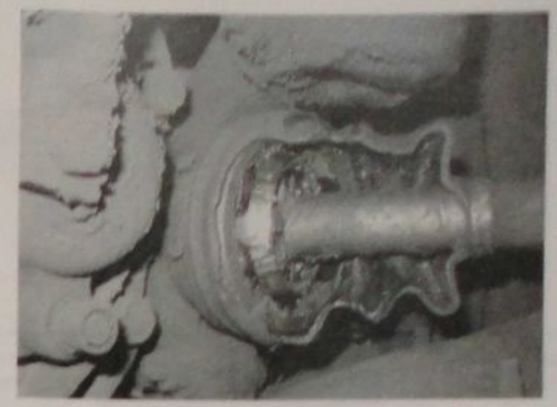


Figure 96–14 The protective CV joint boot has been torn away on this vehicle and all of the grease has been thrown outward onto the brake and suspension parts. The driver of this vehicle noticed a "clicking" noise, especially when turning.

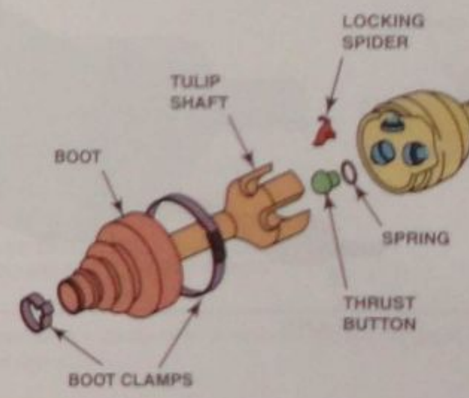


Figure 96–15 A tripod fixed joint. This type of joint is found on some Japanese vehicles. If the joint wears out, it is to be replaced with an entire drive axle shaft assembly.

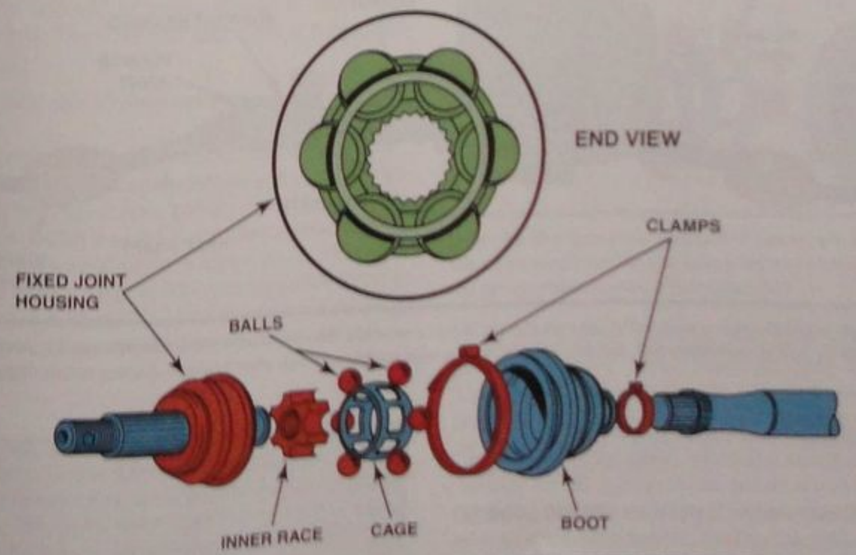


Figure 96–13 A Rzeppa fixed joint. This type of CV joint is commonly used at the wheel side of the drive axle shaft. This joint can operate at high angles to compensate for suspension travel and steering angle changes. *(Courtesy of Dana Corporation)*

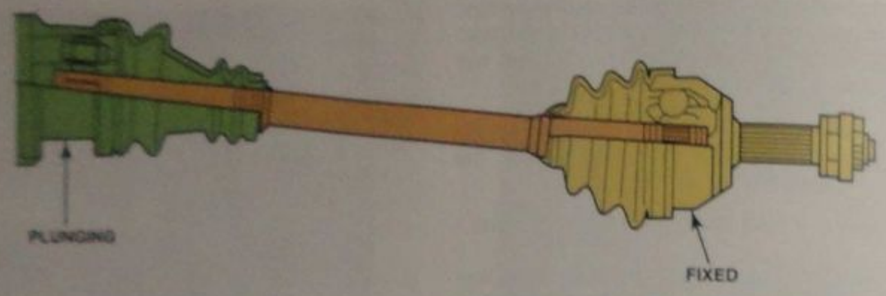


Figure 96–16 The fixed outer joint is required to move in all directions because the wheels must turn for steering as well as move up and down during suspension movement. The inner joint has to be able to not only move up and down but also plunge in and out as the suspension moves up and down. *(Courtesy of Dana Corporation)*

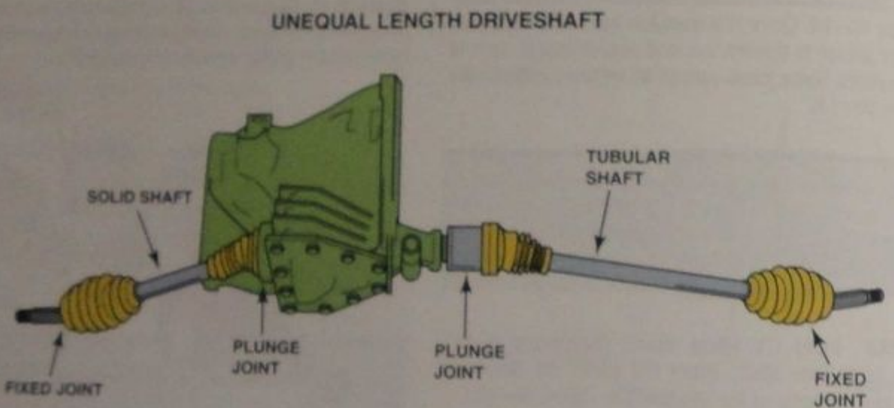


Figure 96–17 Unequal-length driveshafts result in unequal drive axle shaft angles to the front drive wheels. This unequal angle side-to-side often results in a steering of the vehicle during acceleration called torque steer. By using an intermediate shaft, both drive axles are the same angle and the torque steer effect is reduced. *(Courtesy of Dana Corporation)*

2. Allow the drive axle shaft to change length as required during vehicle suspension travel movements (lengthening and shortening as the vehicle moves up and down; same as the slip yoke on a conventional RWD driveshaft). CV joints are also called **plunge joints.**

Drive Axle Shafts Unequal-length **drive axle shafts** [also called **half shafts**] result in unequal drive axle shaft angles to the front drive wheels. See Figure 96–17. This unequal angle often results in a pull on the steering wheel during acceleration. This pulling to one side during acceleration due to unequal engine torque being applied to the front drive wheels is called torque steer. To help reduce the effect of torque steer, some vehicles are manufactured with an intermediate shaft that results in equal drive axle shaft angles. Both designs use fixed outer CV joints with plunge-type inner joints.

FREQUENTLY ASKED QUESTION ???

What Is That Weight for on the Drive Axle Shaft?

Some drive axle shafts are equipped with what looks like a balance weight. See Figure 96–18. It is actually a dampener weight used to dampen out certain drive line vibrations. The weight is not used on all vehicles and may or may not appear on the same vehicle depending on engine, transmission, and other options. The service technician should always try to replace a defective or worn drive axle shaft with the exact replacement. When replacing an entire drive axle shaft, the technician should always follow the manufacturer's instructions regarding either transferring or not transferring the weight to the new shaft.



Figure 96–18 A typical drive axle shaft with dampener weight.

Typical types of inner CV joints that are designed to move axially, or *plunge*, include the following:

1. Tripod. See Figure 96–19.
2. Cross groove. See Figure 96–20.
3. Double offset. See Figure 96–21.

CV joints are also used in rear-wheel-drive vehicles and in many four-wheel-drive vehicles.

CV Joint Boot Materials The pliable boot surrounding the CV joint, or **CV joint boot,** must be able to remain flexible under all weather conditions and still be strong enough to avoid being punctured by road debris. There are four basic types of boot materials used over CV joints:

1. *Natural rubber* (black) uses a bridge-type stainless steel clamp to retain.
2. *Silicone rubber* (gray) is a high-temperature-resistant material that is usually only used in places that need heat protection, such as the inner CV joint of a front-wheel-drive vehicle.
3. *Hard thermoplastic* (black) is a hard plastic material requiring heavy-duty clamps and a lot of torque to tighten (about 100 lb-ft!).
4. *Urethane* (usually blue) is a type of boot material usually found in an aftermarket part. See Figure 96–22 for examples of various types of CV joint boots depending on the manufacturer of the CV joints and shafts.

NOTE: Some aftermarket companies offer a split-style replacement CV joint boot. Being split means that the boot can be replaced without having to remove the drive axle shaft. Vehicle manufacturers usually do *not* recommend this type of replacement boot because the joint cannot be disassembled and properly cleaned with the drive axle still in the vehicle. The split boots must also be kept perfectly clean (a hard job to do with all the grease in the joint) in order to properly seal the seam on the split boot.

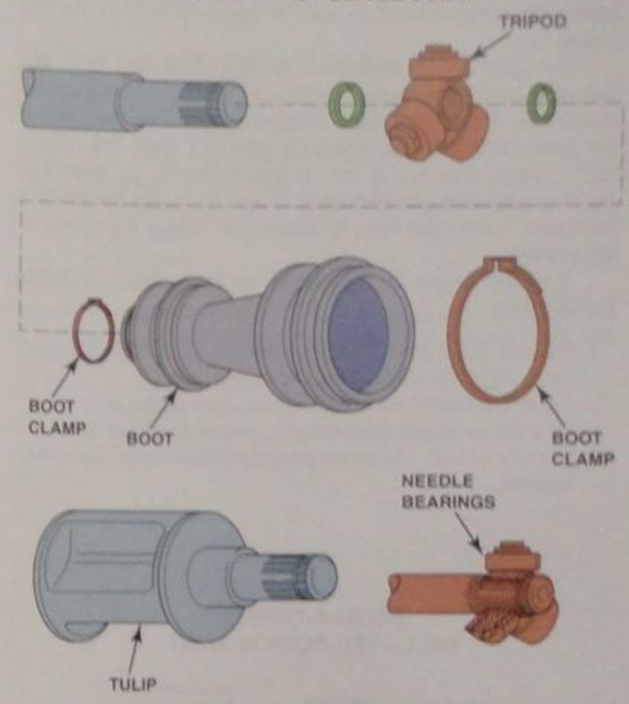


Figure 96–19 A tripod joint is also called a tripot, tripode, or tulip design. *(Courtesy of Dana Corporation)*

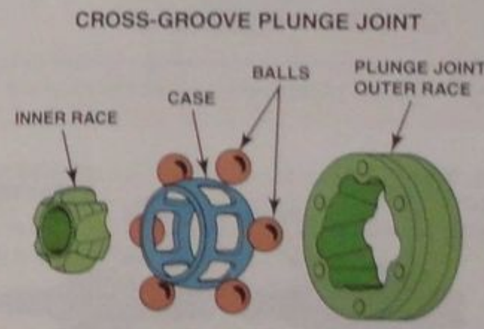


Figure 96–20 A cross-groove plunge joint is used on many German front-wheel-drive vehicles and as both inner and outer joints on the rear of vehicles that use an independent-type rear suspension. *(Courtesy of Dana Corporation)*

It is important that boot seals be inspected regularly and replaced if damaged. The inboard (plunging joint) can often pump water into the joint around the seals or through small holes in the boot material itself because the joint moves in and out. Seal retainers are used to provide a leakproof connection between the boot seal and the housing or axle shaft.

CV Joint Grease CV joints require special greases. Grease is an oil with thickening agents. Greases are named for the thickening agents used.

Most CV joint grease is molybdenum-disulfide-type grease, commonly referred to as *moly* grease. The exact composition of grease

can vary depending on the CV joint manufacturer. *The grease supplied with a replacement CV joint or boot kit should be the only grease used.*

The exact mix of chemicals, viscosity (thickness), wear, and corrosion-resistant properties varies from one CV joint application to another. Some technicians mistakenly think that the *color* of the grease determines in which CV joint it is used. The color—such as black, blue, red, or tan—is used to identify the grease during manufacturing and packaging as well as to give the grease a consistent, even color (due to blending of various ingredients in the grease).

The exact grease to use depends on many factors, including the following:

1. The type (style) of CV joint. For example, outer (fixed) and inner (plunging) joints have different lubricating needs.
2. The location of the joint on the vehicle. For example, inner CV joints are usually exposed to the greatest amount of heat.
3. The type of boot. The grease has to be compatible with the boot material.

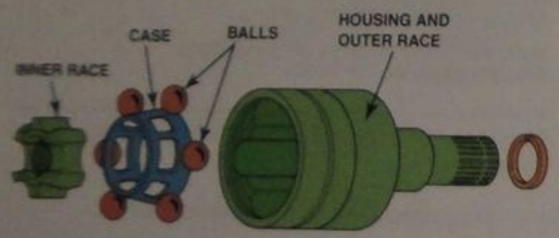


Figure 96-21 Double-offset ball-type plunge joint. (Courtesy of Dana Corporation)

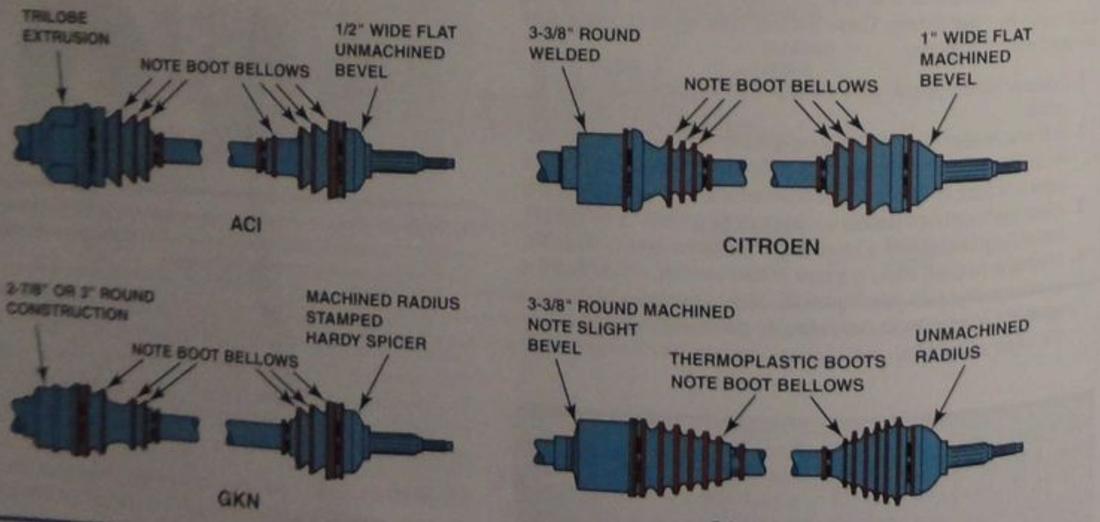


Figure 96-22 Getting the correct boot kit or parts from the parts store is more difficult on many Chrysler front-wheel-drive vehicles because Chrysler has used four different manufacturers for its axle shaft assemblies. (Courtesy of Dana Corporation)

SUMMARY

1. The driveshaft of a rear-wheel-drive vehicle transmits engine torque from the transmission to the differential.
2. Driveshaft length is usually limited to about 65 inches due to balancing considerations unless a two-piece or a composite material shaft is used.
3. Universal joints (U-joints) allow the driveshaft to transmit engine torque while the suspension and the rear axle assembly are moving up and down during normal driving conditions.
4. Acceptable working angles for a Cardan-type U-joint fall within 1/2 to 3 degrees. Some angle is necessary to cause the roller bearings to rotate; a working angle of greater than 3 degrees can lead to driveline vibrations.
5. Constant velocity (CV) joints are used on all front-wheel-drive vehicles and many four-wheel-drive vehicles to provide a smooth transmission of torque to the drive wheels regardless of angularity of the wheel or joint.
6. Outer or fixed CV joints commonly use a Rzeppa design, while inner CV joints are the plunging or tripod type.

REVIEW QUESTIONS

1. Explain why Cardan-type U-joints on a driveshaft must be within 1/2-degree working angles.
2. What makes a constant velocity joint able to transmit engine torque through an angle at a constant velocity?
3. What type of grease must be used in CV joints?

CHAPTER QUIZ

1. The name most often used to describe the universal joints on a conventional rear-wheel-drive vehicle driveshaft is _____.
   a. Trunnion
   b. Cardan
   c. CV
   d. Spider
2. A rear-wheel-drive vehicle shudders or vibrates when first accelerating from a stop. The vibration is less noticeable at higher speeds. The most likely cause is _____.
   a. Driveshaft unbalance
   b. Excessive U-joint working angles
   c. Unequal U-joint working angles
   d. Brinelling of the U-joint
3. All driveshafts are balanced.
   a. True
   b. False
4. The maximum difference between the front and rear working angle of a driveshaft is _____.
   a. 1/4 degree
   b. 1/2 degree
   c. 1 degree
   d. 3 degrees
5. Which series U-joint has the greatest torque capacity?
   a. 1260
   b. 1310
   c. 1350
   d. 1480
6. Two technicians are discussing torque steer on a front-wheel-drive vehicle. Technician A says that equal length drive axle shafts help reduce torque steer. Technician B says that equal drive axle shaft angles help reduce torque steer. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. The outer CV joints used on front-wheel-drive vehicles are _____.
   a. Fixed type
   b. Plunge type
8. The proper grease to use with a CV joint is _____.
   a. Black chassis grease
   b. Dark blue EP grease
   c. Red moly grease
   d. The grease that is supplied with the boot kit
9. Drive axle shafts are also called _____?
   a. Double-Cardon shafts
   b. Half shafts
   c. Driveshafts
   d. Propeller shafts
10. Two technicians are discussing a dented driveshaft. Technician A says that it should be repaired. Technician B says it should be replaced. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 97 Drive Axle Shaft and CV Joint Service

OBJECTIVES: After studying Chapter 97, the reader will be able to: Prepare for ASE Suspension and Steering (A4) certification test content area "C" (Related Suspension and Steering Service). • Explain how to perform a U-joint inspection. • List the steps necessary to replace a U-joint. • Explain how to perform a measurement of the working angles of a U-joint. • Describe the service procedures for replacing CV joints and boots. • Describe the routine maintenance service procedures required for drive axle shafts and universal CV joints.

KEY TERMS: inclinometer • pin bushings • pinch bolt • spline bind • synthetic retainers • torque prevailing nut • U-joints

The driveshaft of a typical rear-wheel-drive (RWD) vehicle rotates about three times faster than the wheels. This is due to the gear reduction that occurs in the differential. The differential not only provides gear reduction but also allows for a difference in the speed of the rear wheels that is necessary whenever turning a corner.

The driveshaft rotates at the same speed as the engine if the transmission ratio is 1 to 1 (1:1). The engine speed, in revolutions per minute (RPM), is transmitted through the transmission at the same speed. In lower gears, the engine speed is many times faster than the output of the transmission. Most transmissions today, both manual and automatic, have an overdrive gear. This means that at highway speeds, the driveshaft is rotating faster than the engine (the engine speed is decreased or overdriven to help reduce engine speed and improve fuel economy).

The driveshaft must travel up and down as the vehicle moves over bumps and dips in the road while rotating and transmitting engine power to the drive wheels. The driveshaft and universal joints should be carefully inspected whenever any of the following problems or symptoms occur:

1. Vibration or harshness at highway speed
2. A clicking sound whenever the vehicle is moving either forward or in reverse
3. A clunking sound whenever changing gears, such as moving from Drive to Reverse

NOTE: A click-click-click sound while moving in reverse is usually the first indication of a defective U-joint. This clicking occurs in reverse because the needle bearings are being forced to rotate in a direction opposite the usual.

REAL WORLD FIX **The Squeaking Pickup Truck**

The owner of a pickup truck complained that a squeaking noise occurred while driving in reverse. The "eeeee-eeeee-eeee" sound increased in frequency as the truck increased in speed, yet the noise did not occur when driving forward.

Because there was no apparent looseness in the U-joints, the service technician at first thought that the problem was inside either the transmission or the rear end. When the driveshaft was removed to further investigate the problem, it became obvious where the noise was coming from. The U-joint needle bearing had worn the cross-shaft bearing surface of the U-joint. See Figure 97–1. The noise occurred only in reverse because the wear had occurred in the forward direction, and therefore only when the torque was applied in the opposite direction did the needle bearing become bound up and start to make noise. A replacement U-joint solved the squeaking noise in reverse.



Figure 97–1 Notice how the needle bearings have worn grooves into the bearing surface of the U-joint.

DRIVESHAFT AND U-JOINT INSPECTION

The driveshaft should be inspected for the following:

1. Any dents or creases caused by incorrect hoisting of the vehicle or by road debris.

CAUTION: A dented or creased driveshaft can collapse, especially when the vehicle is under load. This collapse of the driveshaft can cause severe damage to the vehicle and may cause an accident.

2. Undercoating, grease, or dirt buildup on the driveshaft can cause a vibration.
3. Undercoating should be removed using a suitable solvent and a rag. Always dispose of used rags properly.

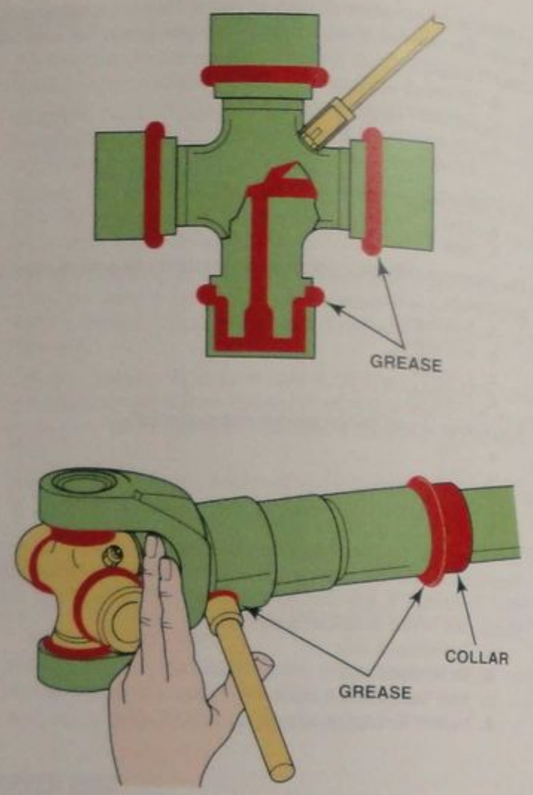


Figure 97–2 All U-joints and spline collars equipped with a grease fitting should be greased four times a year as part of a regular lubrication service. *(Courtesy of Dana Corporation)*

The **U-joints** should be inspected every time the vehicle chassis is lubricated, or four times a year. Original equipment (OE) U-joints are permanently lubricated and have no provision for greasing. If there is a grease fitting, the U-joint should be lubricated by applying grease with a grease gun. See Figures 97–2 and 97–3.

In addition to periodic lubrication, the driveshaft should be grabbed and moved to see if there is any movement of the U-joints. If *any* movement is noticed when the driveshaft is moved, the U-joint is worn and must be replaced.

NOTE: U-joints are not serviceable items and cannot be repaired. If worn or defective, they must be replaced.

U-joints can be defective and still not show noticeable free movement. *A proper U-joint inspection can be performed only by removing the driveshaft from the vehicle.*

Before removing the driveshaft, always mark the position of all mating parts to ensure proper reassembly. White correction fluid, also known as "White Out" or "Liquid Paper," is an easy and fast-drying marking material. See Figure 97–4.

To remove the driveshaft from a rear-wheel-drive vehicle, remove the four fasteners at the rear U-joint at the differential. See Figure 97–5.

Push the driveshaft forward toward the transmission and then down and toward the rear of the vehicle. The driveshaft should slip out of the transmission spline and can be removed from underneath the vehicle.



Figure 97–3 Many U-joints require a special grease gun tool to reach the grease fittings. *(Courtesy of Dana Corporation)*



Figure 97–4 Always mark the original location of U-joints before disassembly.

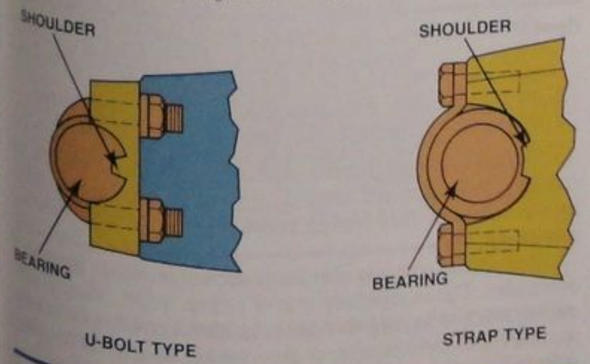


Figure 97–5 Two types of retaining methods that are commonly used at the rear U-joint at the differential. *(Courtesy of Dana Corporation)*

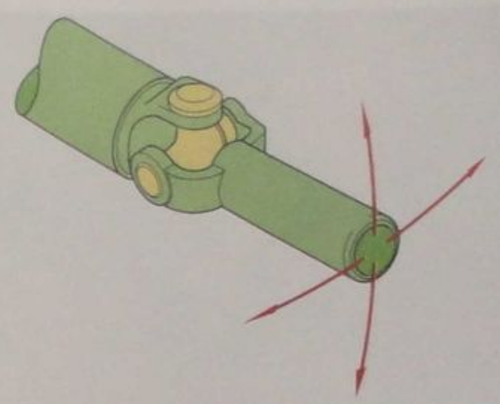


Figure 97–6 The best way to check any U-joint is to remove the driveshaft from the vehicle and move each joint in all directions. A good U-joint should be free to move without binding. *(Courtesy of Dana Corporation)*

NOTE: With the driveshaft removed, transmission lubricant can leak out of the rear extension housing. To prevent a mess, use an old spline the same size as the one being removed or place a plastic bag over the extension housing to hold any escaping lubricant. A rubber band can be used to hold the bag onto the extension housing.

To inspect U-joints, move each joint through its full travel, making sure it can move (articulate) freely and equally in all directions. See Figure 97–6.

U-JOINT REPLACEMENT

All movement in a U-joint should occur between the trunnions and the needle bearings in the end caps. The end caps are press-fit to the yokes, which are welded to the driveshaft. Three types of retainers are used to keep the bearing caps on the U-joints: the outside snap ring (see Figure 97–7), the inside retaining ring (see Figure 97–8), and injected synthetic (usually nylon).

After removing the retainer, use a press or a vise to separate the U-joint from the yoke. See Figure 97–9.

TECH TIP ✔ **Use Tape to Be Safe**

When removing a driveshaft, use tape to prevent the rear U-joint caps from falling off. If the caps fall off the U-joint, all of the needle bearings will fall out and scatter over the floor. See Figure 97–10.

U-joints that use **synthetic retainers** must be separated using a press and a special tool to press onto both sides of the joint in order to shear the plastic retainer, as shown in Figure 97–11 on page 1251.

Replacement U-joints use spring clips instead of injected plastic. Remove the old U-joint from the yoke, as shown in Figure 97–12 on page 1251, and replace with a new U-joint. Replacement U-joints should be *forged* (never cast) and use up to 32 needle bearings (also called **pin bushings**) instead of just 24 needle bearings, as used in lower-quality U-joints. Replacement U-joints usually have a grease fitting so that the new replacement U-joint can be properly lubricated. See Figure 97–13 on page 1251.

After removing any dirt or burrs from the yoke, press in a new U-joint. Rotate the new joint after installation to make sure it



Figure 97–7 Typical U-joint that uses an outside snap ring. This style of joint bolts directly to the companion flange that is attached to the pinion gear in the differential.



Figure 97–8 Removing an inside retaining ring (snap ring).

moves freely, without binding or stiffness. If a U-joint is stiff, it can cause a vibration.

NOTE: If a U-joint is slightly stiff after being installed, strike the U-joint using a brass punch and a light hammer. This often frees a stiff joint and is often called "relieving the joint." The shock aligns the needle bearings in the end caps.

U-JOINT WORKING ANGLES

Unequal or incorrect U-joint working angles can cause severe vibrations. Driveshaft and U-joint angles may change from the original factory setting due to one or more of the following:

1. Defective or collapsed engine or transmission mounts
2. Defective or sagging springs, especially the rear springs due to overloading or other causes

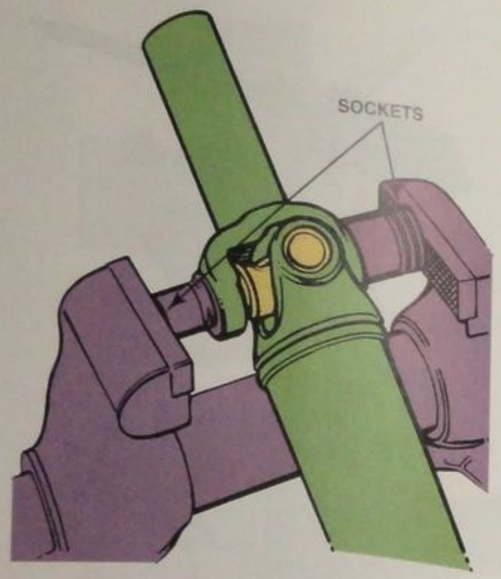


Figure 97–9 Use a vise and two sockets to replace a U-joint. One socket fits over the bearing cup and one fits on the bearing to press fit the cups from the crosspiece.



Figure 97–10 Taping the U-joint to prevent the caps from coming off.

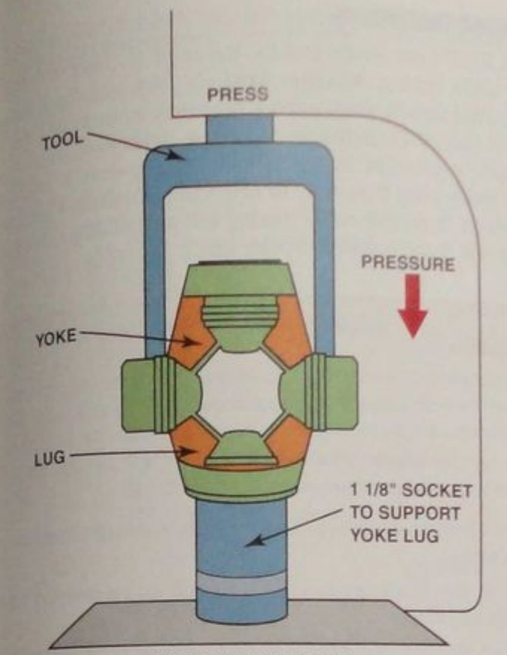
3. Accident damage or other changes to the chassis of the vehicle
4. Vehicle modification that raises or lowers the ride height

Replace any engine or transmission mount that is cracked or collapsed. When a mount collapses, the engine drops from its original location. Now the driveshaft angles are changed and a vibration may be felt.

Rear springs often sag after many years of service or after being overloaded. This is especially true of pickup trucks. Many people carry as much as the cargo bed can hold, often exceeding the factory-recommended carry capacity or gross vehicle weight (GVW) of the vehicle.

To measure U-joint and driveshaft angles, the vehicle must be hoisted using an axle contact or drive-on-type lift so as to maintain the same driveshaft angles as the vehicle has while being driven.

The working angles of the two U-joints on a driveshaft should be within 1/2 degree of each other in order to cancel out speed changes. See Figure 97–14.



U-JOINT REMOVAL
SYNTHETIC RETAINERS

Figure 97–11 A special tool being used to press apart a U-joint that is retained by injected plastic. Heat from a propane torch may be necessary to soften the plastic to avoid exerting too much force on the U-joint.



Figure 97–12 Removing the worn cross from the yoke.



Figure 97–13 When installing a new U-joint, position the grease fitting on the inboard side (toward the driveshaft tube) and in alignment with the grease fitting of the U-joint at the other end.

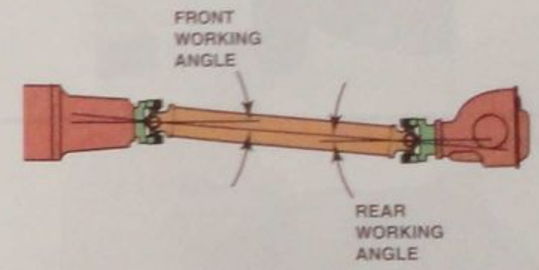


Figure 97–14 The working angle of most U-joints should be at least 1/2 degree (to permit the needle bearing to rotate in the U-joints) and should not exceed 3 degrees or a vibration can occur in the driveshaft, especially at higher speeds. The difference between the front and rear working angles should be within 1/2 degree of each other.

To measure the working angle of a U-joint, follow these steps:

Step #1 Place an **inclinometer** (a tool used to measure angles) on the rear U-joint bearing cap. Level the bubble and read the angle. See Figure 97–15; the pictured reading is 19.5 degrees.

Step #2 Rotate the driveshaft 90 degrees and read the angle of the rear yoke. For example, this reading is 17 degrees.

Step #3 Subtract the smaller reading from the larger reading to obtain the working angle of the joint. In this example, it is 2.5 degrees (19.5 degrees − 17 degrees = 2.5 degrees).

Repeat the same procedure for the front U-joint. The front and rear working angles should be within 0.5 degrees. If the two working angles are not within 0.5 degrees, shims can be added to bring the two angles closer together. The angle of the rear joint is changed by installing a tapered shim between the leaf spring and the axle, as shown in Figure 97–16.

CAUTION: Use caution whenever using wedges between the differential and the rear leaf spring to restore the correct U-joint working angle. Even though wedges are made to raise the front of the differential, the tilt often prevents rear-end lubricant from reaching the pinion bearing, resulting in pinion bearing noise and eventual failure.

The angle of the front joint is changed by adding or removing shims from the mount under the transmission. See Figure 97–17.

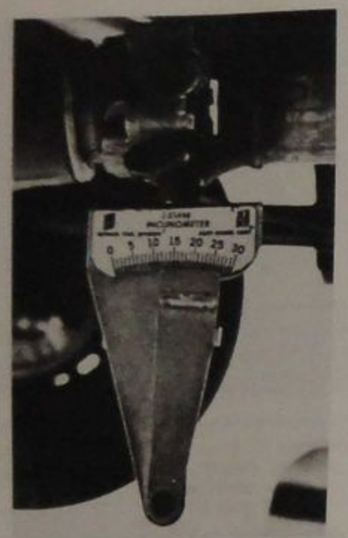


Figure 97–15 Inclinometer reads 19 1/2 degrees at this rear U-joint.

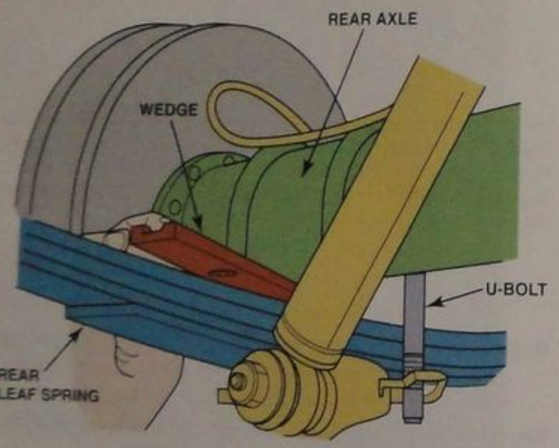


Figure 97–16 Placing a tapered metal wedge between the rear leaf spring and the rear axle pedestal to correct rear U-joint working angles.



Figure 97–17 A transmission oil pan gasket leak allowed automatic transmission fluid (ATF) to saturate the rear transmission mount rubber, causing it to collapse. After replacing the defective mount, proper driveshaft angles were restored and the driveline vibration was corrected.

CV JOINT DIAGNOSIS

When a CV joint wears or fails, the most common symptom is noise while driving. An outer fixed CV joint will most likely be heard when turning sharply and accelerating at the same time. This noise is usually a clicking sound. While inner joint failure is less common, a defective inner CV joint often creates a loud clunk while accelerating from rest. To help verify a defective joint, drive the vehicle in reverse while turning and accelerating. This almost always will reveal a defective outer joint.

TECH TIP ✔ **Quick and Easy Backlash Test**

Whenever a driveline clunk is being diagnosed, one possible cause is excessive backlash (clearance) between the ring gear teeth and differential pinion teeth in the differential. Another common cause of excessive differential backlash is too much clearance between differential carrier pinion teeth and side gear teeth. A quick test to check backlash involves three easy steps:

Step #1 Hoist the vehicle on a frame contact lift, allowing the drive wheels to be rotated.

Step #2 Have an assistant hold one drive wheel and the driveshaft to keep them from turning.

Step #3 Move the other drive wheel, observing how far the tire can rotate. This is the amount of backlash in the differential; it should be less than 1 in. (25 mm) of movement measured *at the tire*.

If the tire can move more than 1 in. (25 mm), then the differential should be inspected for wear and parts should be replaced as necessary. If the tire moves *less* than 1 in. (25 mm), then the backlash between the ring gear and pinion is probably *not* the cause of the noise.

REPLACEMENT SHAFT ASSEMBLIES

Front-wheel-drive vehicles were widely used in Europe and Japan long before they became popular in North America. The standard repair procedure used in these countries is the replacement of the entire drive assembly if there is a CV joint failure. Replacement boot kits are rarely seen in Europe because it is felt that even a slight amount of dirt or water inside a CV joint is unacceptable. Vehicle owners simply wait until the joint wear causes severe noise, and then the entire assembly is replaced.

The entire drive axle shaft assembly can easily be replaced and the defective unit can be sent to a company for remanufacturing. Even though cost to the customer is higher, the parts and repair shop does not have to inventory every type, size, and style of boot kit and CV joint. Service procedures and practices therefore vary according to location and the availability of parts. For example, some service technicians use replacement drive axle assemblies from salvage yards with good success.

NOTE: Some drive axle shafts have a weight attached between the inner and outer CV joints. This is a dampener weight. It is not a balance weight, and it need not be transferred to the replacement drive axle shaft (half shaft) unless instructed to do so in the directions that accompany the replacement shaft assembly.

CV JOINT SERVICE

The hub nut must be removed whenever servicing a CV joint or shaft assembly on a front-wheel-drive vehicle. Since these nuts are usually torqued to almost 200 lb-ft (260 N·m), keep the vehicle on

the ground until the hub nut is loosened and then follow these steps (see Figure 97–18):

Step #1 Remove the front wheel and hub nut.

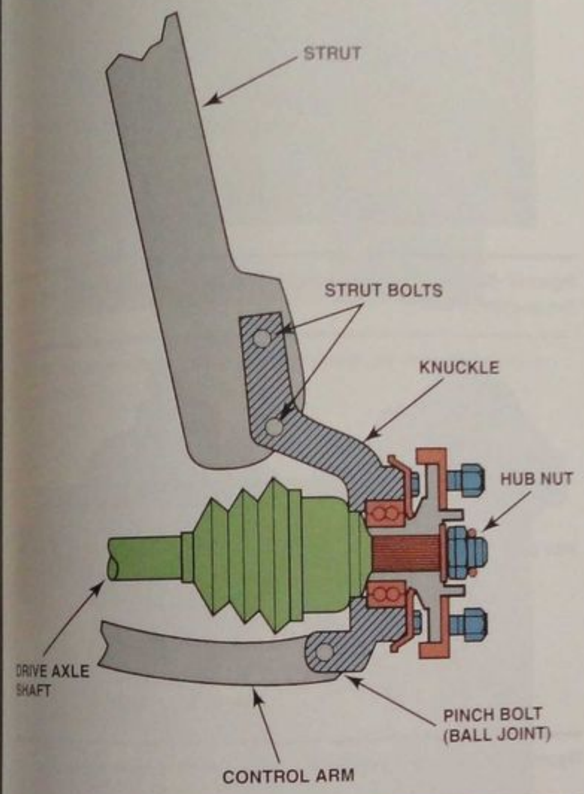


Figure 97–18 The hub nut must be removed before the hub bearing assembly or drive axle shaft can be removed from the vehicle.

NOTE: Most manufacturers warn against using an air impact wrench to remove the hub nut. The impacting force can damage the hub bearing.

Step #2 To allow the knuckle room to move outward enough to remove the drive axle shaft, some or all of the following will have to be disconnected:

a. Lower ball joint or **pinch bolt** (see Figure 97–19).
b. Tie rod end (see Figure 97–20).
c. Stabilizer bar link.
d. Front disc brake caliper.

Step #3 Remove the splined end of the axle from the hub bearing. Sometimes a special puller may be necessary, but in most cases the shaft can be tapped inward through the hub bearing with a

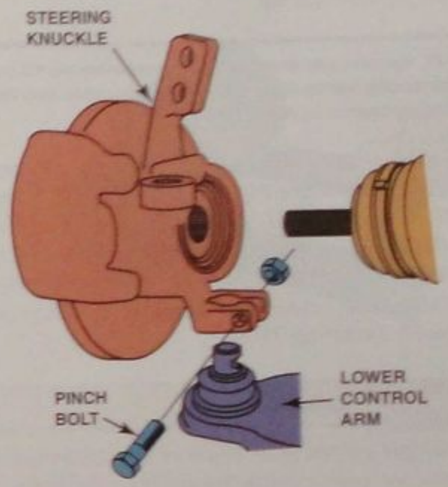


Figure 97–19 Many knuckles are attached to the ball joint on the lower control arm by a pinch bolt.

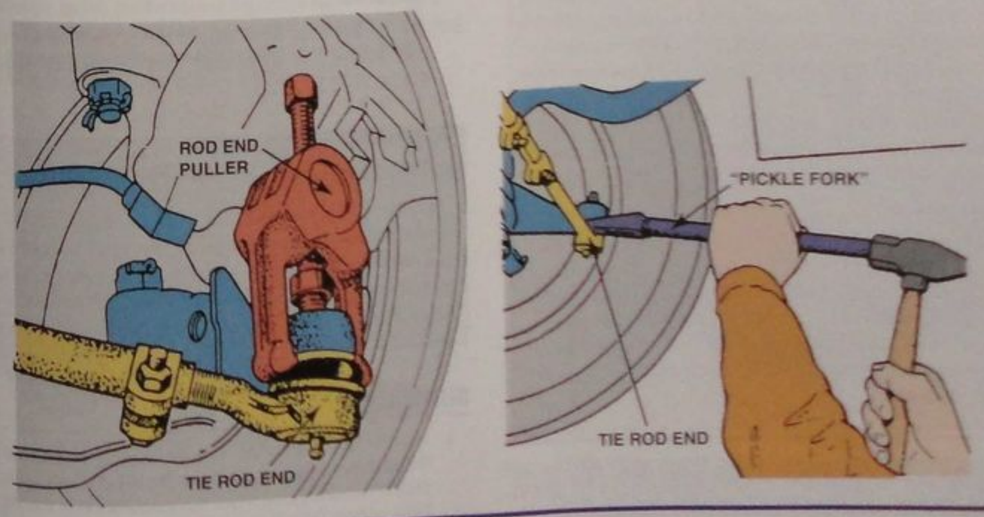


Figure 97–20 The preferred method for separating the tie rod end from the steering knuckle is to use a puller such as the one shown. A "pickle-fork"-type tool should be used only if the tie rod is going to be replaced. A pickle-fork-type tool can damage or tear the rubber grease boot.

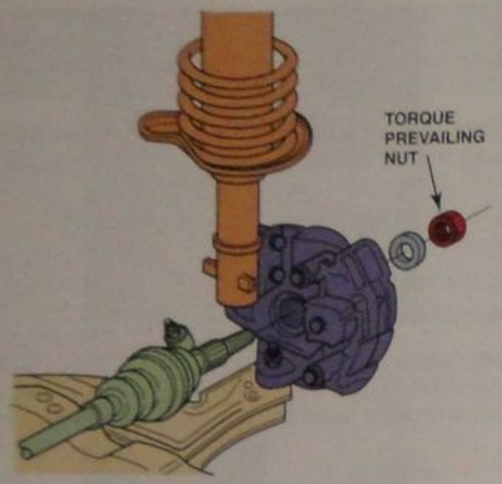


Figure 97–21 Many drive axles are retained by **torque prevailing nuts** that must not be reused. Torque prevailing nuts are slightly deformed or contain a plastic insert that holds the nut tight (retains the torque) to the shaft without loosening.

light hammer and a brass punch can be used. To protect the threads of the drive axle shaft, install the hub nut temporarily. See Figures 97–21 and 97–22.

Step #4 Use a prybar or special tool with a slide hammer, as shown in Figure 97–23, and remove the inner joint from the transaxle.

Step #5 Disassemble, clean, and inspect all components. See Figures 97–24 through 97–30.

TECH TIP **Spline Bind Cure**

Driveline "clunk" often occurs in rear-wheel-drive vehicles when shifting between drive and reverse or when accelerating from a stop. Often the cause of this noise is excessive clearance between the teeth of the ring and pinion in the differential. Another cause is called **spline bind,** where the changing rear pinion angle creates a binding in the spline when the rear springs change in height. For example, when a pickup truck stops, the weight transfers toward the front and unloads the rear springs. The front of the differential noses downward and forward as the rear springs unload. When the driver accelerates forward, the rear of the truck squats downward, causing the drive shaft to be pulled rearward when the front of the differential rotates upward. This upward movement on the spline often causes the spline to bind and make a loud clunk when the bind is finally released.

The method recommended by vehicle manufacturers to eliminate this noise is to follow these steps:

1. Remove the driveshaft.
2. Clean the splines on both the driveshaft yoke and the transmission output shaft.
3. Remove any burrs on the splines with a small metal file (remove all filings).
4. Apply a high-temperature grease to the spline teeth of the yoke. Apply grease to each spline, but do not fill the splines. Synthetic chassis grease is preferred because of its high temperature resistance.
5. Reinstall the driveshaft.

Step #6 Replace the entire joint if there are *any* worn parts. Pack *all* the grease that is supplied into the assembly or joint. See Figure 97–31. Assemble the joint and position the boot in the same location as marked. Before clamping the last seal on the boot, be sure to



Figure 97–22 A special General Motors tool is being used to separate the drive axle shaft from the wheel hub bearing.

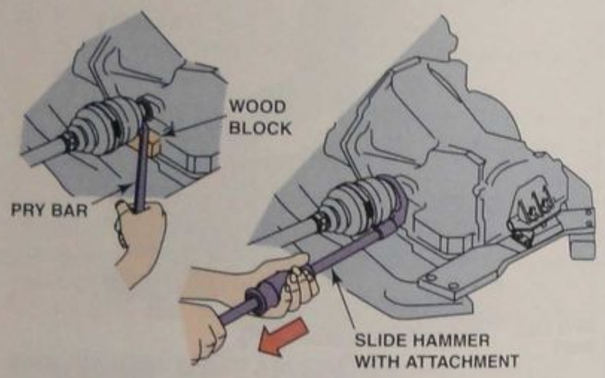


Figure 97–23 Most inner CV joints can be separated from the transaxle with a prybar.

release trapped air to prevent the boot from expanding when heated and collapsing when cold. This is sometimes called *burping the boot.* Clamp the boot according to the manufacturer's specifications.

Step #7 Reinstall the drive axle shaft in the reverse order of removal, and torque the drive axle nut to factory specifications. See Figure 97–32.

REAL WORLD FIX **The Vibrating Buick**

The owner of a front-wheel-drive Buick complained that it vibrated during acceleration only. The vehicle would also pull toward one side during acceleration. An inspection discovered a worn (cracked) engine mount. After replacing the mount, the CV joint angles were restored and both the vibration and the pulling to one side during acceleration were solved. See Figure 97–33.

SUMMARY

1. A defective U-joint often makes a *clicking* sound when the vehicle is driven in reverse. Severely defective U-joints can cause driveline vibrations or a *clunk* sound when the transmission is shifted from Reverse to Drive or from Drive to Reverse.
2. Incorrect driveshaft working angles can result from collapsed engine or transmission mounts.



Figure 97–24 When removing a drive axle shaft assembly, use care to avoid pulling the purge joint apart.



Figure 97–25 If other service work requires that just one end of the drive axle shaft be disconnected from the vehicle, be sure that the free end is supported to prevent damage to the protective boots or allowing the joint to separate. The method shown using a shop cloth to tie up one end may not be very pretty, but at least the technician took precautions to support the end of the shaft while removing the transaxle to replace a clutch.

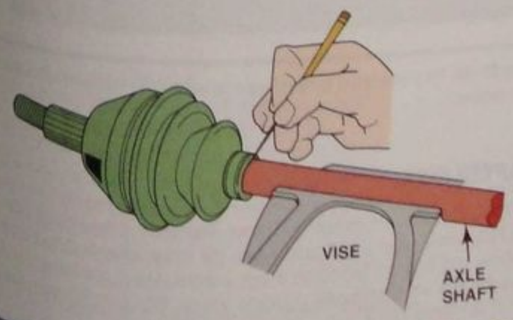


Figure 97–26 With a scribe, mark the location of the boots before removal. The replacement boots must be in the same location.

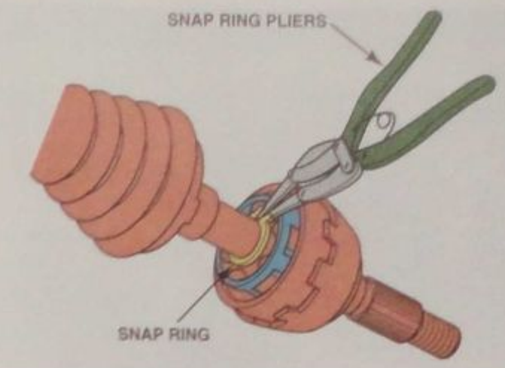


Figure 97–27 Most CV joints use a snap ring to retain the joint on the drive axle shaft.

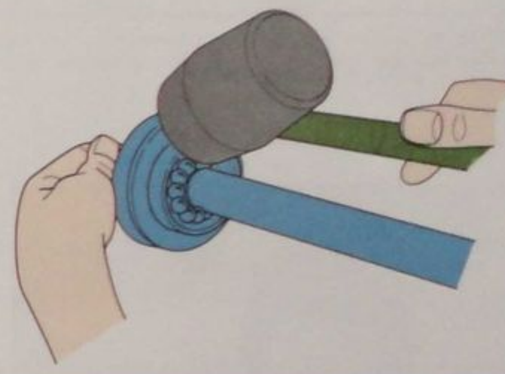


Figure 97–28 After releasing the snap ring, most CV joints can be tapped off the shaft using a brass or shot-filled plastic (dead-blow) hammer.



Figure 97–29 Typical outer CV joint after removing the boot and the joint from the drive axle shaft. This joint was removed from the vehicle because a torn boot was found. After disassembly and cleaning, this joint was found to be OK and was put back into service. Even though the grease looks terrible, there was enough grease in the joint to provide enough lubrication to prevent any wear from occurring.



Figure 97–30 The cage of this Rzeppa-type CV joint is rotated so that one ball at a time can be removed. Some joints require that the technician use a brass punch and a hammer to move the cage.



Figure 97–31 Be sure to use all of the grease supplied with the replacement joint or boot kit. Use only the grease supplied and do not use substitute grease.

3. Driveline clunk noise can often be corrected by applying high-temperature chassis grease to the splines of the front yoke on the driveshaft.
4. CV joints require careful cleaning, inspection, and lubrication with specific CV joint grease.

REVIEW QUESTIONS

1. List two items that should be checked when inspecting a driveshaft.
2. List the steps necessary to measure driveshaft U-joint working angles.
3. Describe how to replace a Cardan-type U-joint.
4. Explain the proper steps to perform when replacing a CV joint.



Figure 97–32 A screwdriver is shown, but a punch would be better, to keep the rotor from rotating while removing or installing the drive axle shaft spindle nut.



Figure 97–33 The engine had to be raised higher to get the new (noncollapsed) engine mount installed.

CHAPTER QUIZ

1. Two technicians are discussing U-joints. Technician A says that a defective U-joint could cause a loud clunk when the transmission is shifted between Drive and Reverse. Technician B says a worn U-joint can cause a clicking sound only when driving the vehicle in reverse. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

PHOTO SEQUENCE Drive Axle Shaft Replacement Step-by-Step



P97–1 Tools needed to replace a drive axle shaft on a General Motors vehicle include a drift, sockets, plus a puller bearing/axle shaft special tool.



P97–2 The drive axle shaft retaining nut can be loosened with the tire on the ground, or use a drift inserted into the rotor cooling fins before removing the nut.



P97–3 Using a special tool to push the drive axle splines from the bearing assembly.



P97–4 Remove the disc brake caliper and support it out of the way. Then, remove the disc brake rotor.



P97–5 To allow for the removal of the drive axle shaft, the strut is removed from the steering knuckle assembly.



P97–6 A pry bar is used to separate the inner drive axle shaft joint from the transaxle.



P97–7 After the inner joint splines have been released from the transaxle, carefully remove the drive axle shaft assembly from the vehicle.



P97–8 To install, reverse the disassembly procedure and be sure to install the washer under the retaining nut, and always use a new prevailing torque nut.



P97–9 Reinstall the disc brake rotor and caliper and then torque the drive axle shaft retaining nut to factory specifications.

2. Incorrect or unequal U-joint working angles are most likely to be caused by _____.
   a. A bent driveshaft
   b. A collapsed engine or transmission mount
   c. A dry output shaft spline
   d. Defective or damaged U-joints
3. A defective outer CV joint will usually make a _____.
   a. Rumbling noise
   b. Growling noise
   c. Clicking noise
   d. Clunking noise
4. The last step after installing a replacement CV boot is to _____.
   a. "Burp the boot"
   b. Lubricate the CV joint with chassis grease
   c. Mark the location of the boot on the drive axle shaft
   d. Separate the CV joint before installation
5. Cardan-type U-joints should be removed from a driveshaft yoke using _____.
   a. A special tool
   b. A torch
   c. A press or a vise
   d. A torque wrench
6. Two technicians are discussing CV joints. Technician A says that the entire front suspension has to be disassembled to remove most CV joints. Technician B says that most CV joints are bolted onto the drive axle shaft. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

7. The splines of the driveshaft yoke should be lubricated to prevent _____.
   a. A vibration
   b. Spline bind
   c. Rust
   d. Transmission fluid leaking from the extension housing
8. It is recommended by many experts that an air impact wrench *not* be used to remove or install the drive axle shaft nut because the impacting force can damage the hub bearing.
   a. True
   b. False
9. Front and rear driveshaft U-joint working angles should be within _____ degrees of each other.
   a. 0.5
   b. 1.0
   c. 3.0
   d. 4.0
10. A defective (collapsed) engine mount on a front-wheel-drive vehicle can cause a vibration.
   a. True
   b. False

CHAPTER 98

Differentials

OBJECTIVES: After studying Chapter 98, the reader will be able to: Prepare for ASE Manual Drive Train and Axles (A3) certification test content area "E" (Rear Axle Diagnosis and Repair). • Describe how the differential allows engine torque to be applied to both drive wheels and still allow a difference in the speed of the drive wheels during cornering. • Determine the rear axle ratio. • Perform a tooth contact pattern check and determine corrective action. • Describe how to determine proper drive pinion gear depth. • Explain how to achieve proper drive pinion bearing preload. • Describe how to adjust the ring gear position to provide the proper backlash.

KEY TERMS: axle ratio • coast (or concave) side • companion flange • crown • diff • differential case • drive (or convex) side • drive pinion gear • floating position • heel • hunting gear sets • hypoid gear set • lap • nonhunting gear sets • partially nonhunting gear sets • pinion gear • pinion shaft • preloaded clutch • rear end • ring gear • ring gear runout • root • side gears • spider gears • straddle-mounted pinion • toe • turning torque • viscous coupling

PURPOSE AND FUNCTION OF A DIFFERENTIAL

The differential allows engine torque to be applied to both drive axles, which rotate at varying speeds during cornering and while traveling over bumps and dips in the road. The differential also changes the direction of engine torque 90° from the rotation of the driveshaft lengthwise with the vehicle. These two purposes of a differential can be summarized as follows:

- To change the direction of engine torque (see Figure 98–1).
- To allow the drive wheels to rotate at different speeds (see Figure 98–2).

A differential is a mechanical addition and subtraction assembly. By splitting the engine torque to the drive wheels when the vehicle is turning a corner, the torque forces cause the side gear and pinion mate gears to subtract torque from one side and add torque to the opposite side. See Figure 98–3.

PARTS OF A DIFFERENTIAL

A differential is also called a **rear end** or abbreviated simply as a **diff.** Whenever any vehicle makes a turn, the outside wheel must travel a greater distance than the inside wheel. The driveshaft applies torque to the **drive pinion gear** that meshes below the center line of a **ring gear** as shown in Figure 98–4. This type of gear set is called a **hypoid gear set** and requires gear lubrication specifically designed for this type of service. The ring gear is attached to a **differential case** that also contains small beveled **spider gears** or **pinion gears.** A **pinion shaft** passes through the two pinion gears in the case. In mesh with the pinion gears are two **side gears** that are splined to the inner ends of the axles. See Figure 98–5.

The Pinion and Ring Gears During Operation During operation, the position of the drive pinion gear on the ring gear changes. The ring gear mounts onto the differential case as shown in Figure 98–6 on page 1260. Each slanted ring gear tooth has two

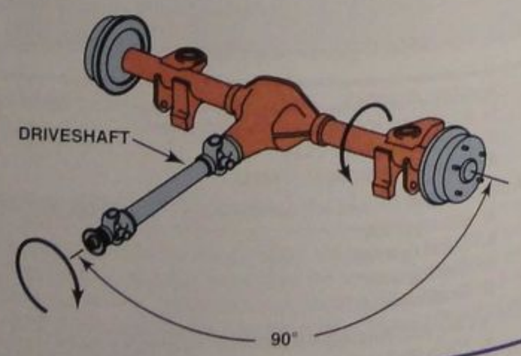


Figure 98–1 The differential assembly changes the direction of engine torque and increases the torque to the drive wheels.

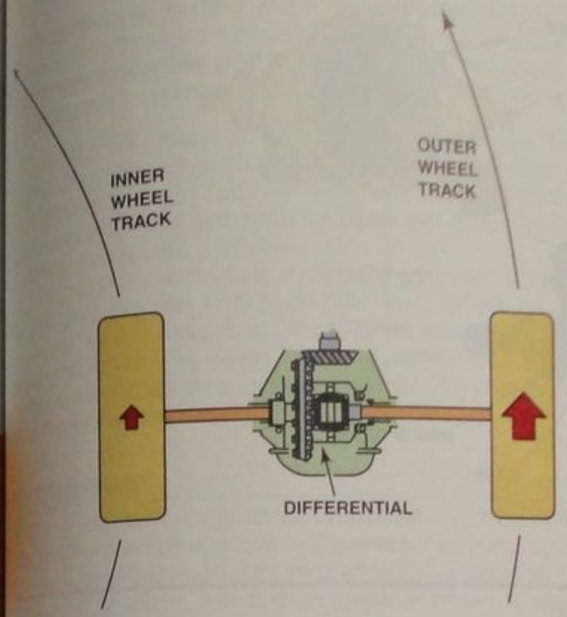


Figure 98–2 The difference between the travel distance of the drive wheels is controlled in the differential.

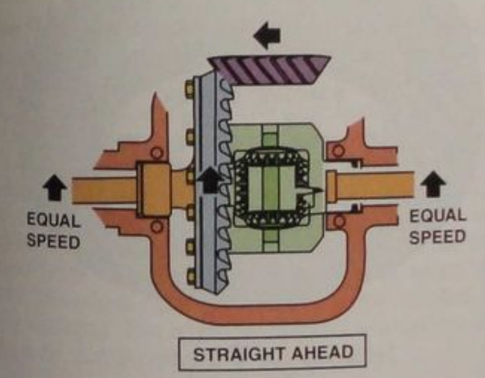


Figure 98–3 When the vehicle turns a corner, the inner wheel slows and the outer wheel increases in speed to compensate. This difference in rotational speed causes the pinion gears to "walk" around the slower side gear.

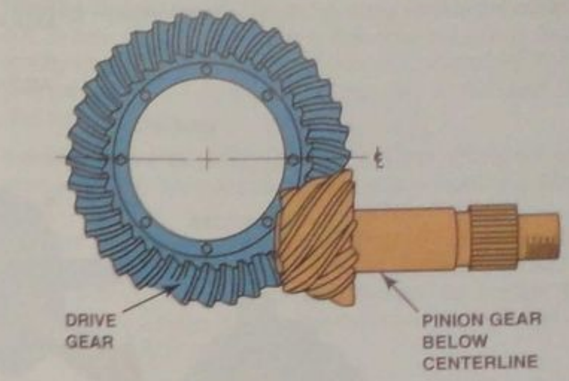


Figure 98–4 A hypoid gear set uses a drive pinion that meshes with the ring gear below the center line of the ring gear.

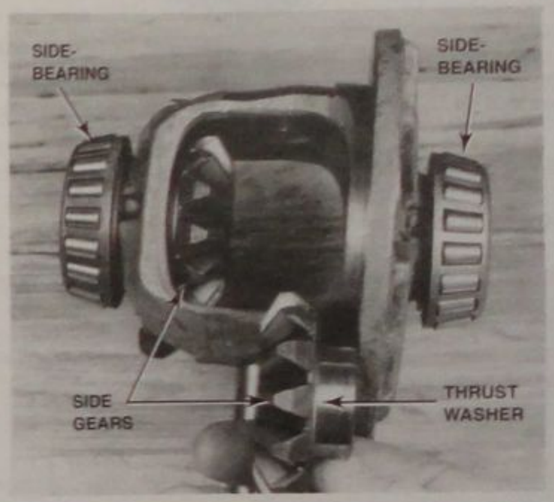


Figure 98–5 The differential case provides the support for the ring gear, side bearings, and side gears.

ends. Its **toe** is closest to the ring gear center; its **heel,** closest to the outside circumference. The tooth **root** is the depression lying between two teeth, and the **crown** is the very top of each tooth.

While a vehicle accelerates, the drive pinion contacts the ring teeth on its **drive,** or **convex side.** While decelerating, the drive pinion contacts the ring teeth on its **coast,** or **concave side.** See Figure 98–7. The intermediate position between drive and coast, when neither the ring gear nor the pinion is driving each other, is called the **"floating" position.**

DIFFERENTIAL GEAR RATIOS

The final gear reduction in the drive train occurs in the differential assembly. The amount of torque a gear set delivers depends on the gear ratio between the drive pinion gear and the driven ring gear. The gear ratio of the final drive (differential) is called the **axle ratio.** To determine the axle ratio, divide the number of teeth of the ring gear (driven gear) by the number of teeth of the drive pinion gear (driving gear):

$$\frac{\text{Ring gear (41 teeth)}}{\text{Pinion gear (10 teeth)}} = 4.10 \text{ (Axle ratio)}$$

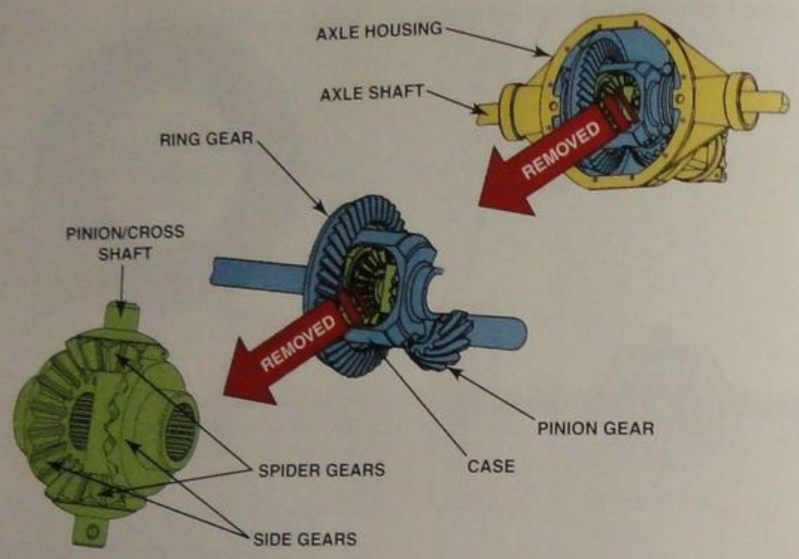


Figure 98–6 The relationship among the ring gear and drive pinion as well as the side and spider gears.

The higher the axle ratio number, the faster the engine rotates for each rotation of the drive wheels. See the High-Performance Tip "Change the Axle Ratio."

HIGH PERFORMANCE TIP **Change the Axle Ratio**

To increase vehicle performance, replace a high ratio (lower number) rear axle ratio with a lower ratio (higher number) rear axle. For example,

Stock rear end = 3.23:1 (drive pinion has 13 teeth and the ring gear has 42 teeth)

Replacement rear end = 3.73:1 (drive pinion has 11 teeth and the ring gear has 41 teeth)

The high-performance axle ratio (3.73:1) allows the engine to rotate faster than the stock 3.23:1 ratio. Because most engines produce greater torque with increasing RPM up to a point, this allows more torque to be applied to the drive wheels. Not only is the engine producing more torque, but the higher-number gear ratio also multiplies the available torque times 3.73 instead of the original 3.23. However, there are several disadvantages associated with changing the rear end ratio:

- Decreased fuel economy
- Incorrect speedometer and odometer readings that can affect the shifting of the automatic transmission unless changes are made to the computer or vehicle speed sensors
- Increased engine noise due to the higher engine speed
- Increased engine wear, again due to the increased engine speed

If you can live with these disadvantages, a change in the rear end ratio generates a real performance gain.

Ring and Pinion Gear Set Types The final drive gear ratio determines how many times a drive pinion tooth will make contact with a particular ring gear tooth during one revolution. This affects final drive gear set manufacture and service.

Final drive gear sets may be divided into three types, depending on the final drive gear ratio.

1. **Hunting gear sets** are gear sets with final drive ratios expressible in a fraction that cannot be reduced to any lower terms. An example of a hunting gear set is one that has 41 teeth on the ring gear and 11 teeth on the drive pinion. This combination creates a 3.73:1 axle ratio. This type of gear set requires no timing marks or alignment during assembly. As the pinion gear drives the ring gear, each pinion tooth will hunt for, or seek, contact with every ring gear tooth.
2. **Nonhunting gear sets** are gear sets with final drive ratios expressible as a whole number. Nonhunting gear sets require timing marks. As the pinion gear drives the ring gear, each pinion tooth contacts only a few ring gear teeth during each revolution.
3. **Partially nonhunting gear sets** are gear sets with final drive ratios expressible as a reducible fraction not equaling a whole number.

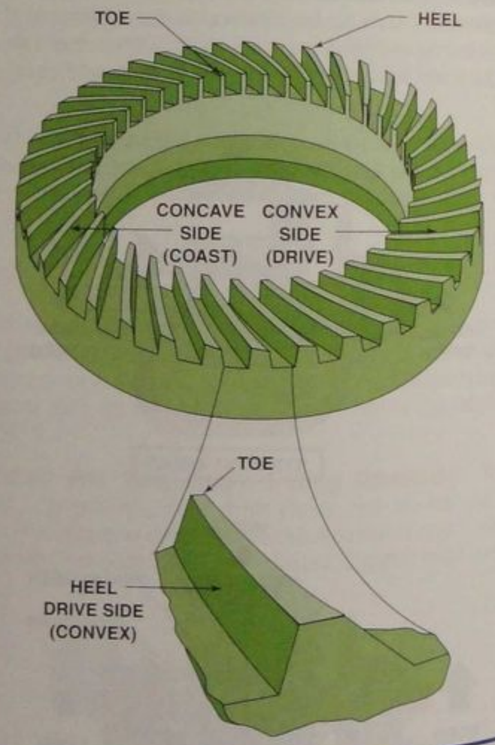


Figure 98–7 The drive side is the convex side of the ring gear except for some front axles used in four-wheel vehicles, and they often use the concave side on the drive side.

Partially nonhunting gear sets also require timing marks. During final drive operation, each pinion tooth contacts only some of the ring pinion teeth. For the pinion teeth to make contact with the highest number of ring gear teeth, the pinion gear must drive the ring gear more than one revolution.

On nonhunting and partially nonhunting gears, manufacturers lap the contacting gear teeth to decrease wear. For this reason, these gear sets are marked to ensure proper alignment during assembly procedures. To preserve the wear patterns, the gear sets should be reassembled using the same alignment. This prolongs the life of the gear set and decreases operational noise.

DIFFERENTIALS

While a vehicle travels straight ahead, the speed of each driven wheel must be allowed to vary slightly as they go over bumps, potholes, railroad tracks, and other road surface irregularities. While cornering, the wheels must be able to turn at much greater differences in speed. Without some mechanism to allow for a difference in speed between the wheels, the left wheel would skid through the turn.

Inside the differential gear housing four to six bevel gears help drive the axles. In most rear axles, two of these bevel gears are smaller pinions mounted on a shaft. They drive two side gears splined with each inner axle end.

Torque Flow Through a Standard Open Differential Open differentials deliver equal torque to both wheels at all times. As the case rotates (driven by the engine through the ring and pinion gears), the cross-shaft applies a drive force to the spider gears. The two side gears apply reaction forces that counter this drive force. See Figure 98–8. Because the spider gear is free to rotate about the cross-shaft, the two reaction forces are equal. As the side gear applies a force to the spider gear, the spider gear applies an equal and opposite force to the side gear. It is this force, on the side gear, that supplies the torque to the axle that drives the wheel. Because the force on each side gear is equal, the torque supplied to each wheel is also equal. This is true regardless of whether one wheel is rotating faster than the other or at the same speed.



Figure 98–8 A close-up view of the side gears and spider (pinion) gear. Note the ridges on the gear teeth. These ridges are manufactured into the gear teeth to help retain lubricant so that no metal-to-metal contact occurs.

Traveling Straight-Ahead Assuming that a vehicle has equal traction at both wheels, differential action does not occur. In other words, when traveling straight on smooth road surfaces the ring gear, carrier, and the drive axles are traveling at the same speed; they rotate as a unit.

Traveling Around Corners The ability of the differential pinion gears to spin on their shafts allows each axle to rotate at a different speed.

Case speed is always equal to the average speed of the two side gears. Since the ring gear rotates with the case and each side gear rotates with its axle; when a vehicle corners, the outside wheel gains the same number of RPMs that the wheel on the inside loses, while ring gear RPM remains constant.

Limited Slip Differentials When a vehicle equipped with a standard differential spins a tire, the opposite wheel does not receive enough torque to move the vehicle. To solve this problem, most manufacturers use differentials that direct more power to the side gear attached to the spinning axle. Many differentials do this by forcing the side gear against the revolving case. This bypasses differential action, allowing the case to drive the side gear directly.

A limited-slip differential distributes torque to both wheels equally or unequally, allowing the wheels to turn at the same or at different speeds. See Figure 98–9.

The only means of having the standard differential apply different amounts of torque to each axle is to have the case drive the side gear directly, bypassing the pinion gears. One means of accomplishing this is to literally "push" the side gear out of mesh with the pinion gears against the rotating case.

Preloaded clutches use two mechanisms to accomplish this action. First, a coil, Belleville, or leaf spring cocks the two side gears. See Figure 98–10. Second, a multidisc clutch pack or cones lie behind one or both of the side gears. Vehicle manufacturers refer to these differentials using various brand names, such as Positive Traction, Sure-Grip, Anti-Spin, and Traction-Lok.

When forces inside the differential push the side gear against the case, the clutch pack allows the gear to lock smoothly without jerking. The pack, lying between at least one of the backs of the side gears and the case, consists of two types of alternatively stacked steel discs with holes through their middle sections. The first is coated with friction material and the second is not. The interior splines of the friction disc holes mesh with the splines on the center hub protruding from the backside of the side gear. The

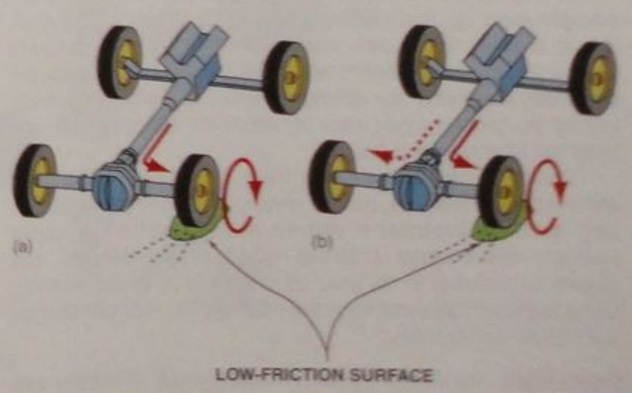


Figure 98–9 (a) A two-wheel-drive vehicle equipped with an open differential. (b) A two-wheel-drive vehicle equipped with a limited-slip differential.

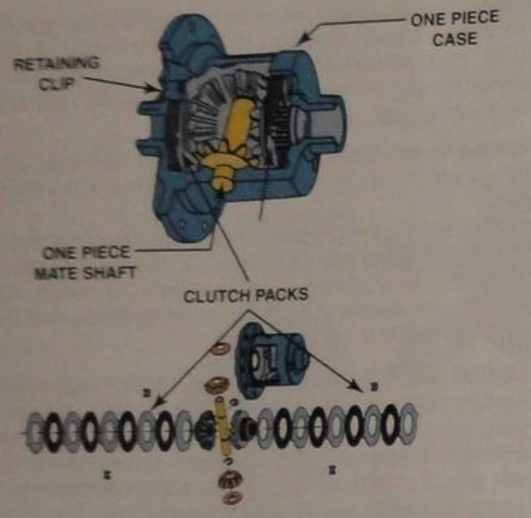


Figure 98–10 Trac-loc limited-slip differential. This type of limited-slip differential uses the preload force from a spring and the torque generated by the side gears as the two axles rotate at different rates to apply the clutches and limit the amount of difference in the speed of two axles.

holes of the steel discs are not splined. Instead, they have two or three tabs along their outside diameter that fit into slots machined into the differential case.

As the side gear is pushed further against the case, each friction plate rubs against the steel plate in front of and behind it, gradually slowing the side gear's rotation until it smoothly locks against the case.

Two forces help to push the side gear out of mesh from the differential pinions and to lock it against the differential case.

1. The rotating differential pinions apply pressure against the side gear. The amount of pressure depends on the traction beneath the tire connected to the side gear.
2. The spring applies the second force that allows the preloaded clutch to work. This spring, whether a coil, leaf, or Belleville, preloads the clutch discs, narrowing the clearances between them. Tighter springs cause the differential to lock up sooner than looser springs.

To vary the amount of traction a tire must have before its axle's side gear locks up, many differentials use adjustment shims. Available in different thicknesses, manufacturers install them between the rear of the clutch packs and the differential case. The thicker the shims, the sooner the differential locks up. Some differentials rely on the preload spring alone to determine when the side gear locks up. They use no shims.

During operation, the clutch discs slide against each other every time the vehicle turns and corners. This action creates friction, making it important to add the manufacturer-recommended lubricant that contains a friction modifier. This lubricant may already be included in the gear oil or may be a special additive. Using improper lubricants may cause the discs to wear prematurely and vibrate during turns.

Cone-Type The second type of preloading clutch differential uses two tapered cones instead of multidisc clutch packs. Positioned between the side gears and the case, the cone's tapered end fits inside a dished receptacle machined into the case. The same forces that push the side gears against the case in the clutch pack differential push the side gears against the case in the tapered-cone differential. When these forces press the cones into their dished receptacles, they come to a stop smoothly, locking the side gears to the case.

Viscous Coupled Limited-Slip Units Differentials can be designed to work on the principle of a **viscous coupling.** This design uses a series of closely positioned plates, which do not physically touch one another. Half of the plates are splined to the case, and the other half are alternately splined to each side gear. The plates are housed in a sealed chamber, which is filled with a thick and viscous silicone-based fluid. The silicone allows normal speed differences between two shafts, resisting high-speed differences associated with wheel spin on one shaft.

This type of viscous-coupled differential is used in the front differentials of some Japanese front-wheel-drive vehicles and in four-wheel-drive vehicles. See Chapter 99 for details.

The Eaton "Locker" Differential The Eaton Locker's sturdier design makes it more efficient in transferring torque from the driveline to the axles while in the locked position than the clutch-type multidisc differential.

When a vehicle spins a rear wheel, both the preloaded multidisc differential and the Eaton "locker" compress their clutch packs lying between the side gears and the case. This allows the case to directly drive the axles, bypassing the effect of the rotating differential pinions.

The Eaton and preloaded multidisc differentials differ in how they compress their clutch packs. The preloaded multidisc uses either a coil, leaf, or Belleville spring to apply initial pressure against the side gears and the clutch pack. As the rotating pinion gears push against a slower moving side gear, it is forced against the case, thereby compressing the discs in the clutch pack together.

The Eaton differential, on the other hand, uses a unique mechanism to collapse the clutch packs. See Figure 98–11. It has four parts:

- A governor with two flyweights
- A cam plate and cam side gear on the left side
- A latching bracket
- A thrust block

These parts allow the Eaton to momentarily shift into the locked mode when side gear and case rotational speeds differ by more than 100 RPM.

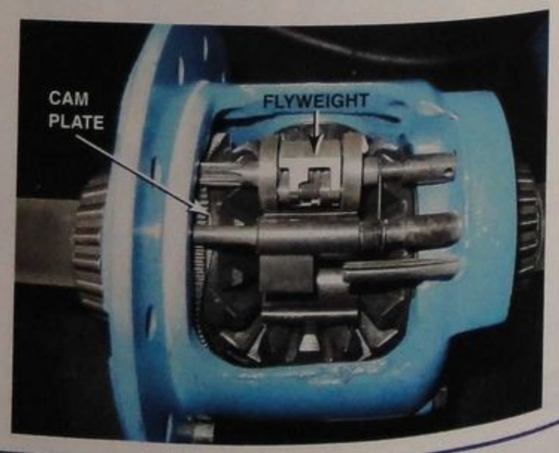


Figure 98–11 An Eaton locker differential.

REAL WORLD FIX — **I Used to Have a Limited-Slip Differential**

An owner of a Chevrolet S-10 pickup truck equipped with a V-6 and five-speed manual transmission complained that he used to be able to spin both rear tires on dry pavement, but lately only one tire spins. The service technician assigned to the repair order was very familiar with what might have occurred. Many General Motors pickup trucks are equipped with an Eaton locking differential that uses a torque limiting disc. The teeth of this disc are designed to shear to prevent the possibility of breaking an axle. See Figure 98–12.

The service procedure to correct the customer's concern is to replace the left-hand clutch plates. Usually, the shearing of the torque-linking teeth is associated with a loud bang in the rear axle. The differential will continue to operate normally as a standard (open) differential.

Torsen Differentials The Torsen differential is a torque sensing, locking design that uses a set of worm side gears in mesh with individual worm wheel pinions that are supported by the differential case. See Figure 98–13. The pinions have spur gear sections machined on them at each end, which form the connection between left and right side pinions. Because of the worm and worm wheel configurations, the side gears can turn the pinions, but the pinions cannot turn the side gears. The result is a complex operation, which meets all drive requirements without excessive wheel slip.

This unit has been available as original equipment on several vehicles as well as for many aftermarket applications.

Drive Pinions The drive pinion is driven by a flange often called a **companion flange.** The heavy bulk of the companion flange helps dampen vibrations and absorb shocks in the driveline. See Figure 98–14. The final drive pinion shaft may be supported by bearings using one of two methods.

1. The first method and most common, uses two opposed taper roller bearings, with a collapsible (compressible) spacer separating the two inner races to support an overhung pinion. See Figure 98–15. This term means all of the bearings supporting the pinion shaft lie on one side of the pinion gear. The bearings are preloaded, a state that minimizes wobble and endwise movement while the drive pinion shaft rotates.
2. The second method uses two opposed taper roller bearings to support a **straddle-mounted pinion,** but the distance between them is smaller than in the overhung design. Most noticeably, a third smaller bearing attaches to a stemlike machined pilot protruding from the gear-end of the drive pinion shaft. This third bearing, usually a straight roller type, fits into a bore in the carrier. Unlike the overhung design, bearings supporting a straddle-mounted pinion lie on both sides of the pinion gear. Like the overhung design, a straddle-mounted pinion shaft usually has a compressible preloaded spacer positioned between the two larger differential case bearings. Straddle-mounted pinions are usually mounted in a pinion housing that can be removed from the carrier.



Figure 98–13 A Torsen differential. This type of differential provides torque to both drive wheels even if one tire is on ice. The complex system of gears allows this smooth transfer of torque without the use of clutches.

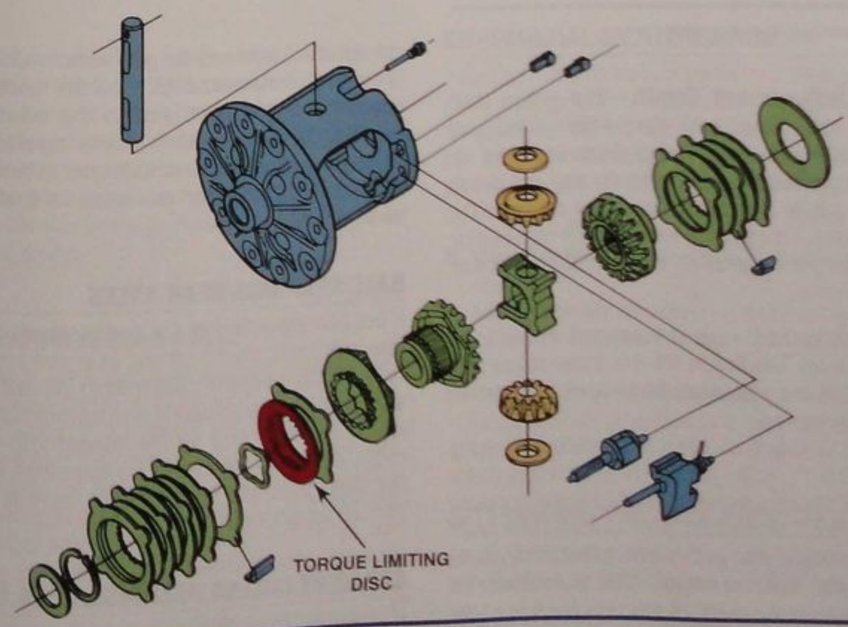


Figure 98–12 This Eaton design differential uses a torque-limiting disc to prevent the possibility of breaking an axle in the event of a high-torque demand. When the disc tangs shear, the differential will continue to function but as an open rather than as a limited-slip differential.



Figure 98–14 This pinion flange is equipped with a damper weight to help dampen driveline vibrations.

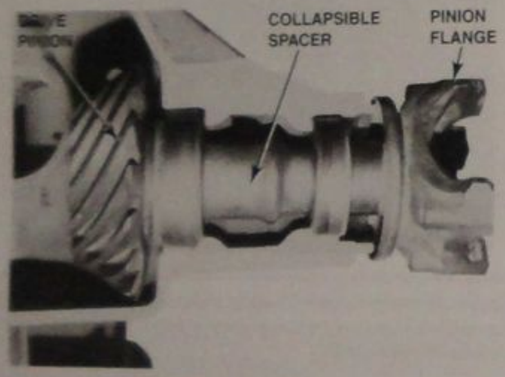


Figure 98–15 A collapsible spacer-type drive pinion shaft.

Drive Pinion Gear Adjustment Depth The pinion shaft mounting method also determines how deeply the pinion gear meshes into the ring gear. This is called pinion depth and helps adjust the precise gear tooth relationship between the ring and pinion gears. You can vary the pinion depth adjustment by changing the thickness of a shim (spacer). This shim is located between the rear preloaded bearing and the pinion gear, or between the removable pinion housing and the carrier.

Side Bearings The differential case is supported by two side bearings pressed onto its sides. See Figure 98–16. These are usually tapered roller bearings and are preloaded to ensure case rotation without axial or radial movement.

Side bearing preload is adjusted either by threaded adjusting nuts as shown in Figure 98–17, or by placement of adjusting shims (spacers) on either side of the case between the bearing outer races and the inside of the carrier. The method used to adjust side bearing preload is also used to adjust ring gear-to-pinion backlash (tooth clearance between one gear and the other). This is necessary to ensure enough space between the teeth of the two gears to allow for expansion of the gear tooth dimensions as the unit warms up to operating temperature. When the unit is warm, there must be just



Figure 98–16 Side bearings are press fit on the differential case.

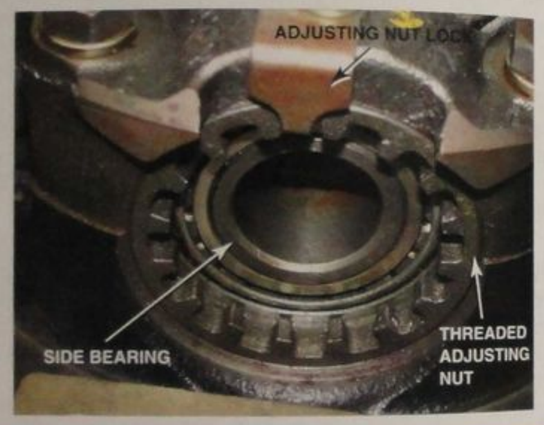


Figure 98–17 Some side bearings use threaded adjusters to adjust preload.

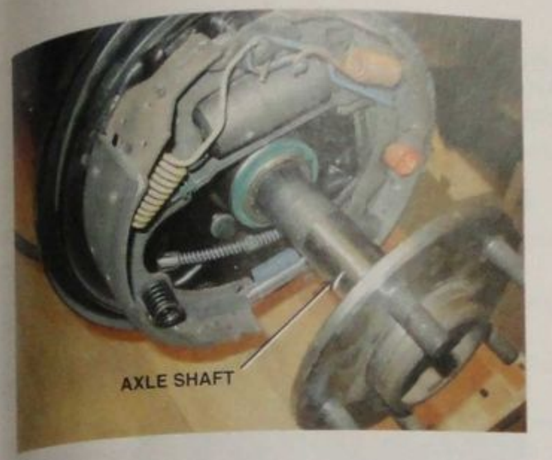
enough space between the gear teeth to allow adequate lubrication of the tooth surfaces and still allow full tooth contact for good transfer of torque from one gear to the other. Too much clearance between the gears will allow one to travel too far before contacting the other when the power train goes from drive to coast and back again. Excess clearance can result in final drive noise and gear tooth damage.

BALL BEARINGS/REAR AXLES

If ball bearings are used, the bearing itself absorbs the radial forces. The bearing is placed on the axle and retained by a pressed-on collar. A stamped steel plate bolts to the axle housing and keeps the axle in place. The bearing is prelubricated when it is manufactured. An oil seal is located on the inboard side of the bearing retainer collar, and keeps the hypoid lubricant from reaching the bearing or the brake assembly. In this design, there is no axle shaft end play (thrust) adjustment.

STRAIGHT ROLLER BEARINGS/REAR AXLES

If a straight roller bearing is used, the axle surface serves as the inner race. See Figure 98–18. The outer race is pressed into the housing, and a grease seal is pressed in afterward. The bearing is



(a)



(b)

Figure 98–18 (a) The axle shaft itself is the inner race if a straight roller bearing is used. (b) The straight roller bearings are lubricated by the rear axle fluid, and a leak at the rear axle seal can cause this fluid to get onto brake components.

lubricated by the hypoid lubricant. This design uses a C-washer on the inboard end of the axle, which prevents the axle from moving outward. Outward thrust forces are taken by the C-washer through the axle's side gear and thrust washer, to the differential case and side bearing. Inward thrust forces are taken by the axle shaft inner end pushing on the spider pinion shaft, and passed on to the differential case and the opposite side bearing. There is no axle shaft end play adjustment with this design.

TAPERED ROLLER BEARINGS/REAR AXLES

If a tapered roller bearing is used, axle shaft end play is adjustable. The bearing is prelubricated before it is installed, and is held in place by a pressed collar behind it. The axle is prevented from moving outward by a stamped steel retainer plate that bolts to the axle housing. The inner diameter of the plate is threaded to accept a bearing-adjusting nut, which is similar in appearance and function to a differential side bearing adjuster. A variation of this design has the end play adjustment made by shims between the axle housing and the brake backing plate. Thrust is taken from the inner end of the axle by a thrust block mounted on the spider pinion shaft, and passed on to the opposite axle, through its length to the opposite wheel bearing.

TECH TIP ✔ **Don't Spin Those Wheels!**

While driving on ice or snow-covered roads, it is common to see drivers moving slowly up a hill by simply spinning one drive wheel. However, when one wheel is spinning and the other wheel is stationary (or close to stationary), the pinion gears are spinning twice as fast as the drive wheel. This spinning of the drive wheel has been known to completely wear down the pinion gear thrust washers in less than one minute! See Figure 98–19. The same wear can occur if different-size tires are used on the same drive axle. Therefore, to prevent expensive repairs, avoid unnecessary tire spinning and check that both tires on the same axle are the same size, brand name, and condition.

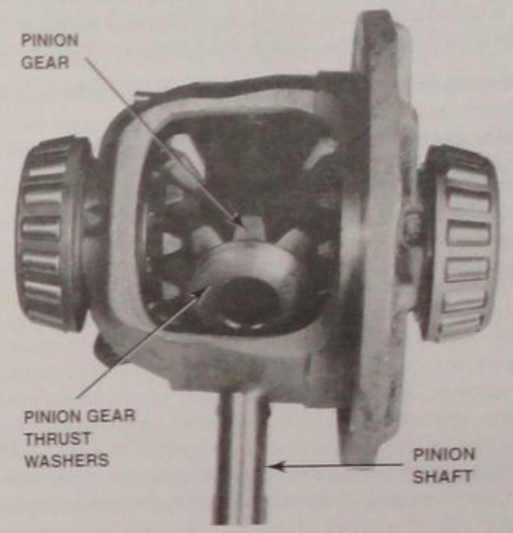


Figure 98–19 The pinion gear thrust washers can be destroyed by spinning one wheel for an extended period of time.

DIFFERENTIAL IDENTIFICATION

Before any service work is performed on a differential assembly, the *exact* axle specification must be determined. Vehicle manufacturers often use differentials from more than one axle manufacturer, and each manufacturer has its own individual ratios, parts, service procedures, and specifications. Differential assembly identification includes

- **Visual identification**—usually identifies the manufacturer and size only
- **Axle assembly number**—usually stamped in the axle tube of the differential assembly and identifies the gear ratio and other information
- **Limited-slip identification tag**—often the only external identification whether or not the axle assembly is an open design or limited-slip design

DETERMINING THE AXLE RATIO OF A DIFFERENTIAL

To determine the axle ratio of a differential without having to remove the axle housing cover, simply follow these steps:

Step #1 Hoist the vehicle safely.

Step #2 Mark the rear tires with masking tape at 12 o'clock position.

Step #3 Mark the driveshaft with masking tape.

Step #4 Have an assistant hold one drive tire to keep it from moving and slowly rotate the other drive tire exactly 10 times while the assistant counts the driveshaft revolutions.

Step #5 Multiply the driveshaft revolutions by 2 (except for a limited-slip differential), and then move the decimal point one place to the left. For example, if 10 turns of the tire result in 18.5 turns of the driveshaft, that multiplied by 2 equals 37.0; then, moving the decimal point to the left one place equals a 3.70:1 gear ratio.

REAR END NOISE DIAGNOSIS

One of the major reasons why differentials are serviced is to correct a noise problem. Knowing when and under what conditions the noise is noticeable is a big help in identifying which bearing or component is the likely cause. Typical noise and its sources include

- **Grinding or growling noise while turning**—usual cause is a defective axle bearing.
- **Whine noise during cruise**—drive pinion bearings are the likely causes of this type of noise.

TECH TIP ✔ **A Quick-and-Easy Backlash Test**

Excessive clearance (lash) between the drive pinion and the ring gear can cause driveline clash noise during a gear selector change. To check if the cause is due to the differential, simply hoist the vehicle and, while one wheel and the driveshaft are being held stationary, use your hand to move the opposite wheel. The maximum amount the tire should move is 1 inch (2.5 cm) measured at the tread of the tire. If backlash is greater than this, then further inspection of the differential assembly is required. Beside excessive clearance between the drive pinion and the ring gear, the wear may also be between the pinion and the side gears.

DIFFERENTIAL INSPECTION

Carefully inspect the ring gear, side, and pinion gears for obvious damage or wear. See Figure 98–20. Check the backlash. The backlash is the amount of clearance between the drive pinion and the ring gear; excessive backlash could indicate excessive wear. Use a dial indicator as shown in Figure 98–21 to check and compare the results with specifications.

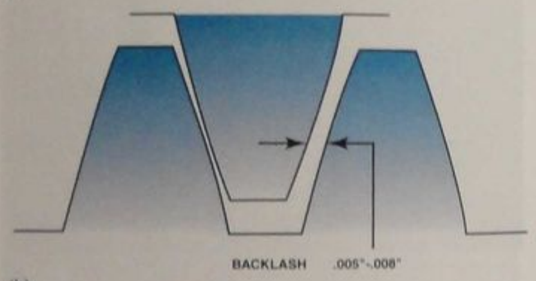


Figure 98–20 This differential has obviously been leaking. If the differential lubricant is low, wear may have occurred that would require further inspection.

Also use a dial indicator to check ring gear runout (see Figure 98–22). If any of the visual measurement tests indicate a problem or a noise analysis indicates a bearing problem, the axle assembly should be disassembled for further analysis and service.



(a)



(b)

Figure 98–21 (a) Backlash is determined by mounting a dial indicator to the differential housing and placing the button of the gauge against a tooth of the ring gear. Moving the ring gear back and forth will indicate on the dial indicator the amount of backlash. (b) Backlash is the clearance between the drive pinion and the ring gear teeth.



Figure 98–22 Ring gear runout should be less than 0.002 inch (0.05 mm) as measured by a dial indicator.

TOOTH CONTACT PATTERN TEST

A tooth contact pattern test is an excellent method for checking proper drive pinion depth as well as proper backlash between the drive pinion and the ring gear. Any faults in these areas will be reflected in the pattern. The pattern test involves the following steps:

Step #1 Clean the gear teeth of the ring gear and the drive pinion.

Step #2 Using a small brush, apply a light coating of iron oxide compound.

Step #3 Use a small pry bar to apply a load to the ring gear to achieve a more accurate contact pattern. See Figure 98–23.

Step #4 Rotate the drive pinion until the ring gear turns one revolution (about three revolutions of the drive pinion gear).

Step #5 Repeat rotating the drive pinion in the opposite direction. This will create a contact pattern on both the drive side and the coast side of the ring gear.

NOTE: The drive side is the convex surface of the ring gear teeth. The coast side is the concave side of the ring gear. This is true except for many differentials used on the front of four-wheel-drive vehicles. In this case, the drive side in the front differential is the concave surface and the coast side is the convex surface of the ring gear teeth. Always check the service information for the vehicle being serviced for the correct interpretation of the pattern results.

See Figure 98–24 for good and bad tooth contact patterns and what could have caused them.

DIFFERENTIAL DISASSEMBLY

Start the differential disassembly by removing the axle housing cover. Be sure that the old rear end lubricant is drained into a disposal container according to local, state, provincial, and federal laws and regulations. After the cover has been removed, complete the disassembly by following these steps:

Step #1 Remove the driveshafts and inspect the axle bearing and seals for damage.

Step #2 Remove the third member by unbolting it from the housing or by removing the side bearing caps, as shown in Figure 98–25.

Step #3 Remove the drive pinion by first removing the pinion nut. See Figure 98–26. Discard the drive pinion nut. Always replace it with a new one.



Figure 98–23 Force has to be applied to the ring gear to achieve a proper contact pattern.

CAUTION: Do not use an air impact wrench to remove or install the drive pinion nut. The hammer action of the impact wrench can cause the roller bearings to be pounded into the race. This denting of the race is called *brinelling* and can cause premature bearing failure.

PINION SHAFT BEARING REPLACEMENT

The pinion shaft usually has two tapered roller bearings; the small diameter of each bearing faces the other. This arrangement allows the two bearings to absorb thrust load in both directions. When tapered roller bearings are used in a differential, it is very important that they have the proper preload. If a tapered roller bearing is too loose (too little preload), then the bearing cannot properly support and position the pinion shaft. If the preload is too great, excessive heat will quickly destroy the bearing as it expands with heat during normal operation of the rear axle assembly. Two methods are used to ensure proper drive pinion gear preload (see Figure 98–27).

- Preload shims
- Collapsible spacer

The rear pinion shaft bearing (closest to the drive pinion gear) is usually pressed out the drive pinion. A shim is usually located between the drive pinion gear and the rear drive pinion bearing to properly position the drive pinion in relation to the ring gear. The ring gear and pinion are manufactured as a matched pair and must be installed correctly to be assured of quiet operation and long service life. See Figure 98–28. The drive pinion bearing must be pressed off using a hydraulic press or a special tool.

DRIVE PINION DEPTH

The drive pinion gear and ring gear are manufactured as a matched set and must be installed as a set. Due to variances in the production of these gears, it is often necessary to vary the thickness of a shim (thin metal spacer) between the rear pinion bearing and the pinion gear to provide the correct contact tooth pattern when the gears are assembled. Correct drive pinion depth measurement can be determined in several different ways:

- **Wear pattern analysis.** This method is useful as a first step and a last step to verify correct setup (discussed earlier in the chapter). It is time consuming to use this method to determine the thickness of the drive pinion shim because the rear pinion bearing must be pressed off and then back on for each shim change.
- **Plus (+) and minus (−) markings on the drive pinion.** The end of the pinion gear is usually marked as to the variance needed to create the proper ring gear-to-drive pinion pattern:

  A plus (+) sign means the gear is too long and removing a shim(s) is required when assembling the drive pinion into the axle housing.

  A minus (−) sign means that the gear is too short and a shim(s) will be needed when assembling the drive pinion into the axle housing.

- **A gauging set and depth micrometer.** This is a common method used to determine the correct shim thickness necessary to provide the proper gear pattern; see Figure 98–29.

PINION GEAR PRELOAD

After the proper drive pinion depth has been determined, the correct size shim is installed and the rear drive pinion bearing is pressed onto the drive pinion. The outer races of the pinion bearing should be

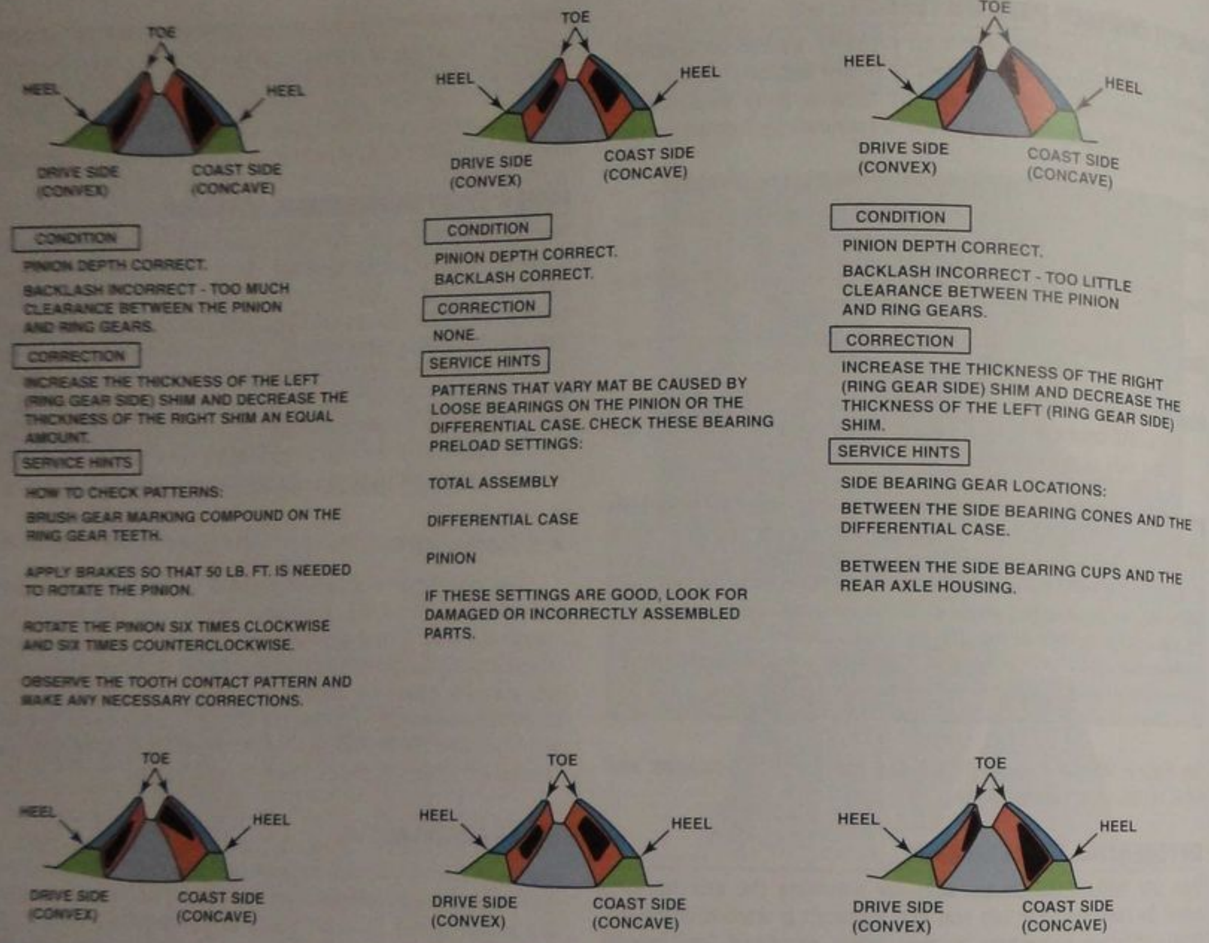


Figure 98–24 Tooth contact pattern.

replaced in the axle housing and the pinion shaft placed in the housing. It is then necessary to apply the specified preload to the pinion bearings. A new drive pinion nut should be used and tightened to specifications. After the nut has been tightened, torque needed to rotate the drive pinion should be measured using a beam-type torque wrench. The drive pinion nut is then tightened further until the **turning torque** is within specifications. See Figure 98–30.

CHECKING AND CORRECTING BACKLASH

If the ring gear and pinion are being replaced, the bolts that hold the ring gear to the differential case *must* be replaced. See Figure 98–31. The differential case with the ring gear is then placed into the differential housing. Backlash is the clearance between the drive pinion gear and the ring gear. A dial indicator is used to measure backlash, as shown in Figure 98–32. The backlash should

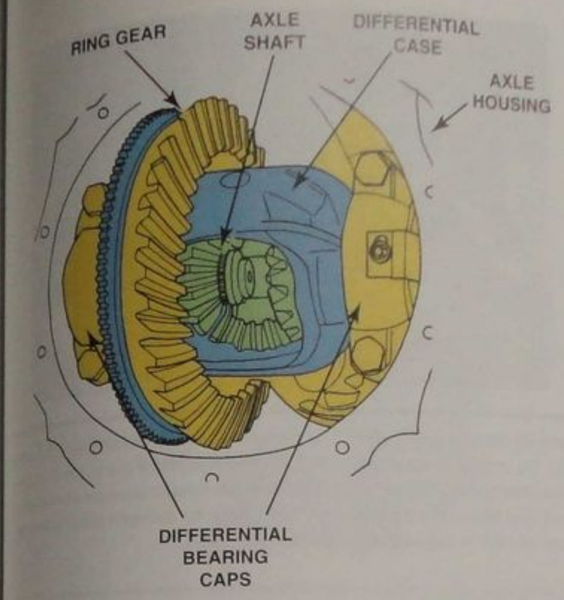


Figure 98–25 Mark the differential bearing caps before removing them to make sure that they are replaced in the same location.

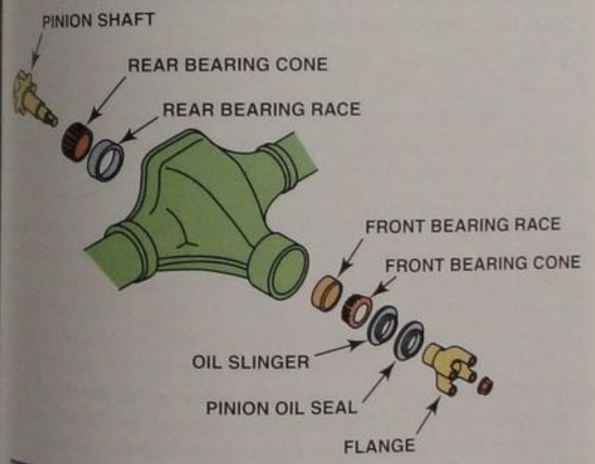


Figure 98–26 Pinion gear and associated parts. The pinion end yoke is also called the pinion flange.

be checked at three or four points around the ring gear and the lash should not vary over 0.002 inch (0.05 mm). Backlash normally is between 0.005 and 0.008 inch (0.10 and 0.20 mm) for most axle assemblies. Always check the specifications for the differential being serviced. See Figure 98–33.

Backlash is corrected by moving the ring gear either closer or farther away from the drive pinion gear. The correction is made by either of two methods depending on the manufacturer and the type of differential:

- Transferring shims from one side of the axle housing to the other
- Turning threaded adjusters located in the differential housing bores, as shown in Figure 98–34

TECH TIP ✓ **"Click-Click" Is Okay—"Clunk-Clunk" Is Not**

An experienced service technician was observed checking the backlash on a differential. The technician was simply turning the drive pinion by grasping the pinion flange and using wrist action to quickly rotate it first in one direction and then the other. The technician explained that if it made a "click-click" sound, the backlash was usually between 0.005 and 0.008 inch, which is usually within specifications for most differentials. If however, the sound made was more like a "clunk-clunk," then the backlash was greater than 0.010 inch and had to be corrected. To summarize what the sounds mean when the drive pinion is moved back and forth:

- *No sound when moved back and forth* —too little or no backlash; backlash must be adjusted.
- *A "click-click" sound* —backlash is usually within specifications; double-check with a dial indicator and compare against specifications for the axle being serviced.
- *A "clunk-clunk" sound* —usually too much backlash; correction is required to restore proper backlash.

SETTING SIDE BEARING PRELOAD

After the correct backlash has been determined, the side bearing must be correctly preloaded. To accomplish the proper preload, thicker shims than were used to set proper backlash are placed between the housing and the differential to provide for the proper

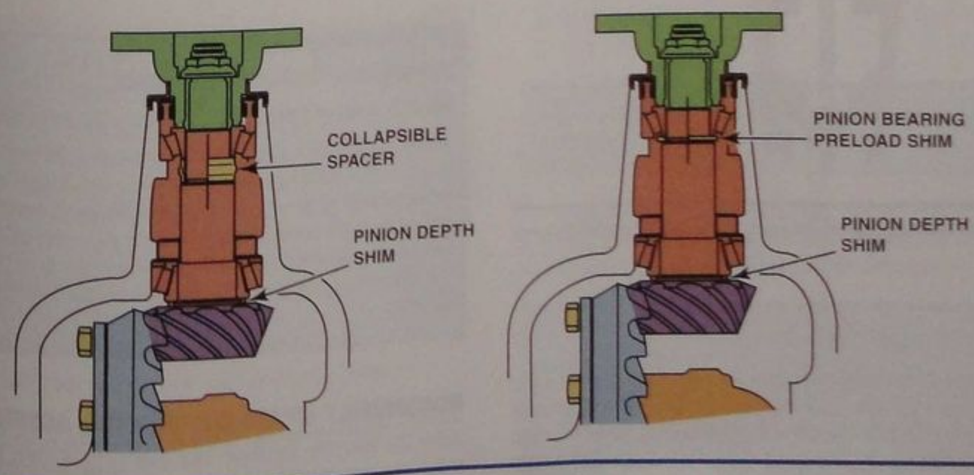


Figure 98–27 The pinion on the left uses a collapsible spacer, and the pinion on the right uses shims to provide the necessary preload to the pinion shaft bearings.

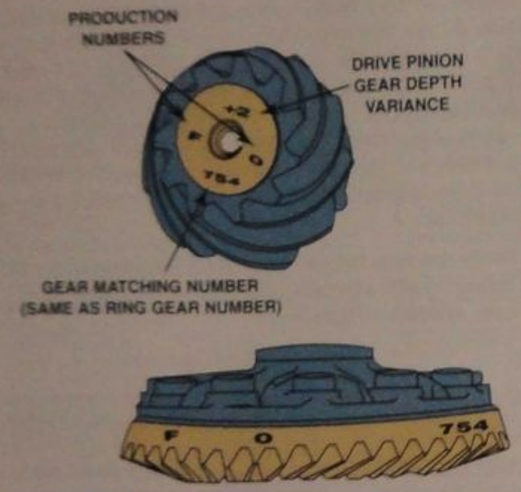


Figure 98–28 The ring and pinion gears are a matched set and are marked for correct pinion depth variance.

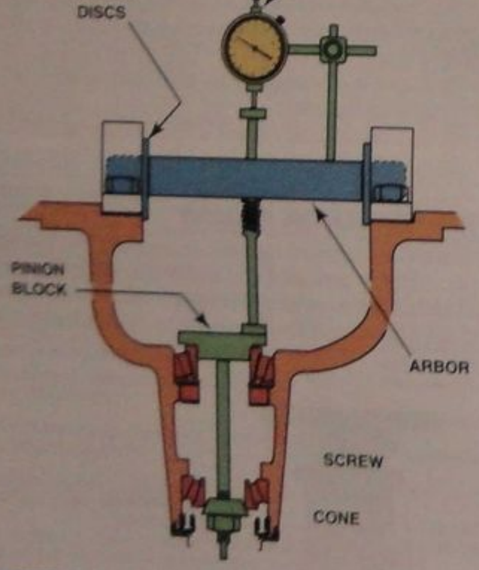


Figure 98–29 Special tool kit used for determining the correct pinion shaft shim thickness.

preload on the side bearings. See Figure 98–35. Always follow the procedures specified for the axle being serviced. A typical axle may require the installation of a shim 0.004 thicker on both sides. After setting the preload, double-check that the backlash is within specification.



Figure 98–30 Using an inch-pound torque wrench to check the rotating torque of the drive pinion. This procedure is very important if the axle uses a collapsible spacer. The drive pinion nut should be gradually tightened and the rotating torque checked to prevent overtightening the nut. If the rotating torque is higher than specifications, the collapsible spacer will require replacement and the installation procedure must be repeated.

FREQUENTLY ASKED QUESTION ???

What Do I Do About Drive Pinion Bearing Preload When I Replace Just the Pinion Seal?

To replace a pinion seal, the drive pinion nut and pinion flange must be removed.

CAUTION: Do not use an air impact wrench on the drive pinion nut. The pinion bearings can be damaged by the impact of the wrench.

Before the nut is removed, make a mark on the pinion nut and on the axle housing. After the new pinion seal is installed, tighten the pinion nut to the same position it was in before disassembly and then rotate the nut 1/16 inch (1.5 mm) further. This extra rotation makes sure that the collapsible space (crush sleeve) is still able to maintain the proper preload on the pinion bearing. Another method is to measure the rotating torque of the drive pinion using an inch-pound beam-type torque wrench after removing both rear wheels and brake drums. After installing the replacement pinion shaft seal, tighten the drive pinion nut until the rotating torque is 3 to 5 in-lb more than the reading obtained before the pinion nut was removed.

FREQUENTLY ASKED QUESTION ???

What Is a Spool Rear End?

A spool is a solid piece of metal that takes the place of the side gears and pinion gears in a differential assembly (see Figure 98–36). A spool used in drag racing is not suitable for street driving because the spool does not allow for any differences in the speeds of the drive wheel during cornering. Obviously, drag vehicles do not turn corners while racing and the spool rear end is one of the reasons they bounce when turning around at the end of the strip to return to the pits.

REASSEMBLY OF THE DIFFERENTIAL ASSEMBLY

After the backlash has been checked to be within factory specifications, the axle shafts can be installed. See Figure 98–37. Install the retaining "C" clip or bolt the retainer to the axle housing. Clean

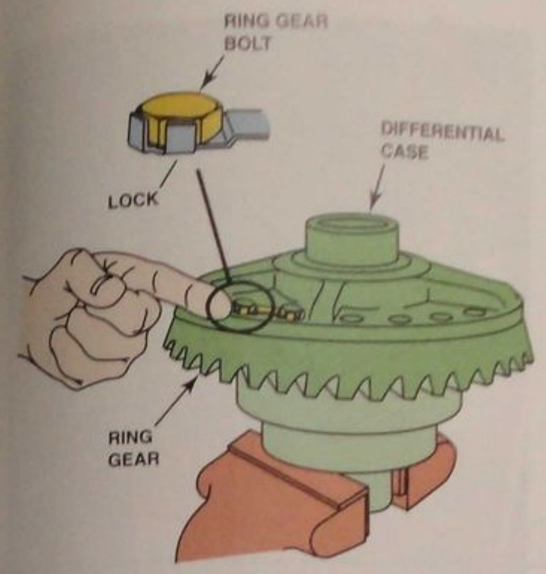


Figure 98–31 If the ring gear has been removed from the differential case or if a new ring gear is being installed, always replace the ring gear bolts.



Figure 98–32 Backlash should be between 0.005 and 0.008 inch on most differentials. If the backlash is too great, add shim thickness to the ring gear side and subtract shim thickness from the opposite side.

and install the differential cover and fill with the specified differential lubrication.

DIFFERENTIAL LUBRICANT

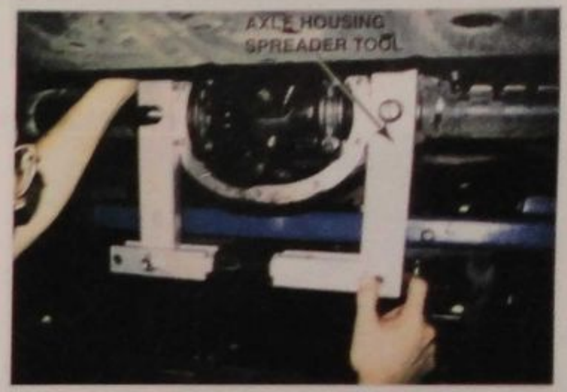
Because all differentials use hypoid gear sets, a special lubricant is necessary because the gears both roll and slide between their meshed teeth. Gear lubes (GL) are specified by the American Petroleum Institute (API):

GL-1 Straight mineral oil
GL-2 Worm gear lubricant
GL-3 Mild EP lubricant (will *not* protect hypoid gears)
GL-4 Mild EP lubricant suitable for manual transmissions/transaxles
GL-5 EP lubricant okay for hypoid gears (meets military Mil-L2150B requirements)

See Figure 98–38.



(a)



(b)

Figure 98–33 (a) Some vehicle manufacturers recommend using a housing spreader tool that fits into the round openings on both sides. (b) The spreader tool being installed. The housing is spread a specified amount and the differential is then installed into the housing.

NOTE: EP additives contain sulfurized esters and organic sulfur phosphorous compounds. These ingredients give the lubricant a very strong pungent smell. To avoid possible skin irritation, always wear protective gloves or wash your hands thoroughly with soap and water if exposed to differential lubricant.

Most differentials require

1. SAE 80W-90 GL-5
2. SAE 75W-90 GL-5
3. SAE 80W GL-5

NOTE: Always check the *exact* specification before adding or replacing rear axle lubricant.

Limited-slip differentials (often abbreviated LSD) usually use an additive that modifies the friction characteristics of the rear axle lubricant to prevent chattering while cornering.

HINT: If chattering becomes noticeable while cornering, replace the old differential lubricant with the correct lubricant and add limited-slip additives if specified by the vehicle manufacturer. After refilling the differential, drive the vehicle in a figure-eight pattern at least four times to help all of the lubricant and additives get into the clutch plates. This usually stops the chattering-while-cornering problem.

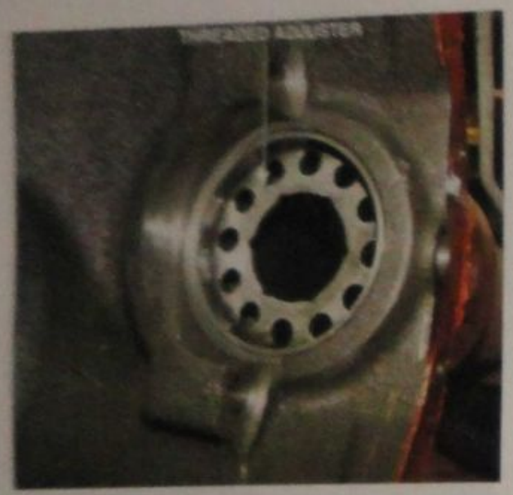




Figure 98–34 (a) Note the new shape of the threaded adjuster used to adjust side bearing preload and ring gear backlash on a Dodge Dakota truck. (b) A long handled adjuster tool is needed to turn the side bearing adjuster on this truck.

REAL WORLD FIX — **I Didn't Know It Would Fit the Wrong Way!**

An automotive student changed the differential lubricant by removing the housing cover. The cover was reinstalled and then filled with the correct lubricant. However, when the student drove the vehicle it made a grinding sound that was not there before the differential service. When the cover was removed, it was discovered that the cover had been installed with the raised area on the right side of the housing instead of on the left side and the ring gear had rubbed a groove in the cover as shown in Figure 98–39. Installing the cover correctly stopped the grinding sound.



Figure 98–35 On many axles, it is necessary to use a special tool to install steel spacers (shims) to achieve the specified backlash and side bearing preload.



Figure 98–36 A spool used in a rear end for drag racing only.



Figure 98–37 Install the axle shaft, being careful to not damage the seal.



Figure 98–38 A container of GL-5 SAE 80W-90 gear lubricant.

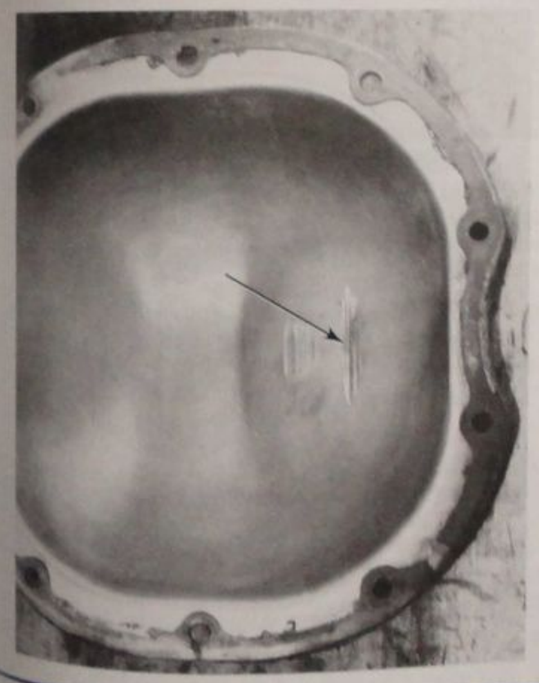


Figure 98–39 The beginning automotive student did not realize that the axle housing cover could fit the wrong way. The only problem was that the ring gear scraped against the cover.

SUMMARY

1. A differential allows the drive wheels to rotate at different speeds while traveling around a corner or over bumps and dips in the road.
2. The drive pinion transfers torque to the ring gear, which is attached to the differential case. The case revolves with the ring gear. The case is equipped with pinion gears that mesh with side gears. The side gears are splined to the axles.
3. When one wheel is rotating faster than the other, the pinion gears "walk around" the side gears.
4. The gear ratio of a differential is determined by dividing the number of teeth of the drive pinion into the number of teeth of the ring gear.
5. Most axle assemblies have numbers and/or letters stamped into the axle housing as an identification.
6. A tooth contact pattern test is important to determine if the relationship between the drive pinion and ring gear is correct.
7. The depth of the drive pinion in the differential housing is critical to the proper operation of the differential.
8. A shim pack or a collapsible spacer is used to provide the proper drive pinion shaft bearing preload.
9. Backlash should be about 0.005 to 0.008 inch for most differentials.
10. Many limited-slip differentials use clutches to limit the amount of slippage that can occur between the two drive axles.

REVIEW QUESTIONS

1. Explain how to determine the axle ratio without removing the housing cover.
2. Describe how to perform a ring gear tooth contact pattern test.
3. List three methods that may be used to determine the proper drive pinion gear depth.
4. Explain how to achieve proper drive pinion gear bearing preload.
5. Describe how to adjust the position of the ring gear to achieve the proper backlash.
6. List the steps for replacing a drive pinion gear seal while still maintaining proper preload on the drive pinion bearing.

CHAPTER QUIZ

1. Technician A says that the convex side of the ring gear is the drive side on most rear axle assemblies. Technician B says that the convex side of the ring gear is the drive side on differentials used in the front of many four-wheel-drive vehicles. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. The drive pinion gear is positioned with a shim that is too thick. This will cause contact with the ring gear teeth too close to the _____.
   a. Toe
   b. Heel
   c. Flank
   d. Face
3. The backlash exceeds specifications. The technician should position the ring gear _____.
   a. Closer to the drive pinion gear
   b. Further from the drive pinion gear
4. The backlash is less than specifications (too low). This will cause the ring gear tooth pattern to be too close to the _____.
   a. Heel
   b. Flank
   c. Toe
   d. Face
5. A collapsible spacer is used in some differentials to provide _____.
   a. A lubrication path to the drive pinion bearing
   b. The proper preload for the side bearings
   c. The proper preload for the drive pinion bearings
   d. The proper amount of slippage in a limited-slip differential

6. A growling sound is heard from the rear of a rear-wheel-drive vehicle during cornering only. Technician A says that defective rear axle bearings may be the cause. Technician B says that defective drive pinion bearings may be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. The spacer used on a drive pinion gear is used to properly position the gear so that it can correctly mesh with the
   a. Ring gear
   b. Side gear
   c. Differential pinion gears
   d. Both b and c
8. What part(s) wears rapidly if a vehicle equipped with an open differential spins one wheel on ice or snow for an extended period of time?
   a. Ring gear and pinion
   b. Side gear
   c. Pinion bearings
   d. Pinion and side gear thrust washers
9. Technician A says that if the backlash is okay, then the side bearing preload is also okay. Technician B says that a ring gear tooth pattern check will indicate if the drive pinion depth is correct. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Two technicians are discussing which lubricants are used in a limited-slip differential. Technician A says to use SAE 80W-140. Technician B says that most vehicle manufacturers usually specify SAE 80W-90 be used with or without special limited-slip additives. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 99

Four-Wheel Drive and All-Wheel Drive

OBJECTIVES: After studying Chapter 99, the reader will be able to: Prepare for ASE Manual Drive Train and Axles (A3) certification test content area "F" (Four-Wheel Drive Component Diagnosis and Repair). • Explain the difference between a mode shift and a range shift. • Describe the purpose and function of the center differential. • Explain the purpose and function of a viscous coupling. • Describe the difference between four-wheel drive and all-wheel drive. • Explain how the front axle is disconnected when two-wheel drive is selected.

KEY TERMS: annulus gear • bevel gear differential • electronically controlled clutch assembly • input member • interaxle differential (center differential) • internal gear • locking hubs • low range • mode shift • output member • part-time four-wheel drive • planet carrier • planet pinions • range shift • reaction member • ring gear • sun gear • viscous coupling

FOUR-WHEEL-DRIVE SYSTEMS

Two-wheel drive vehicles use engine torque to turn either the front or the rear wheels. A differential is required to allow the drive wheels to travel different distances and speeds while cornering or driving over bumps or dips in the road. A four-wheel-drive vehicle, therefore, requires two differentials—one for the front wheels and one for the rear wheels.

NOTE: The term *4 × 4* means a four-wheeled vehicle that has engine torque applied to all four wheels (four-wheel drive). A *4 × 2* means a four-wheeled vehicle that has engine torque applied to only two wheels (two-wheel drive).

Four-wheel-drive vehicles require more than just two differentials. The front and the rear wheels of a four-wheel-drive vehicle also travel different distances and speeds whenever cornering or running over dips or rises in the road. There are three different methods used to allow for front-to-rear driveline speed variation.

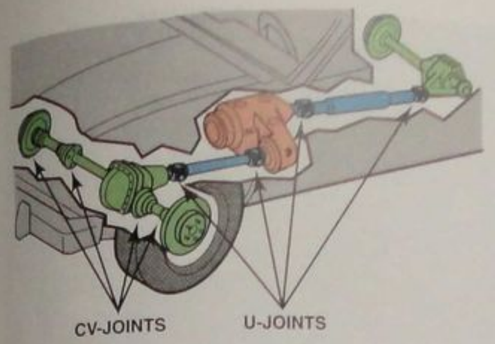
Method 1—Locking Hubs Engine torque from the transmission is applied directly to the rear differential through the transfer case. See Figure 99–1. The transfer case permits the driver to select a low-speed, high-power gear ratio inside the transfer case while in four-wheel drive. These positions and their meanings include

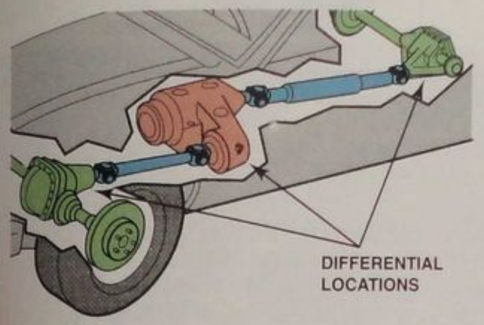
4H four-wheel drive with no gear reduction in the transfer case.

4L four-wheel drive with gear reduction. Use of this position is usually restricted to low speeds on slippery surfaces.

2H two-wheel drive (rear wheels only) in high range, meaning no gear reduction in the transfer case.

CAUTION: Check the owner's manual or service manual for the recommended procedure to follow when changing from one position to another in the transfer case. Some vehicles require that the vehicle be stopped before selecting between two- and four-wheel drive and between high and low range.





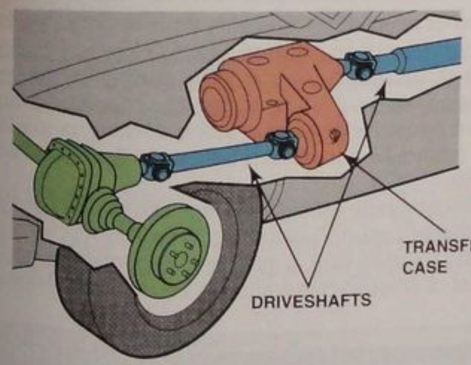


Figure 99–1 Many light trucks and sport utility vehicles use a transfer case to provide engine torque to all four wheels and to allow a gear reduction for maximum power to get through mud or snow. *(Courtesy of Dana Corporation, Perfect Circle Products)*

The transfer case also applies power to the front differential. Power is then applied to the front wheels through the drive axles to the **locking hubs.** In normal 4H driving on hard surfaces, the front hubs *must* be in the unlocked position. The front hubs are locked whenever driving on loose road surfaces to absorb and allow for tire slippage due to the different tire speeds front to back. This type of four-wheel-drive system is called **part-time four-wheel drive** because it can only be driven in four-wheel drive on slippery surfaces. See Figure 99–2.

CAUTION: Failure to unlock the front wheel hubs while driving on a hard road surface can cause serious driveline vibrations and damage to driveshafts, U-joints, and bearings as well as to the transfer case, transmission, and even the engine.

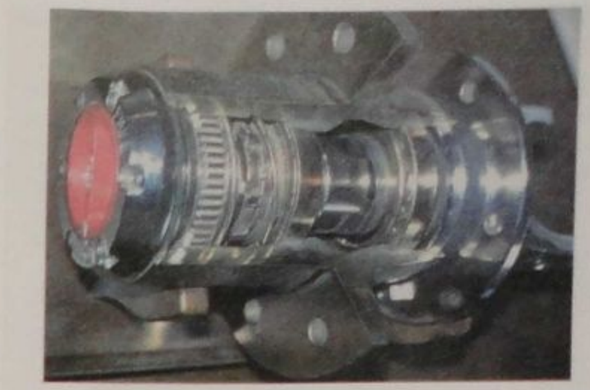


Figure 99–2 Cutaway of a manually-operated locking hub.

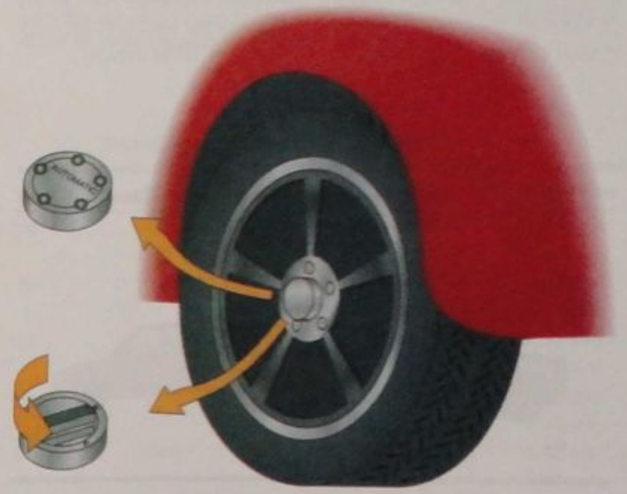


Figure 99–3 Manual locking hubs require that the hubs be rotated to the locked position by hand to allow torque to be applied to the front wheels. Automatic locking hubs enable the driver to shift into four-wheel drive from inside the vehicle.

Method 2—Autolocking Hubs Another method of locking the hubs on a part-time four-wheel-drive system is with a clutch arrangement built into the hub assembly. Whenever driving on smooth, hard road surfaces, the hubs "free wheel" and allow the front wheels to rotate at different speeds from the rear wheels. When the speed difference between the wheels and the front drive axle is great, the hubs will automatically lock and allow engine torque to be applied to the front wheels. Figure 99–3 shows an autolocking hub with the cover removed. Automatic-locking hubs are unlocked by disengaging four-wheel drive at the transfer case and driving in reverse for several feet.

NOTE: One of the disadvantages of automatic-locking hubs is that they do not transfer torque to the front wheels when the vehicle is in reverse.

TECH TIP ✓ **How to Tow a Four-Wheel-Drive Vehicle Without Doing Harm**

If any of the drive wheels are on the ground, the wheels are turning the axles. Depending on the exact type of four-wheel-drive vehicle being towed, this rotation of the wheels can cause severe wear; therefore most experts suggest the following options:

- *Placing the vehicle on a flatbed or trailer.* This keeps all four wheels off the ground and is the safest method for transporting a four-wheel-drive (or all-wheel-drive) vehicle without doing any harm.
- *Hoisting the front wheels off the ground and placing the rear wheels on a dolly.* This procedure also keeps all wheels off the ground and therefore prevents any damage being done to the power train as a result of towing. See Figure 99–4.

Method 3—Full-Time Four-Wheel Drive This method uses a center differential to allow front and rear wheels to travel at different speeds under all operating conditions, as shown in Figure 99–5. Although this drive train design is the easiest to operate both on and off the road, the center differential can cause the vehicle to get stuck in mud or snow even though it is a four-wheel-drive vehicle.



(a)



(b)

Figure 99–4 If a four-wheel-drive vehicle must be towed, it should be either on (a) a flatbed truck or (b) a dolly.

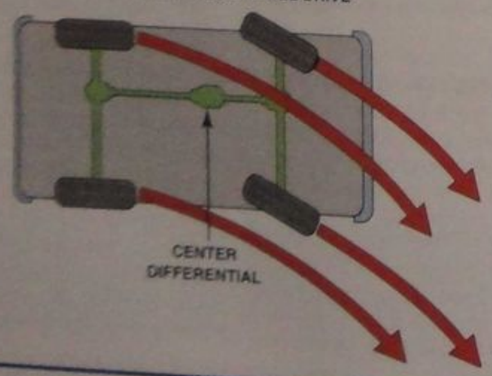


Figure 99–5 When turning a corner, each wheel takes a slightly different path and rotates at a slightly different speed. Unlike a part-time four-wheel-drive system, which when engaged locks the front and rear axles together, a full-time system uses a center differential that allows for any speed differences between the front and rear axles. It can therefore be activated on any surface—slippery or dry.

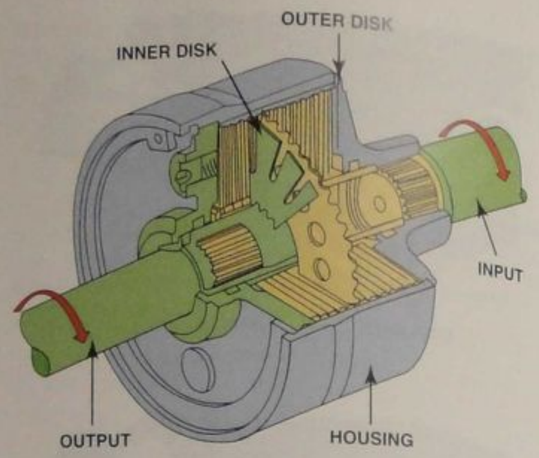


Figure 99–6 A viscous coupling is a sealed unit containing many steel discs. One-half of them are splined to the input shaft, with every other disc splined to the output shaft. Surrounding these discs is a thick (viscous) silicone fluid that expands when hot and effectively locks the discs together.

All open-style differentials allow for speed differences and torque is applied equally, so if one wheel is on ice or mud, the other wheel receives the same low torque. This is why many vehicles spin just one wheel when stuck on ice or snow. But if one rear wheel starts to spin, the vehicle may not move forward at all!

There are two methods used to lock the center differential to prevent this from happening.

- A **viscous coupling** is commonly used on many four-wheel-drive vehicles to provide an "automatic" lockup of the center differential. A viscous coupling is a type of fluid clutch. When the speed difference between the front and rear wheels is high enough, the silicone fluid inside the coupling stiffens to reduce the speed difference between the front and rear drive shafts. See Figures 99–6 and 99–7.
- An **electronically controlled clutch assembly** is actuated by the vehicle's computer based on inputs from the ABS wheel speed sensors. If a wheel starts to spin, the computer can pulse the clutch on and off as necessary to control the amount of wheel slippage.

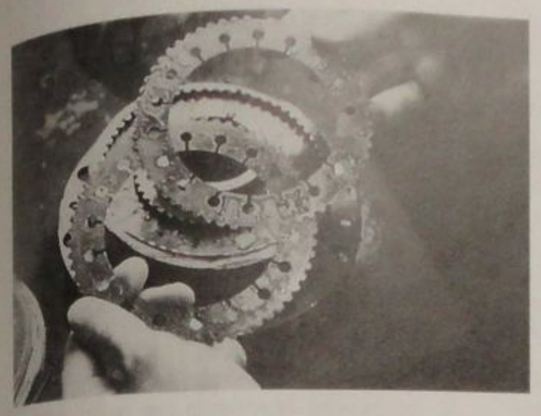
FREQUENTLY ASKED QUESTION ???

What Is Brake-Actuated Traction Control?

The engine torque of a full-time four-wheel-drive vehicle (with the center differential unlocked) is split into four nearly equal parts. One quarter of the torque is applied to each wheel. If a brake is applied to a spinning wheel, the torque to that wheel is increased, which will increase the torque to all of the other wheels. The increased torque applied to the wheels that have contact with a surface that has some traction will enable the vehicle to proceed. This is the principle involved in brake-controlled traction control such as is used on the Mercedes M4 sport utility vehicle (SUV).

ALL-WHEEL DRIVE

Some cars and light trucks are equipped with an all-wheel-drive system that uses a transfer case with a center differential and only one speed (high). Low-range gear reduction is not used. A viscous coupling is usually incorporated into the center differential to



(a)



(b)

Figure 99–7 (a) The inside of the viscous coupling consists of thin metal discs. (b) Viscous silicone fluid is used between the metal discs. (b) Viscous silicone fluid is used between the metal discs.

provide superior all-weather traction. Combined with a limited-slip differential in the rear, and sometimes also in the front, an all-wheel-drive system can provide ideal road traction under all driving conditions without any action by the driver. See Figure 99–8.

FREQUENTLY ASKED QUESTION ???

What Is the Difference Between Four-Wheel Drive (4WD) and All-Wheel Drive (AWD)?

The major difference between four-wheel drive and all-wheel drive is that four-wheel-drive units contain a transfer case with a low range. Most all-wheel-drive vehicles do not have low range and are in high four-wheel drive all the time. Both use a center (interaxle) differential and both usually use a viscous coupling or an electronically controlled clutch to control (lock) the center differential.

FRONT AND REAR DIFFERENTIAL AXLE RATIOS

In most four-wheel-drive vehicles, the overall gear ratio of the front differential is slightly higher than the overall ratio of the rear differential. The overall ratio is determined by multiplying the gear ratio by the differential ratio. See the following chart comparing the ratios for the front and rear differentials of a typical four-wheel-drive vehicle equipped with a manual five-speed transmission.

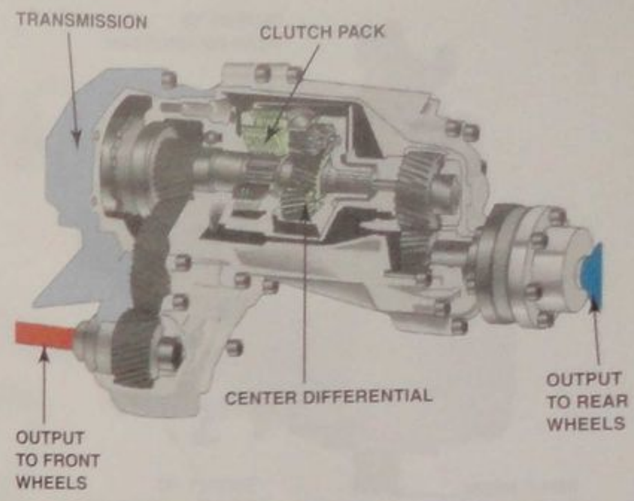


Figure 99–8 The center differential is the heart of a typical all-wheel-drive system. All-wheel-drive systems do not use a low range, and therefore the vehicle may not be able to go off-road like a vehicle equipped with a four-wheel drive with a low range.

Manual Transmission and Final-Drive Gear Ratios

Speed	Gear Ratio	Final-Drive Ratio	Overall Ratio
1st	3.083:1	4.933 front	15.208 front
		4.927 rear	15.190 rear
2nd	1.684:1	4.933 front	8.307 front
		4.927 rear	8.297 rear
3rd	1.115:1	4.933 front	5.500 front
		4.927 rear	5.494 rear
4th	0.833:1	4.933 front	4.109 font
		4.927 rear	4.104 rear
5th	0.666:1	4.933 front	3.285 font
		4.927 rear	3.281 rear

Although the difference between the ratios is small, the purpose is to prevent the drive train from binding. With the front differential ratio being just slightly higher, the tendency is for the front of the vehicle to pull the vehicle thereby eliminating the problem of having the rear pushing at the exact same ratio as the front is pulling. The different ratios also help reduce resonant vibration and noise created in the driveline.

TRANSFER CASE

The purpose and function of the transfer case is to direct engine torque to the front and rear axle assemblies. See Figure 99–9. A four-wheel-drive transfer case is basically an auxiliary 2-speed transmission. It uses the transmission output as an input to a secondary gear train or planetary gear set, which provides a low and high range. The transfer of torque to the front axle output shaft can be accomplished either by a gear-to-gear transfer or a gear and chain transfer. The gear ranges can be engaged a number of ways, such as a manual lever, electrical, or vacuum actuators. A transfer case has one input shaft (connected to the output of the transmission) and two output shafts (see Figure 99–10). The two output shafts are connected to the driveshafts and transfer torque to the



Figure 99–9 A typical transfer case is attached to the output of the transmission and directs engine torque to the rear or to the front and rear differentials.

front and rear differentials. Most transfer cases also provide for two types of shifts:

- **Mode shift.** Either two-wheel drive or four-wheel drive may be selected. Many transfer cases also have a neutral position. The mode shift is achieved by the use of a floor-mounted lever to engage and disengage a clutch inside the transfer case. This shift is usually performed when the vehicle is stopped. However, new designs allow the mode shift to be performed under most driving conditions.

NOTE: The mode shift is not available on all-wheel-drive vehicles.

- **Range shift.** A **low range** may be selected to deliver high torque at low speeds to the drive wheels. Low range usually provides a 2:1 to 3:1 gear reduction. High range (usually 1:1) simply transfers engine torque at the same speed as the output shaft of the transmission.

NOTE: Part-time four-wheel drive means that the transfer case does not include a differential.

Gear-to-Gear Transfer Cases Gear-to-gear transfer cases are simple in design. Three gear shafts are in mesh within the transfer case. One gear shaft is attached to the transmission output shaft. The second shaft acts as an idler, and the third shaft is the output to the front axle. Gear-to-gear transfer cases, in most cases, have two speeds. The first, 4-wheel-drive low, is a gear reduction that is usually around two to one. The second gear in the transfer case is a direct drive. The gears are engaged by sliding collars or synchronizers to lock the gears to the shaft. Neutral is accomplished when neither gear collar is locking a gear in place.

Two-Wheel-Drive Operation When the transfer case controls are in two-wheel drive, the front differential assembly is disconnected from the transfer case. This disconnection is usually accomplished by disconnecting one of the drive axles, as shown in Figures 99–11 and 99–12. The disconnect mechanism in the front axle and a synchronizer assembly in the transfer case combine to remove torque for the front wheels.

Four-Wheel-Drive Operation To achieve four-wheel drive, two things must occur:

- A synchronizer assembly connects the torque from the engine to the front driveshaft in the transfer case.
- The drive axles must be connected to allow the torque from the front differential to be applied to the drive wheels. See Figure 99–13.

Planetary Gear Set Transfer Cases Many transfer cases use a planetary gear set for gear reduction in low range. A planetary gear set includes the following three elements:

1. **Sun gear.** This gear is in the center like the position of the sun is in our solar system.
2. **Planet pinions.** The planet pinion gears rotate around the sun gear, like the planets around the sun, and are attached by a **planet carrier.**
3. **Ring gear.** The outer ring gear has teeth on the inside that mesh with the teeth of the planet pinion gears. The ring gear is also called the **annulus gear** or **internal gear** because the gear teeth are on the inside (rather than the outside) portion of the gear.

The gear teeth of a planetary gear set remain in constant mesh. When gear reduction is needed, the sun gear is often the drive gear and the planet carrier is often the driven gear. The gear ratio reduction depends on the number of teeth on the various gears used in a planetary gear set. See Figures 99–14 and 99–15. To achieve direct 1:1 output from the transfer case, any two of the three elements can be locked together and the entire assembly will rotate as a unit.

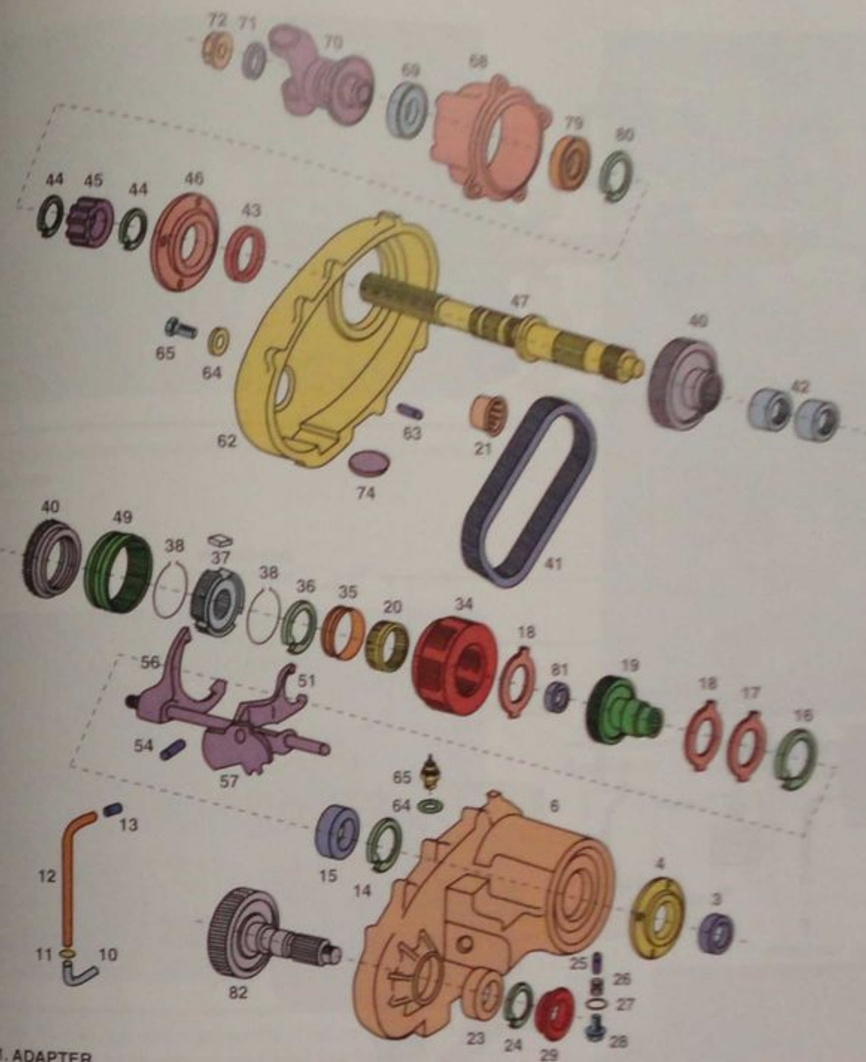
Power flows through a planetary gear set in several steps to get from the drive action of the first member to the driven action of the last member. The terms "drive" and "driven" simply describe how any two gears work together. When three or more gears are involved, the second gear is a *driven* gear in relation to the first, but a *drive* gear in relation to the third. For this reason, the drive member of a planetary gear set is called the **input member,** the held member, the **reaction member,** and the driven member, the **output member.** See Figures 99–16 through 99–18.

INTERAXLE DIFFERENTIAL

All-the-time four-wheel-drive, all-wheel-drive, and full-time four-wheel-drive systems use an **interaxle differential (center differential)** to prevent driveline harshness and vibration, commonly referred to as driveline windup. An interaxle differential can be found in various configurations including:

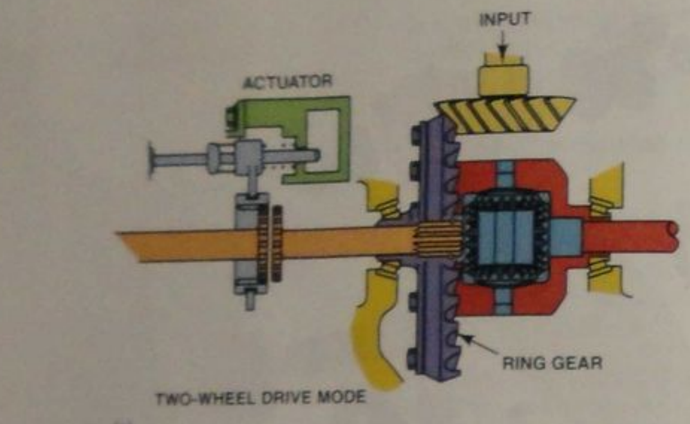
- Standard bevel gear differential
- Planetary gear differential
- Viscous coupling

Although they are different in appearance, interaxle differentials serve the same purpose, to maintain smooth operation while making turns in a four-wheel-drive/all-wheel-drive vehicle. The **bevel gear differential** uses two bevel gears or spider gears attached to the output shaft of the transmission. Two to four differential pinion gears are attached to a carrier, which is attached to the transfer gears. In other words, it operates in the same fashion as the differential in a rear axle; power is transferred to the tire with the least traction.



1. ADAPTER
2. LOCKNUT
3. FRONT RETAINER SEAL
4. FRONT BEARING RETAINER
5. RETAINER SCREW
6. FRONT CASE
7. CASE STUD
8. VACUUM SWITCH
9. O-RING
10. VENT
11. CLAMP
12. HOSE
13. HOSE END CAP
14. SNAP RING
15. BEARING
16. SNAP RING
17. RETAINER
18. THRUST WASHER
19. INPUT GEAR
20. PILOT BEARING
21. BEARING
22. OUTPUT SHAFT
23. BEARING
24. SNAP RING
25. DETENT PLUNGER
26. SPRING
27. O-RING
28. PLUG
29. SEAL
30. OIL SLINGER
31. YOKE
32. WASHER
33. NUT
34. LOW RANGE GEAR
35. SHIFT HUB
36. SNAP RING
37. SYNCHRONIZER
38. SPRINGS
39. STOP RING
40. SPROCKET
41. DRIVE CHAIN
42. BEARING
43. SEAL
44. SNAP RING
45. SPEEDOMETER GEAR
46. OIL PUMP
47. MAINSHAFT
48. SHIFT FORK PADS
49. RANGE FORK PADS
50. MODE FORK PADS
51. MODE FORK
52. SPRING
53. SHIFT RAIL
54. PIN
55. BUSHING
56. RANGE FORK
57. SHIFT SECTOR
58. O-RING
59. RETAINER
60. RANGE LEVER
61. NUT
62. REAR CASE
63. ALIGNMENT DOWEL
64. WASHER
65. BOLT
66. CASE BOLT
67. RETAINER SCREW
68. RETAINER
69. SEAL
70. YOKE
71. SEAL
72. YOKE NUT
73. WASHER
74. MAGNET
75. O-RING
76. OIL TUBE
77. TUBE CONNECTOR
78. SCREEN
79. BEARING
80. SNAP RING
81. PLUG
82. FRONT SHAFT
83. SNAP RING
84. GASKET

Figure 99–10 An exploded view of a New Venture 241 transfer case.



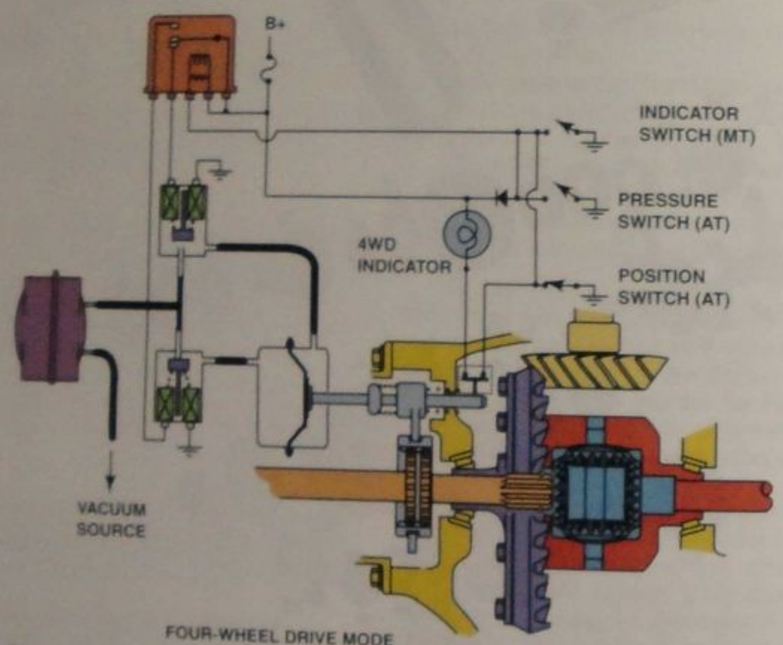


Figure 99–11 (a) When one axle shaft is disconnected, both front wheels can rotate independently, reducing excessive tire wear. (b) In four-wheel-drive mode, vacuum is applied to the front part and the opposite side is vented to atmospheric pressure retracting the shift motor stem. The shift fork and collar move into engagement with both axle shaft gears. Engine torque from the front differential can now be applied to both front axles. When the transfer case is placed in two-wheel drive, the vacuum is applied to the other side of the diaphragm and the shift collar moves, uncoupling the front axles.

When there is unequal traction between the front and rear axles, the axle with the most traction is allowed to slip enough to prevent damage to driveline components. See Figure 99–19.

With this setup, the loss of traction at one wheel could effectively disable the vehicle. For example, if one wheel had zero traction, the majority of engine torque would be applied to that wheel. In a standard bevel gear setup, torque is split between the front and rear axles. If there is a loss of traction in the front, the transfer of torque to the rear axle will be significantly lowered. To remedy this condition, auto manufacturers incorporate an internal clutch mechanism, much like a limited-slip unit, to increase torque transfer and still lessen driveline vibration and harshness.

A planetary gear set is often incorporated in transfer cases to act as a differential.

A viscous coupling is nothing more than a selection of steel plates housed in a sealed steel drum. See Figure 99–20. The viscous coupling is not active during equal traction conditions. The viscous coupling does actively transfer torque during light to moderate cornering, but there is a certain amount of slippage under these conditions to prevent driveline windup. If there is a significant loss of traction, the speed differences between the front and rear axles increase, and this increase in plate speed heats the silicon fluid in the viscous coupling, causing it to thicken to the point that it transfers more torque to the axle that is losing traction. During a severe loss of traction, the viscous fluid thickens enough to lock the plates together, dividing engine torque equally 50/50 between the front and rear axles.

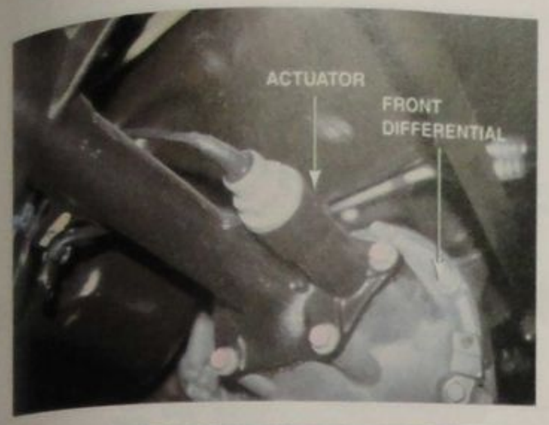


Figure 99–12 A General Motors sport utility vehicle front axle showing the electric axle disconnect actuator.



Figure 99–13 The range shift selector on a Hummer H1 sport utility vehicle. This vehicle is always in four-wheel drive, but the driver can select neutral (N) or low range.

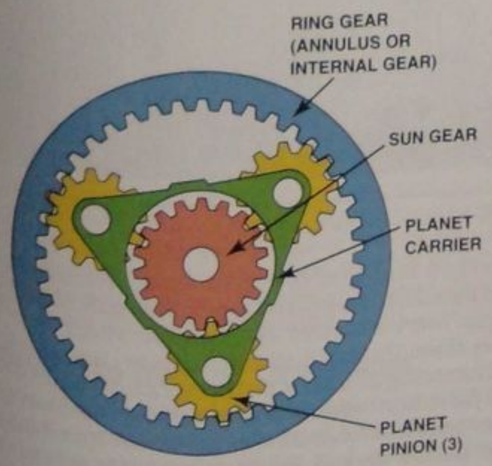


Figure 99–14 A typical planetary gear set used in a transfer case.

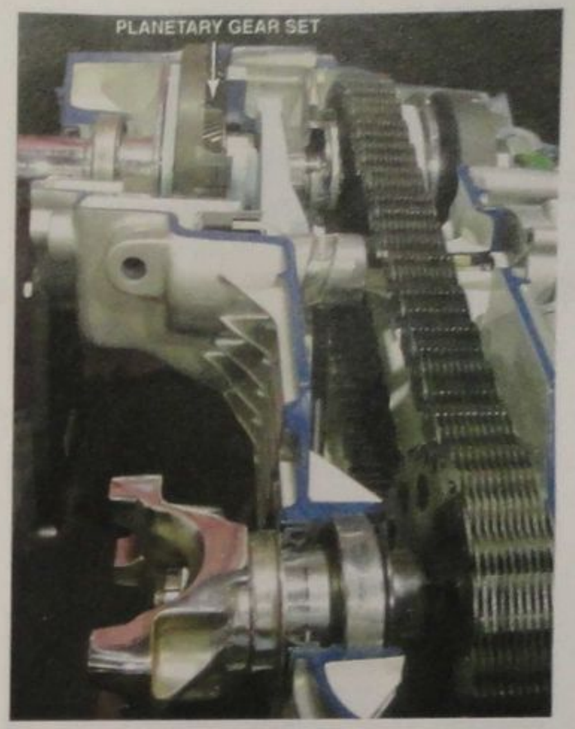


Figure 99–15 Cutaway of a planetary gear set transfer case.

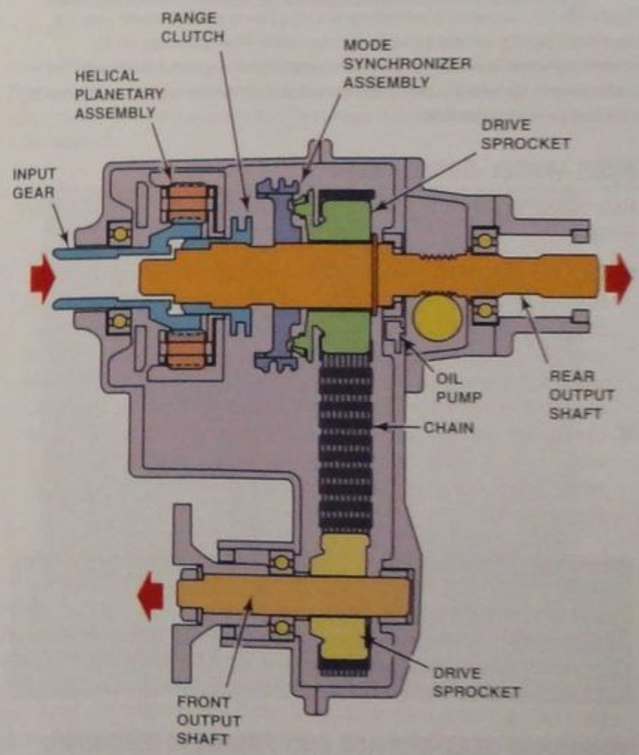


Figure 99–16 Two-wheel-drive/high-range torque flow in a NV231 transfer case. The sliding range clutch is shifted to the forward position by the range lever and fork, which connects the input gear to the output shaft and rear axle. The mode synchronizer sleeve is moved out of engagement from the drive sprocket to remove torque from the front axle.

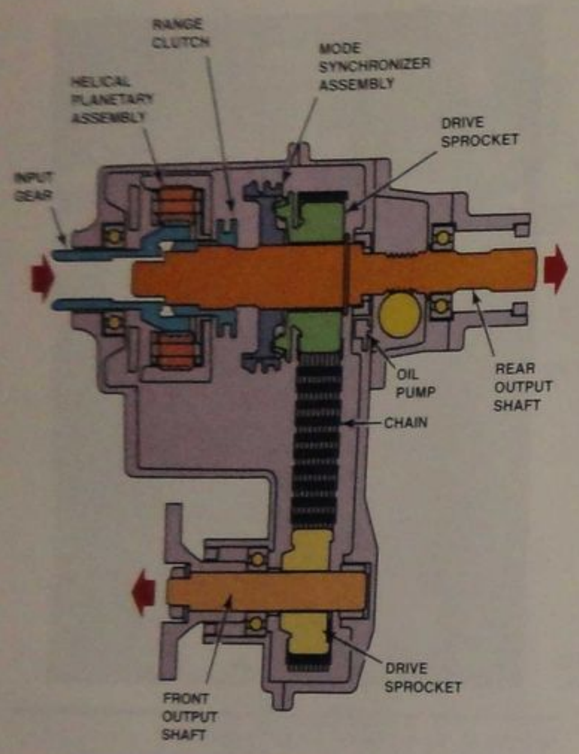


Figure 99–17 Four-wheel-drive/high-range torque flow in a NV231 transfer case. The range clutch position remains the same as in two-wheel drive/high-range, but the synchronizer sleeve is moved rearward and engages the drive sprocket clutch teeth. This action connects the drive sprocket to the rear output shaft, thereby applying equal torque to both front and rear output shafts.

FOUR-WHEEL-DRIVE AXLES

Four-wheel-drive vehicles use a variety of driveshafts and U-joint designs:

- **Standard Cardan-type U-joints.** See Figure 99–21. If this type of U-joint is used on the front wheels of a four-wheel-drive vehicle, the different speeds it creates can cause the front wheels to skip, hop, and shake if engine torque is applied while on dry pavement and turning a corner at the same time. This is normal for this type of U-joint used on the front wheels of a four-wheel-drive vehicle.
- **Constant velocity (CV) joints.** The use of CV joints at the front wheels allows engine torque to be applied without changes in wheel speed, as can often occur if standard U-joints are used. See Figure 99–22.

NOTE: Constant velocity (CV) joints are commonly used on vehicles that have the differential assembly attached to the frame of the vehicle. This design reduces the amount of weight that has to move up and down during suspension movement and helps provide a smooth ride.

TRANSFER CASE SERVICE AND PROBLEM DIAGNOSIS

Four-wheel-drive transfer cases and related components are usually built strong enough for heavy-duty use. However, there is some preventative maintenance that may need to be done:

- **Draining and refilling the transfer case.** Most transfer cases require automatic transmission fluid (ATF), yet some (especially older) units require SAE 80W-90 GL-4 gear lube. Obviously, any fluid leaks should be corrected as soon as possible to avoid damage from low lubricant level. See Figure 99–23.
- **Drive chain.** The chain in chain-drive transfer cases can stretch and start hitting the inside of the transfer case. See Figure 99–24. This occurs most frequently in vehicles that use four-wheel drive under heavy loads for extended periods of time. The noise the chain makes is very loud, and the chain should be replaced as soon as possible to avoid excessive damage to the case.
- **Bearings.** Transfer case bearings may cause noise whenever the input shaft is rotating even if the transfer case is in neutral. Consult the factory service information for details on transfer case bearing noise diagnosis procedures.
- **Shifting.** Shifting problems can be caused by several items: shift linkage bent or binding, worn shift fork or synchronizer assembly (see Figure 99–25), incorrect transfer case lubricant.

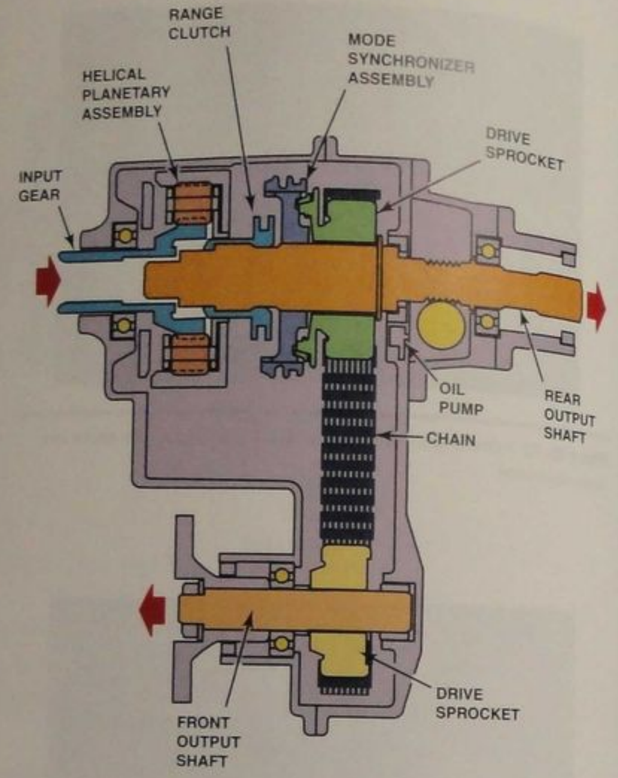


Figure 99–18 Four-wheel-drive/low-range torque flow in a NV231 transfer case. The mode synchronizer assembly remains engaged and the range clutch is moved to the rearward position. The annulus (ring) gear is fixed to the case and the input (sun) gear drives the pinion gears, which walk around the stationary annulus gear and drive the planetary carrier and output shaft at a speed lower than the input gear.



Figure 99–19 A bevel gear-type interaxle differential.

NOTE: The transfer case may be difficult to shift if the recommended procedure is not followed. For example, many manufacturers recommend that the vehicle be completely stopped before attempting to make a mode and/or a range shift. Verify proper shifting procedures before further testing or disassembly.

TECH TIP ✔ Please Install Snap Rings Correctly

Many snap rings are tapered at their opening, as shown in Figure 99–26. This allows the snap ring pliers to grasp the points of the snap ring so that it can be expanded and easily removed. If the points are facing down, it is very difficult for snap-ring pliers to grasp the end of the snap ring. Therefore, to make it easier to disassemble a transfer case later, always install snap rings as they were designed to be installed.

TECH TIP ✔ Keep the Differential Vents Clear

All differentials are vented to allow for expansion and contraction of differential lubricant in all temperature ranges. Typically, these vents are shielded openings near the top of the differential. Most trucks, especially four-wheel-drive vehicles, use an extended vent hose to prevent water from getting into the differential if the vehicle is driven in deep water.

If mud gets into the vent, pressure can build up inside the differential and cause lubricant leakage past the rear axle seals. Therefore, whenever replacing rear axle seals, always check to make sure that the differential vent is clear. Remember that four-wheel-drive vehicles use two differentials and that both the front and rear vents plus the vent on the transfer case should be checked.

DIAGNOSING AND SERVICING LOCKING HUBS

Locking front hubs should be cleaned periodically, especially if the vehicle has been driven under water or in dusty conditions. Most vehicle manufacturers recommend that the hubs be cleaned and lightly coated with grease at the same time the front wheel bearings are serviced. Check the service information for the exact procedure for the vehicle being serviced. See Figure 99–27.



Figure 99–20 A viscous coupling. Note that the unit is attached to the output shaft between the transfer case (or transaxle) and the rear differential. A typical viscous coupling in a sealed unit is serviced as a complete assembly.



(a)



(b)

Figure 99–21 (a) A standard Cardan U-joint used on the output driveshaft from the transfer case to the front differential assembly. (b) A Cardan-type U-joint at the front drive wheels on a Jeep Wrangler.



Figure 99–22 Constant velocity (CV) joints are used on the front axles of many four-wheel-drive vehicles like this Chevrolet Blazer.

Start the inspection of the front hubs by removing the cover plate. Many problems associated with locking hubs can be corrected by cleaning and lubricating the components. If noise is heard from the hubs, carefully inspect the inner components on both sides of the vehicle. A damaged part can cause noise in the hub on the other side. Service kits are often available for the hubs. These kits contain the gaskets, seals, and retaining rings necessary for installing the hubs correctly after wheel bearing or front brake work has been completed.



Figure 99–23 Most transfer cases use an internal oil pump to force the lubricant throughout the unit. Using the correct lubricant is critical to the proper operation of the transfer case.



Figure 99–24 A cutaway view of a transfer case showing the drive chain.

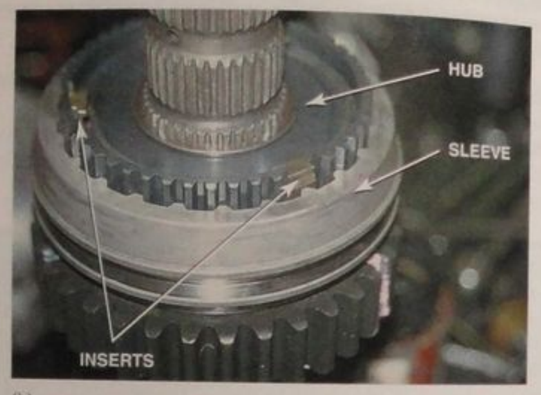
NOTE: Check the amount of axle end play. Excessive end play caused by defective bearings can cause the drive axle to move enough to damage the hubs.

REAL WORLD FIX — **The Differential Lubricant Story**

A four-wheel-drive vehicle was serviced and both differentials were drained and refilled as recommended by the vehicle manufacturer. The owner returned shortly after picking up the vehicle and complained that the vehicle drove as if the parking brake was still applied. The vehicle lacked power and would decelerate rapidly whenever the accelerator pedal was released. Careful inspection of the parking brake revealed that everything was functioning correctly. Because all that was done was the differential fluid service, the fluid level was checked and again, the level was correct and not overfull. Then the technician checked the container of gear lubricant that was used and discovered that the parts store had accidentally sent SAE 80W-140 instead of the requested, and more commonly used, SAE 80W-90. Both lubricants were listed GL-5 meaning that they were acceptable for differentials. The container of lubricant had been installed in the portable lubricating dispenser when it was delivered, and therefore the label on the container was not visible to the technician. The correct lubricant was installed in the differential and normal vehicle performance was restored. The technician and the parts store learned to double-check the product before shipping or using it.



(a)



(b)

Figure 99–25 (a) The transfer case shift forks attach to the synchronizer sleeve. (b) The sleeve, hub, and inserts are similar in design except larger than those used in a manual transmission/transaxle.



Figure 99–26 When reassembling a transfer case (or another automotive component) that includes a snap ring, always be sure that the upper opening is tapered from the top to allow snap-ring pliers room to get a grip on the open end.

TRANSFER CASE SERVICE

Transfer cases usually require occasional lubricant change during normal service life. However, driver abuse often causes parts to break, requiring the overhaul or replacement of the entire assembly. Always follow the vehicle manufacturer's recommended servicing procedure.



(a)

(b)

Figure 99–27 (a) An exploded view of a Dualmatic® manual locking hub. (b) A Warn® manual locking hub.

SUMMARY

1. A 4 × 4 is a four-wheel vehicle that has engine torque applied to all four wheels, whereas a 4 × 2 is a four-wheel vehicle that has engine torque applied to just two wheels.
2. Part-time four-wheel drive means that four-wheel drive should only be used on a slippery surface because the transfer case does not include a center differential to allow for differences in front-to-rear wheel rotational speeds.
3. Most part-time four-wheel-drive vehicles use either manual- or automatic-locking front hubs.
4. All four-wheel-drive vehicles should be towed with all four wheels off the ground if possible to avoid possible drive train damage.
5. Full-time four-wheel-drive vehicles use a center differential.
6. All-wheel-drive vehicles usually do not have a low range transfer case and are therefore not suited for serious off-road usage.

PHOTO SEQUENCE NV-242 Transfer Case Service



P99–1 The identification plate on the housing indicates the transfer case is a New Venture (New Process) model #242 and has a low-range gear ratio of 2.72:1.



P99–2 Rear output shaft housing being removed.



P99–3 Before the case can be separated, the bearing training snap ring must be removed using snap-ring pliers.



P99–4 The lubricating oil pump is visible after the cover and bearing assembly have been removed.



P99–5 The two case halves are being separated.



P99–6 The oil pump assembly, pickup screen, and tube are visible on the backside of the case cover.

(continued)



P99–7 The rear output shaft and sprocket are visible on the right. The front output shaft and sprocket are visible on the left connected by the drive chain.



P99–8 View of the shift levers and the center differential after the chain has been removed.



P99–9 Differential being removed.



P99–10 Center differential assembly after removal from the transfer case.



P99–11 Mode shift fork (upper fork) is used to change two-wheel drive and four-wheel drive. The fork is attached to the range hub, which changes four-wheel drive high to four-wheel drive low.



P99–12 Main shaft showing the range hub (left), which changes the transfer case between four-wheel high and four-wheel low.



P99–13 The chain used on the NV-242 (right) is larger than the chain used in the smaller version NV-231 (left).



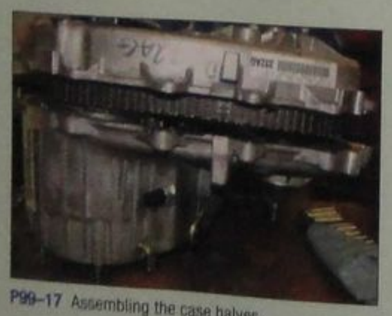
P99–14 Reinstalling the components and the drive chain.



P99–15 The drive chain should be installed with the black (dark) link(s) up.



P99–16 Install all snap rings so that the sharpest tips face up so snap-ring pliers can grab onto the tips for easier removal.



P99–17 Assembling the case halves.



P99–18 The parting surface should be sealed with RTV silicone. Do not use too much or the oil pump screen can become clogged.



P99–19 After attaching the oil pump and tube, the output shaft housing is installed.



P99–20 The output shaft speed sensor drive gear is correctly installed in this photo. The slip yoke of the drive shaft slips onto the splines and inside the nylon gear.



P99–21 The electronically-shifted version of the case is identical except that the shifting is achieve an electric motor, shown here installed in a vehicle.

7. The center differential can be locked to provide additional traction by the use of either a viscous coupling or an electronically controlled clutch assembly.
8. A mode shift selects two-wheel drive or four-wheel drive, whereas a range shift selects either low range, neutral, or high range.
9. Some four-wheel-drive vehicles use Cardan-type U-joints for the front wheels, which may cause driveline vibration during rapid acceleration while cornering.
10. Transfer cases may use either automatic transmission fluid (ATF) or SAE 80W-90 gear lube.

REVIEW QUESTIONS

1. Explain the difference between four-wheel drive and all-wheel drive.
2. Explain why part-time four-wheel-drive vehicles use locking front hubs.
3. Describe the difference between a mode shift and a range shift in a transfer case.
4. Describe how a viscous coupling works.
5. List the elements of the planetary gear set used in many transfer cases.

CHAPTER QUIZ

1. A customer complained of excessive vibration while cornering and accelerating at the same time. Technician A says that a fault in the transfer case is the most likely cause. Technician B says that the vibration may be normal if the vehicle is equipped with Cardan U-joints at the front wheels. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that the gear ratios of both differentials are the same in a four-wheel-drive vehicle. Technician B says that the rear differential has a slightly higher ratio (lower number) than the front differential. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Technician A says that most automatic-locking front hubs do not lock the wheels to the drive train when driving in reverse. Technician B says that to unlock most automatic-locking hubs, the transfer case should be placed in two-wheel drive and the vehicle driven in reverse several feet. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that a vehicle equipped with part-time four-wheel drive should be driven in four-wheel drive only on slippery surfaces. Technician B says that full-time four-wheel- drive vehicles use a center differential in the transfer case. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Which type of system uses a one-speed transfer case and a center differential with a viscous coupling?
   a. Part-time four-wheel drive
   b. Full-time four-wheel drive
   c. Full-time four-wheel drive with automatic locking front hubs
   d. All-wheel drive
6. Technician A says that a transfer case may use GL-4 gear lube such as SAE 80W-90. Technician B says that a transfer case may use automatic transmission fluid (ATF) such as Dexron III. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. A transfer case is extremely noisy in all selections except neutral (N) whenever the vehicle is moving. Technician A says the drive chain may be stretched, causing the noise as it hits the inside of the case. Technician B says that one or more of the transfer case bearings could be defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

8. A transaxle case is difficult to shift (range shift). Technician A says that the shift linkage or shift fork may be worn or damaged. Technician B says that the blocking ring may be worn or damaged. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

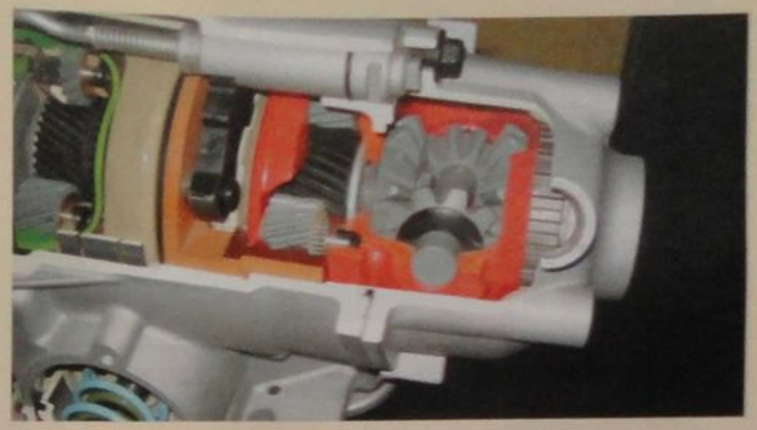
9. Two technicians are discussing the towing of a four-wheel-drive vehicle. Technician A says that the vehicle should be transported on a flatbed truck to avoid the possibility of doing damage to the drive train. Technician B says that the wheels not lifted off the ground by the tow truck should be placed on a dolly to prevent doing damage to the drive train. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

10. Two technicians are discussing the front axle disconnect mechanism. Technician A says that the front axles are only disconnected if the vehicle is being towed. Technician B says that this unit is only used on all-wheel-drive vehicles. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B

SECTION XIV

Automatic Transmission and Transaxles

100 Automatic Transmission/Transaxle Principles
101 Hydraulic Components and Control Systems
102 Automatic Transmission/Transaxle Diagnosis and In-Vehicle Service
103 Automatic Transmission/Transaxle Unit Repair



CHAPTER 100

Automatic Transmission/ Transaxle Principles

OBJECTIVES: After studying Chapter 100, the reader will be able to: Prepare for the ASE Automatic Transmission/Transaxle (A2) certification test content area "A" (General Transmission/Transaxle Diagnosis). • Explain how a torque converter can transmit and multiply engine torque. • Describe how a planetary gear set can be used for gear reduction and reverse. • Explain how automatic transmission fluid is circulated through the system and how it is cooled.

KEY TERMS: compound planetary gear set • coupling phase • flexplate • impeller • input member • Lapelleties gear set • lube oil • output member • pump • Ravigneaux gear set • reaction member • Simpson gear set • stall speed • stator • torque converter clutch (TCC) • torque multiplication phase • turbine

Automatic transmissions were first used on a large scale in the late 1940s, and now about 85% of the vehicles in North America are so equipped. Unlike manual transmissions, most automatic transmissions do not actually "shift gears" but apply clutches (or bands) to hold various sections of two or more planetary gear sets. See Figure 100–1. The torque converter is attached between the engine and the transmission/transaxle and transmits and multiplies engine torque.

TORQUE CONVERTERS

The **impeller,** also known as the **pump,** is the driving member and rotates with the engine. The impeller vanes pick up fluid in the converter housing and direct it toward the **turbine.** Fluid flow drives the turbine, and when the flow between the impeller and turbine is adequate, the turbine rotates and turns the transmission input shaft. A torque converter also contains the **stator,** or reactor, which is a reaction member mounted on a one-way clutch.

The vanes used in each of the three elements of a torque converter are curved to increase the diversion angle of the fluid. This also increases the force exerted by the fluid and improves the hydraulic advantage. The outlet side of the impeller vanes accelerates the fluid as it leaves the impeller to increase torque transfer to the turbine. See Figure 100–2. The inlet side of the turbine vanes absorb shock and limit power loss that occurs when flow between the impeller and turbine suddenly changes. The curve of the stator vanes is opposite to the curve of the impeller and turbine vanes. See Figure 100–3. Since the stator is located between the impeller and turbine, it adds to the original impeller flow and multiplies the force delivered to the turbine. See Figure 100–4.

Torque converters are single-piece, welded assemblies that cannot be disassembled or repaired easily. Although they can be rebuilt using specialized equipment, most shops simply replace welded converters as a unit if they fail.



Figure 100–1 A cross-sectional view of a Chrysler Power Flight 2-speed automatic transmission used in the 1950s. Most of the heat generated in an automatic transmission is created in the torque converter. This air-cooled unit has a vent to allow hot air to escape.

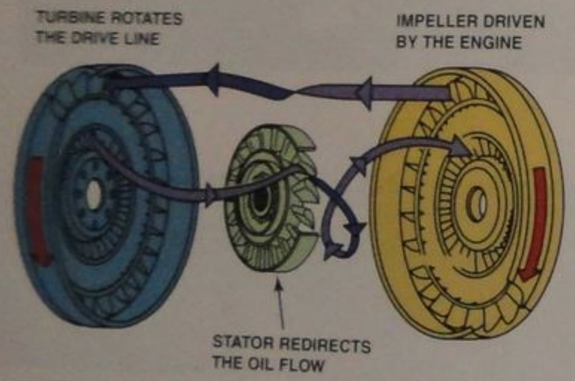


Figure 100–2 Fluid flow within a torque converter. The stator redirects the fluid that is thrown out by the turbine, thereby improving efficiency.

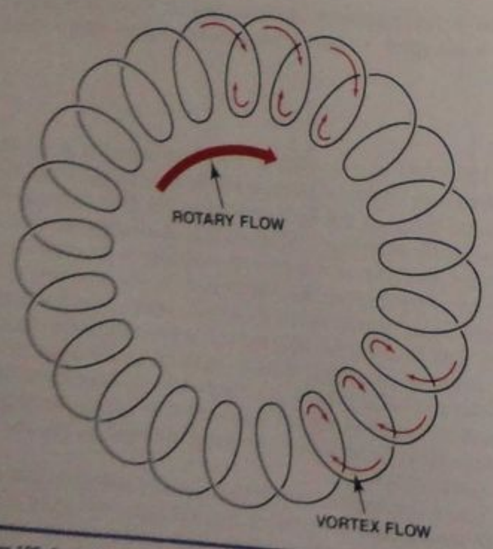


Figure 100–3 Fluid pumped into the turbine by the impeller not only creates rotary fluid flow but also vortex flow that increases the efficiency of the torque converter.

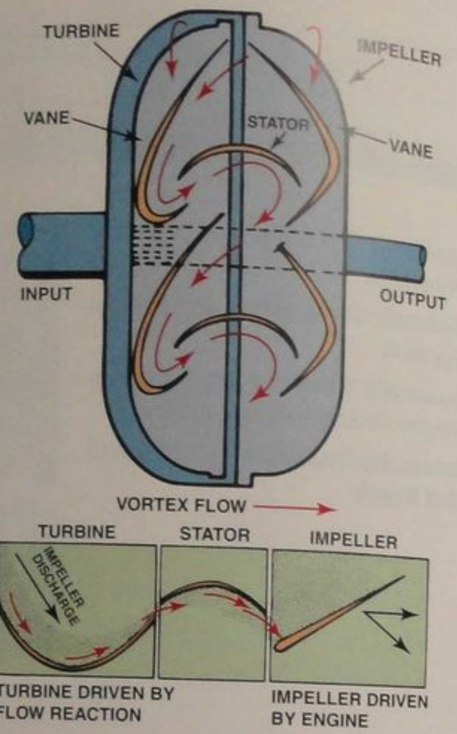


Figure 100–4 The vane curvature of each element in a torque converter helps maintain efficient fluid flow.

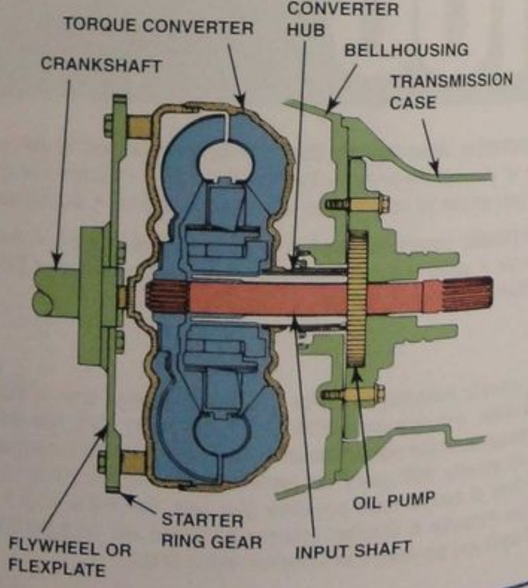


Figure 100–5 The torque converter bolts to the flexplate, which is attached to the crankshaft and rotates at engine speed. The hub of the converter drives the oil pump directly on most rear-wheel-drive transmissions.

Torque Converter Attachments The torque converter normally attaches to the engine through a **flexplate** that mounts on the crankshaft flange of the engine. See Figure 100–5. The flexplate replaces the heavy flywheel used with a manual transmission. An important function of a flywheel is to smooth out engine pulsations and dampen vibrations. An automatic transmission does not require a conventional flywheel because the fluid in the torque converter provides enough mass to dampen engine vibrations.

An external ring gear generally attaches to the outer rim of the flexplate. This ring gear engages the starter motor pinion gear to turn the engine during starting.

NOTE: On some older applications, such as the Ford C4 and Chrysler Torqueflite, the ring gear may be welded to the outside of the torque converter cover.

To ensure the pump will deliver fluid to the transmission whenever the engine turns, an integral hub is located on the converter housing and directly engages the pump. See Figure 100–6. Oil pump drive shafts generally pass through the converter inside a hollow input or transfer shaft and internally connect to the converter housing by splines.

Most rear-wheel-drive transmissions use an inline method to drive the converter and provide a direct mechanical connection between the turbine and the transmission input shaft. In a typical design, splines on the turbine connect it to the transmission input shaft and the stator hub mounts on a one-way overrunning clutch. The one-way clutch mounts on splines to a stationary extension of the oil pump called the stator support, or reaction shaft. See Figure 100–7. The converter drive hub at the rear of the torque converter housing passes over the stator support and through the front oil seal to drive the oil pump.

Many transaxles, and a few rear-wheel-drive transmissions, use an offset drive arrangement to conserve space. An offset drive design generally uses a drive chain to provide the mechanical connection between the turbine and the input shaft. See Figure 100–8. The oil pump may be driven directly by the converter housing or by a separate drive shaft.

Torque Converter Operation Fluid sent to the torque converter from the transmission oil pump is picked up by the rotating vanes of the impeller and transferred to the turbine vanes through rotary and vortex flow paths.

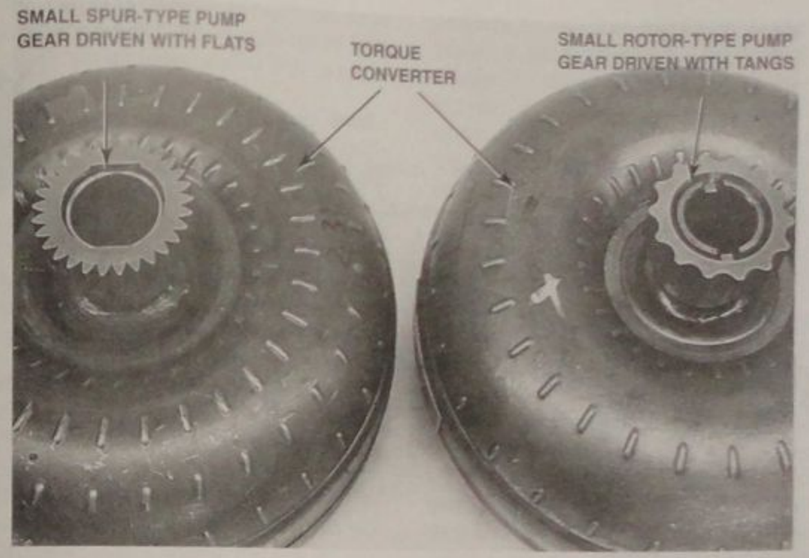


Figure 100–6 The inner oil pump gear is keyed to the hub of the torque converter, which drives the pump. Notice that the hub does not engage the full depth of the gear. This is the major reason why the torque converter *must* be fully installed. Failure to fully engage the oil pump gear can cause serious damage to both the pump and the torque converter.

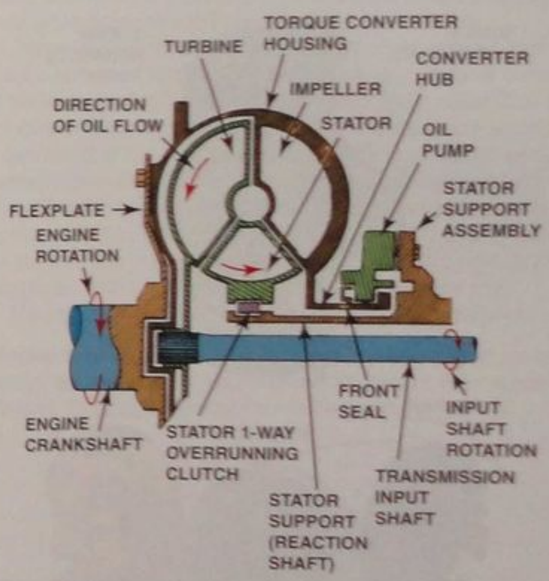


Figure 100–7 The transmission input shaft connects directly to the turbine through splines in most rear-wheel-drive transmissions.

Torque Multiplication Phase Torque multiplication phase occurs when fluid leaving the turbine vanes strikes the concave, or front side, of the stator vanes. The stator vanes redirect this fluid so that it joins the fluid flow being delivered from the impeller to the next turbine vane. See Figure 100–9. The force of the fluid from the stator adds to the force of the fluid flowing from the impeller to increase the overall torque being transferred from the impeller to the turbine.

Torque multiplication occurs whenever the vortex flow makes a full cycle from impeller to turbine, then through the stator and back to the impeller. A torque converter multiplies torque in relation to the speed ratio. At low speed ratios, the impeller is turning much faster than the turbine, so vortex flow is high and torque multiplication occurs. As turbine speed increases and approaches

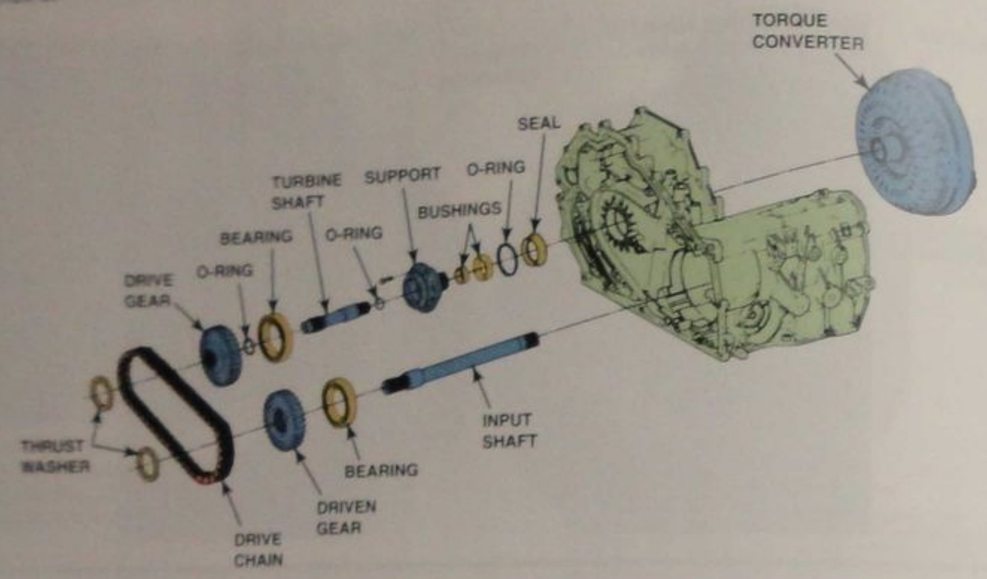


Figure 100–9 On a transaxle, the turbine drives the input shaft through a drive chain assembly.

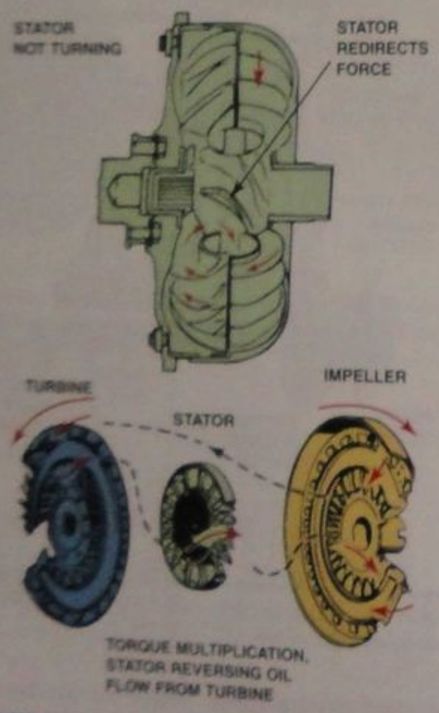


Figure 100–8 Torque multiplication occurs when fluid leaving the turbine strikes the front of the stator vanes and is redirected back to the impeller.

impeller speed, rotary flow increases, which reduces both vortex flow and torque multiplication. As the speed ratio approaches 90%, torque multiplication becomes minimal and a torque converter functions like a fluid coupling.

The stator redirects fluid flow because it remains stationary during the torque multiplication phase. The stator hub mounts on a one-way clutch, freewheeling in a clockwise direction, but locking



Figure 100–10 A stator contains a one-way roller clutch, which locks it from rotating in one direction and allows it to rotate freely in the opposite direction.

when driven in a counterclockwise direction. See Figure 100–10. When fluid from the turbine strikes the concave face of the stator vanes, it tries to drive the stator counterclockwise. By locking the stator it can redirect the fluid back to the impeller.

Coupling Phase When the speed ratio is 90% or more, fluid flow in the toque converter is mostly rotary flow and the angle of flow from turbine to stator increases. Fluid eventually strikes the convex side, or backside, of the stator vanes rather than the concave. As the force of fluid striking the backside becomes great enough to drive the stator clockwise, the one-way clutch overruns. With the clutch overrunning the turbine, impeller, and stator, all rotate in the same direction and at approximately the same speed. This is called the **coupling phase.** The stator unlocks and freewheels once the angle of fluid flow changes enough to strike the opposite side of the stator vanes and rotate the stator clockwise.

Torque multiplication drops as the torque converter approaches the coupling phase because the stator no longer redirects fluid to increase the flow from impeller to turbine. When the torque converter

reaches coupling speed, the turbine is traveling at nearly the same speed as the impeller, rotary flow is much greater than vortex flow, and the torque converter simply transmits torque like a fluid coupling.

Stall Speed During converter stall, the impeller rotates but the turbine does not. This occurs just before the drive wheels of a vehicle begin to move. The greatest amount of stall occurs when the engine drives the impeller at the maximum speed possible without moving the turbine. The engine speed at which this occurs is called the torque converter **stall speed.** When the impeller rotates but the turbine does not, the speed ratio is zero. This is the lowest possible speed ratio and the greatest possible torque multiplication. Most modern torque converters multiply torque in the range of 2:1 to 2.5:1 at the stall speed.

Torque Converter Diameter The outside diameter of a torque converter and the angle of its stator blades determines the stall speed of the converter. When both a small and large diameter converter share the same stator blade angle and turn at the same speed, the smaller converter creates less centrifugal force to move the fluid inside. As a result, the small diameter converter has a higher stall speed, multiplies torque at higher engine speeds, and will not couple until the engine reaches high speeds. In comparison, the large diameter converter has a lower stall speed, multiplies torque at lower engine speeds, and also couples at a lower engine speed.

Vehicle manufacturers select torque converters to match the power train requirements and operating demands of each application. A vehicle with a large engine that produces a lot of torque at low RPM will often use a torque converter that couples at low speeds for greater fuel economy. Vehicles with smaller engines that produce less torque at low RPM will use a torque converter that allows the engine to operate higher in its torque curve, where more power is available. High-performance vehicles with automatic transmissions use small diameter converters for the same reason.

Lockup Torque Converter Even the most efficient torque converters slip 3% to 6% during operation. This is because the fluid that transmits torque exhibits a type of slippage known as fluid shear. Fluid shear creates friction heat, but performs no work when the different layers of fluid slide past each other.

Eliminating torque converter slippage can improve fuel economy approximately 4% to 5% during freeway cruising. With the increased emphasis on fuel economy for late-model vehicles, this became an important goal for automotive engineers. An additional benefit to no slippage is a reduction of transmission operating temperature, which increases transmission life expectancy. Lockup torque converters reduce slippage by using a **torque converter clutch (TCC)** to lock the impeller to the turbine. Similar to a clutch for a manual transmission, a TCC uses a friction disc operated by a hydraulic piston to mechanically couple the turbine to the impeller. See Figure 100–11. Engaging the clutch creates mechanical connection between the engine and transmission, resulting in a direct, 1:1, drive ratio.

Converter Clutch Control The first hydraulic lockup converters were controlled entirely by hydraulic pressure and spool valves in the transmission valve body. Some later designs added simple electric switches and solenoids to control pressure to the converter clutch. Late-model hydraulic TCCs use an electronic control system to regulate the timing and application of the clutch.

Early hydraulic converter clutches will engage only in high gear because lockup in the lower gears reduces the torque multiplication needed for acceleration. Lockup may also be limited to specific vehicle speeds or operating conditions. For most vehicles, lockup can occur at speeds over 25 to 30 mph (40 to 48 km/h) after the transmission upshifts into high gear. Once lockup occurs, the clutch may disengage automatically during certain operating conditions such as part- or full-throttle downshift. At these times, the increased acceleration requirements generally override the need for better fuel economy.

The more sophisticated electronic control systems can lock and unlock a converter clutch hundreds of times per minute to meet the vehicle demands of the moment. Some recent systems also allow partial lockup of the torque converter. Traditional lockup torque converters operate either locked or unlocked. Partial lockup converters allow a regulated amount of slippage at the clutch. See Figure 100–12 that shows that each type of torque converter clutch control requires a certain type of friction material to be used on the TCC clutch. This allows the converter to lockup smoothly, improving fuel economy and performance, without the drawback of shock to the driveline.

The summary of torque converter operation is as follows:

- **Engine speed is low** with the vehicle in gear and stopped. At low engine speeds, automatic transmission fluid does not exert enough force on the turbine to permit the vehicle to move at a *creep.*

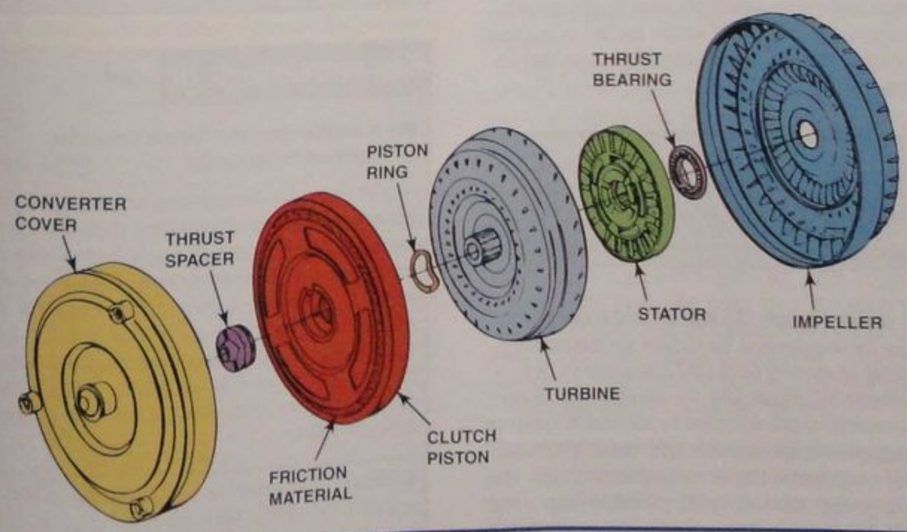


Figure 100–11 An expanded view of a typical General Motors torque converter clutch (TCC).



Figure 100–12 The type of torque converter clutch control determines the type of friction material that is used on a torque converter clutch. A paper friction material is usually used on clutches that are turned on or off, whereas Kevlar® or carbon fiber friction materials are used where the clutch is pulse-width modulated.

- **Engine speed increases and vehicle speed starts to increase.** As more engine torque is applied to the torque converter, the torque is transmitted through the movement of the fluid to the turbine. The stator is locked (prevented from moving) and redirects the fluid flow back against the turbine. The redirection of the fluid back to the turbine creates a torque on the turbine that is greater than the engine torque. This is called *torque multiplication*. Most torque converters are capable of doubling the applied engine torque due to redirection of the fluid by the stator.
- **Engine speed is steady and vehicle speed is steady.** When the speed of both the impeller and the turbine reach about the same speed (85% to 90%), the one-way clutch in the stator unlocks and the stator is free to rotate. This point is called the *coupling point*.
- **Vehicle is accelerated rapidly.** During periods of rapid acceleration, the engine speed and therefore the impeller speed are a great deal faster than the turbine speed. The greatest amount of torque multiplication occurs when the turbine is stopped and the impeller is turning as fast as the engine will turn it. This speed is called the *stall speed*. The *maximum* torque multiplication at stall speed is about 2:1, meaning that the amount of torque applied to the input shaft of the transmission/transaxle is double the amount that the engine is producing.

NOTE: The fact that the torque converter can double the torque to the transmission is the major advantage of using an automatic transmission. A clutch used in a manual transmission/transaxle can only transmit engine torque.

- **Vehicle speed is above 35 mph (55 km/h) and steady.** To improve fuel economy, the impeller and the turbine are mechanically connected by a *torque converter clutch (TCC)*, also known as a *lockup torque converter*. See Figure 100–13. Except for some rare cases, the torque converter clutch is applied by the vehicle computer. The computer senses vehicle speed (VS), engine load (MAP), and throttle position (TP) and applies the torque converter clutch. This lockup can occur in second, third, or fourth (overdrive) gear if the conditions are right. When the torque converter clutch engages, the engine RPM usually drops by 150 to 250 RPM. This reduction in engine speed and the elimination of the normal slippage in the torque converter improves fuel economy. The torque converter clutch is released during rapid acceleration for maximum torque multiplication through the torque converter for best acceleration.

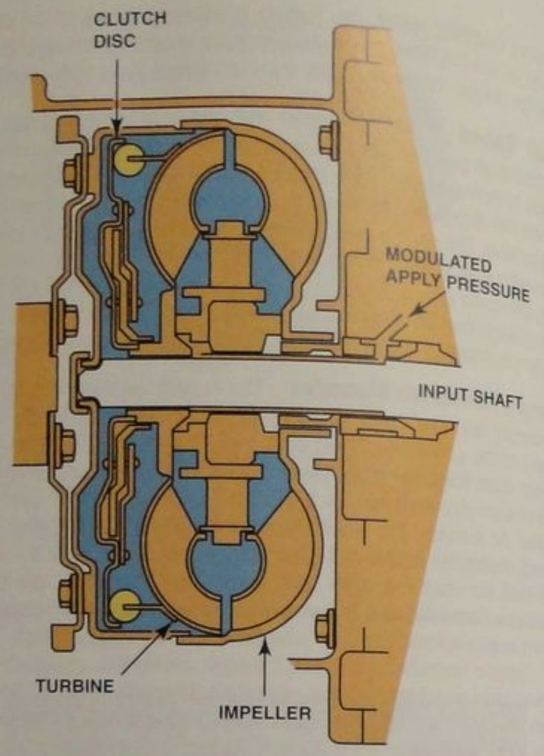


Figure 100–13 A cross-sectional view of a computer-controlled (modulated) torque converter clutch. The vehicle computer is capable of pulsing the solenoid that controls the fluid flow on and off to apply the torque converter clutch.

NOTE: The application of the torque converter clutch feels like a normal shift to most drivers. Therefore, a three-speed automatic transaxle will feel to many drivers as "shifting" three times (1-2, 2-3, and TCC engagement).

HIGH-PERFORMANCE TIP

Use a Smaller Diameter Torque Converter for Improved Performance

A smaller-than-stock-diameter torque converter will not be capable of absorbing as much torque as a larger (stock) torque converter. As a result, the stall speed is increased. Because an engine develops more torque with increased speed (up to a point), the smaller torque converter will allow the engine to increase to a higher speed and create more torque to the transmission than would be capable with the stock torque converter.

This is especially helpful for modified engines because an engine having a camshaft with increased lift and duration usually lacks low RPM torque. By using a smaller torque converter, the stall speed is increased to better match the engine torque.

CAUTION: Using a nonstock torque converter is likely to increase exhaust emissions and decrease fuel economy.

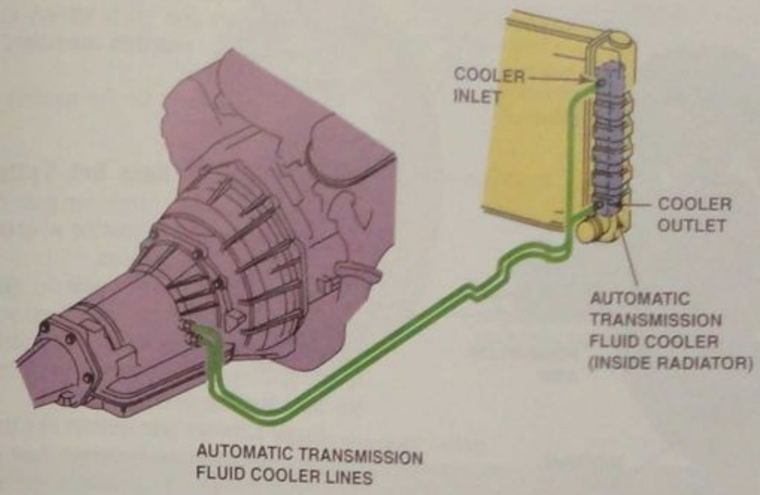


Figure 100–14 Automatic transmission fluid is routed from the torque converter, where most of the heat in an automatic transmission is generated, to the radiator, where it is cooled. The cooled fluid then returns to the transmission/transaxle to lubricate the bearings and bushings.

Automatic Transmission Fluid Cooler The torque converter generates a lot of heat due to the slippage and torque multiplication that occurs inside. The greatest amount of heat is generated when the vehicle is operating under a heavy load and the torque converter clutch is disengaged. The automatic transmission fluid (ATF) can reach high temperatures (over 250°F [120°C]) very quickly. This is the reason an automatic transmission fluid cooler is used. Most vehicles use a small section of the engine radiator to cool the ATF. Automatic transmissions/transaxles use a pump to circulate ATF and to provide the necessary hydraulic pressure to operate the hydraulic components of the unit. The ATF is pumped from the torque converter (greatest source of heat) to the cooler. The ATF flows through the cooler and returns to the transmission/transaxle to passages that lubricate the bearings and bushings of the unit. This returned fluid is called **lube oil.** See Figures 100–14 and 100–15.

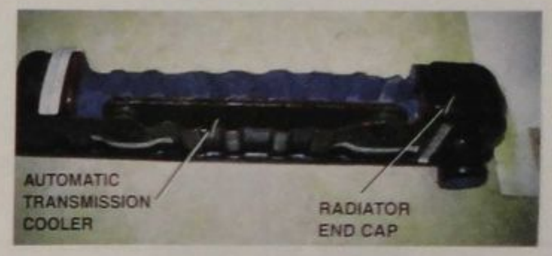


Figure 100–15 A cutaway section of a typical radiator showing the automatic transmission fluid cooler. The heat from the automatic transmission fluid is released to the engine coolant. The engine coolant also warms the automatic transmission fluid after a cold start.

CAUTION: Because the lube oil uses the ATF flowing from the cooler, if there is a blockage in the cooler, the transmission/transaxle may not have enough fluid to properly cool or lubricate the bearings and bushings inside the unit, leading to wear and eventually premature failure.

PLANETARY GEAR SETS

In a manual transmission, different gear ratios are obtained by sliding the gears into mesh. However, torque flow must be momentarily interrupted (accomplished by using a clutch) before the gears are shifted. With an automatic transmission there is no driver-operated clutch, so gear shifts are not made by sliding gears into mesh. Automatic transmissions use a planetary gear set system that does not require manual gear shifting or an interruption of torque flow to change gear ratios. A simple planetary gear set consists of three primary components:

- Sun gear
- Planet carrier assembly
- Ring gear

As discussed in the last chapter, the *sun gear* gets its name from its position at the center of the gear set. The *planet carrier assembly* holds the pinion gears, also known as planet gears, which revolve around the sun gear. The outermost member of the gear set is the *ring gear*, which is the internal type with the teeth inside. The pinion gears are in simultaneous mesh with both the sun and ring gear.

The pinion gears are free to rotate on pins that are part of the carrier, and the entire assembly rotates to direct torque flow. The simple planetary gear set as seen in Figure 100–16 has only two planet pinions, but most transmission gear sets use three or four. The pinions are fully meshed with both the sun gear and internal ring gear *at all times*. The planetary gears never disengage to change gear ratios; torque is simply redirected.

All gears in a planetary gear set are in constant mesh. The torque flow through a planetary gear set, both input and output, occurs along a single axis. The parts in a planetary gear system may be known by several different names. The internal ring gear is sometimes called an annulus gear or a ring gear. The planet pinion gears are often called planet gears or pinion gears. The planet carrier assembly is commonly referred to as the "carrier."

Planetary Gear Set Torque Flow In any planetary gear set, each gear always meshes with several other gears. Therefore, driving one gear will drive all of the other gears as well. This allows the gear set to provide different gear ratios; depending upon how torque is distributed through the assembly. To transmit torque through a

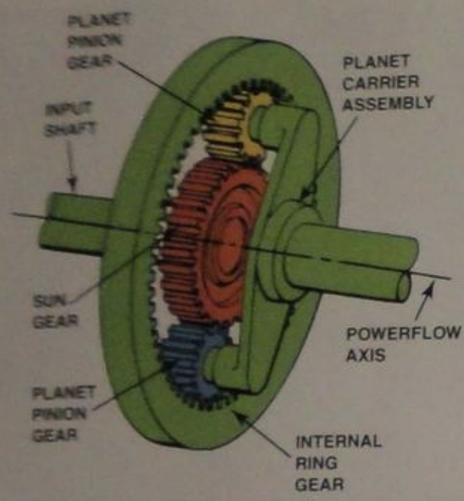


Figure 100–16 The three members of a simple planetary gear set are the sun gear, internal ring gear, and planet carrier assembly.

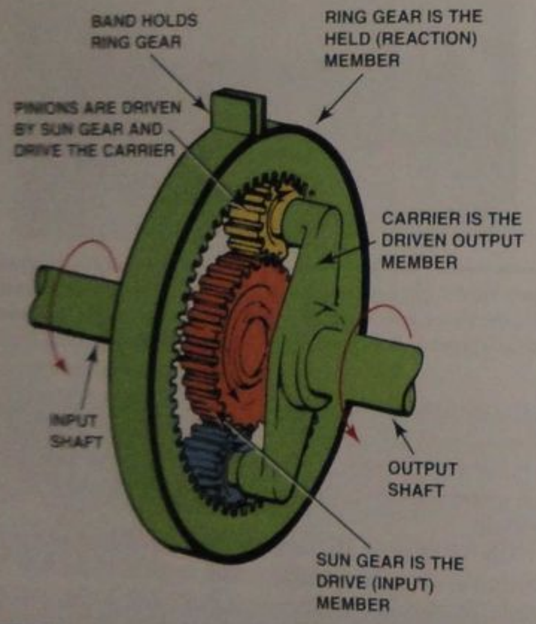


Figure 100–17 To transmit torque through a planetary gear set, one (input) member drives, another (reaction) member is held, and the third (output) member is driven.

planetary gear set, a drive member rotates while a second member is held, which causes a third member to be driven. See Figure 100–17. Each member of a planetary gear set can play any one of these three roles to transmit torque. The various combinations of drive, held, and driven members result in the number of gear ratios available. Certain combinations of drive, hold, and driven can change the direction of rotation as well.

Torque flows through a planetary gear set in several steps to get from the drive action of the first member to the driven action of the last member. The terms "drive" and "driven" simply describe how any two gears work together. When three or more gears are involved, the second gear is a *driven gear* in relation to the first, but a *drive* gear in relation to the third. For this reason, the drive member of a planetary gear set is known as the **input member,** the held member is the **reaction member,** and the driven member is the **output member.**

See Figure 100–18 for the possible gear ratios and how they are achieved.

Simple Planetary Gear Set Systems A simple planetary gear set system consists of one sun gear, carrier, and ring gear. A single planetary gear set can provide all of the necessary gear ratios for a basic automatic transmission.

Using a simple planetary gear set along with a brake band and multiple disc clutch as apply devices, you can design a two-speed automatic transmission. The transmission provides neutral and reverse gearing, and performs "low to drive" gear changes without any input from the driver.

Simple planetary gear systems like this were used in some early automatic transmissions. However, they are no longer used because they do not provide enough usable gear ratios for present-day applications. They also present design problems for the particular gear set members that must be driven or held. However, the simple planetary gear set remains the foundation upon which the compound planetary gear sets used in modern transmissions are build. In fact, a simple planetary gear set is often used together with a compound planetary gear set to provide additional overdrive gearing.

SIMPSON GEAR SET

A **compound planetary gear set** system is a configuration that contains more than just the three basic members of a simple planetary system. Compound planetary gear sets are capable of providing various combinations of gear reduction, direct drive, neutral, reverse, and overdrive. The most popular compound planetary design is the **Simpson gear set.** Named for its inventor, the Simpson gear set consists of two simple planetary gear sets that share a common sun gear. See Figure 100–19. This combination is capable of providing three forward gears, as well as neutral and reverse. Basic operation, construction, and methods of obtaining various gear ratios with a simple planetary gear set also apply to the Simpson gear set. The main difference is the number of gear ratios.

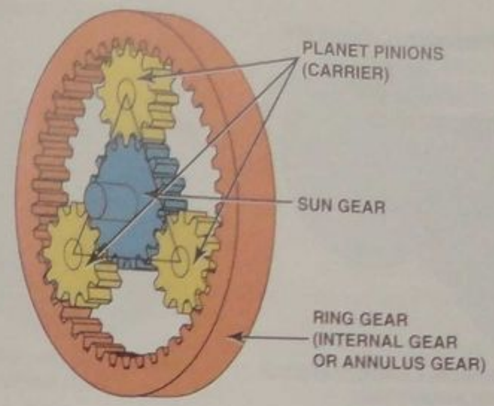
RAVIGNEAUX GEAR SET

Another popular compound planetary design is the **Ravigneaux gear set.** The Ravigneaux system has two sun gears; two sets, one longer than the other, of planet pinions supported in one carrier; and a single ring gear. See Figure 100–20. This design provides four forward gears, two in reduction, one direct, and one overdrive, as well as neutral and reverse. Basic planetary gear set operation, construction, and control methods also apply to the Ravigneaux gear set.

Both of these compound planetary gear set designs have been used over the years by import and domestic manufacturers.

LAPELLETIES GEAR SET

The **Lapelleties** (pronounced La-plet-e-ay) **gear set** was invented by Pierre Lapelleties, a retired engineer who figured out a unique way to create a simple and efficient six-speed automatic transmission gear set. It was first produced by ZF in 2002. The Lapelleties gear set is constructed by connecting a planetary gear set in front of a Ravigneaux gear set. Besides ZF, General Motors uses the Lapelleties gear set in the 6L45, 6L50, and 6L90 rear-wheel-drive transmission and Ford uses it in their 6R60, 6R75, and 6R80.



PLANETARY GEAR CHART

INPUT	OUTPUT	HELD	RESULTS
PLANET CARRIER	RING GEAR	SUN GEAR	REDUCTION
SUN GEAR	RING GEAR	PLANET CARRIER	REDUCTION
RING GEAR	PLANET CARRIER	SUN GEAR	OVERDRIVE
RING GEAR	SUN GEAR	PLANET CARRIER	OVERDRIVE
PLANET CARRIER	SUN GEAR	RING GEAR	REDUCTION AND REVERSAL

Figure 100–18 Different modes of transferring torque through a planetary gear set.

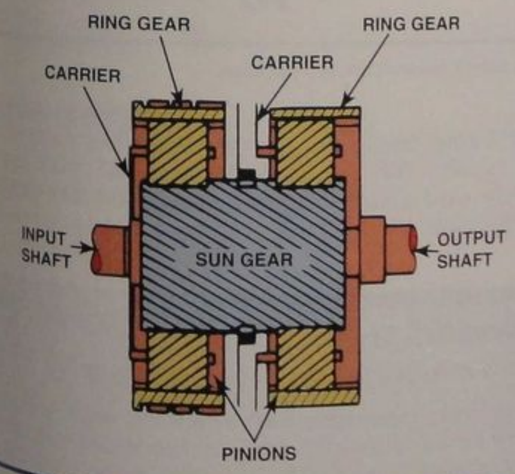


Figure 100–19 A Simpson planetary gear set is composed of two ring gears and two planet carrier assemblies that share a common sun gear.

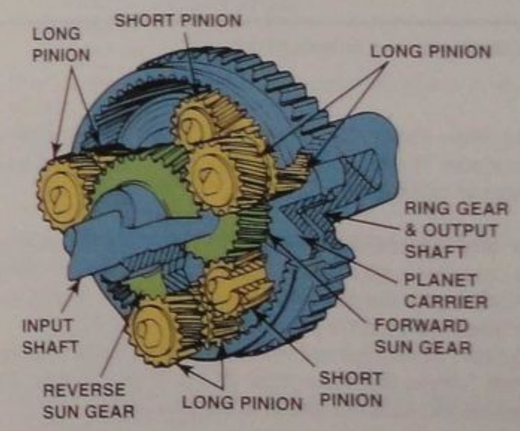


Figure 100–20 A Ravigneaux gear set is composed of two sun gears, one carrier that supports two sets of pinion gears, and a single ring gear.

CONTINUOUSLY VARIABLE TRANSMISSION (CVT)

A **continuously variable transmission** (CVT) is usually found on front-wheel-drive vehicles, which use a transaxle. Instead of using three or more gears, a continuously variable transmission uses two variable width pulleys sometimes called *variators* to change the gear ratio from about 2.5:1 to an overdrive ratio of 0.5:1. See Figure 100–21.

Purpose and Function The purpose and function of a continuously variable transmission is to allow the engine to operate in a speed range where it is most efficient. Therefore, instead of causing the engine speed to vary as the transmission shifts gears, the engine

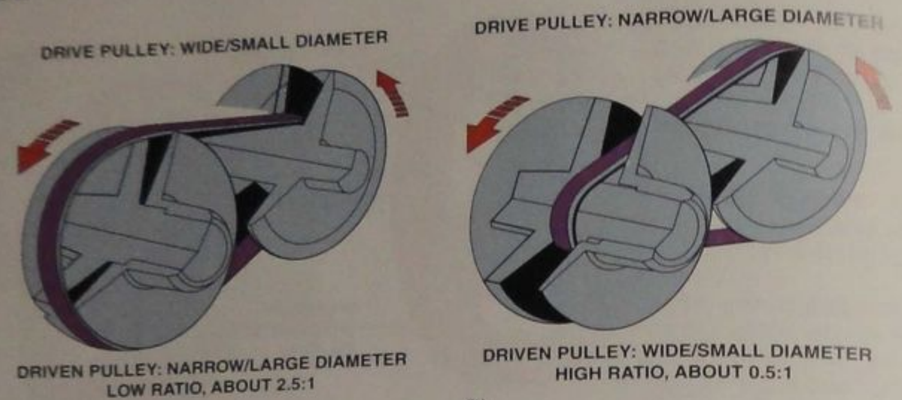


Figure 100–21 The belt-and-pulley CVT uses variable-width pulleys and a special steel belt to provide an infinite number of speed ratios.



Figure 100–22 Location of the Honda CVT start clutch.

speed is more constant as the pulleys change to increase the speed of the vehicle. The result of using a CVT is improved fuel economy and reduced exhaust emissions.

Parts and Operation Most CVT units use a conventional torque converter with a torque converter clutch except the Honda Civic CVT. In the Honda Civic CVT, a *start clutch* is used to apply engine torque to the drive pulley. See Figure 100–22.

The start clutch slips and provides a small amount of creep until the driver releases the brake pedal. At this point, the start clutch is fully applied and transmits torque to the drive pulley.

CAUTION: As with any CVT unit, the use of the specified fluid is critical to its proper operation. Even a little dirt can cause wear to pulleys so be sure to clean around the dip stick before removing it to check the level of fluid.

The two pulleys are moved at the same time. One pulley is made smaller in diameter while at the same time the other pulley is enlarged. This change in pulley width allows the drive chain to move, thereby changing the rate between the input and output pulleys. The chain is *pushed* rather than pulled through the pulleys and is made of hundreds of individual steel elements. See Figure 100–23.

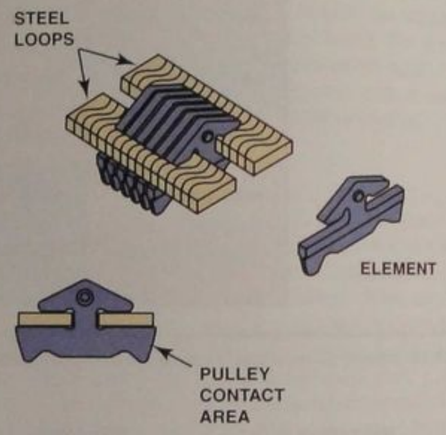


Figure 100–23 Honda CVT drive belt construction.

FREQUENTLY ASKED QUESTION ???

What Is It Like to Drive a Vehicle Equipped with CVT?

For most, driving a vehicle equipped with a continuously variable transmission (CVT) is the same as driving the same vehicle equipped with a conventional automatic transmission/transaxle. The vehicle creeps slightly when the brake is released and the acceleration when the throttle is opened. Because no shifts occur, the first thing the driver and passenger notice is that it is very smooth. If the vehicle is equipped with a tachometer, the driver may notice that the engine speed increases when first accelerating and often remains higher until the vehicle speed increases. During periods of rapid acceleration, the engine speed may be close to its maximum and thereby create noise and vibration often not experienced in a similar vehicle. However, the fuel economy savings of a CVT compared to a conventional automatic transmission makes the slight difference a reasonable trade-off.

NOTE: Some vehicles equipped with a continuously variable transmission (CVT) have shifter paddles on the steering wheel or a manual shift mode on the gear selector. When using these paddles to upshift or downshift, the transmission control module selects preprogrammed ratios, which give the driver a sense that it is actively shifting gears.

Servicing Continuously Variable Transmissions Routine service of a continuously variable transmission/transaxle usually involves changing the fluid at regular intervals. Always use the exact fluid specified by the vehicle manufacturer. The price of CVT fluid is often several times higher than conventional automatic transmission fluid but the special additives needed by a CVT make it critical that the specified fluid be used.

Except for the replacement of the start clutch on a Honda Civic CVT, most continuously variable transmissions are replaced as an assembly and not overhauled or repaired.

SUMMARY

1. The torque converter attaches to the engine and transmits engine torque to the automatic transmission/transaxle assembly.
2. The torque converter consists of three major components: the impeller (driving member), turbine (driven member), and the stator, which helps the torque converter double the available engine torque at stall speed.
3. Since the early 1980s, a torque converter clutch has usually been used on most automatic transmissions/transaxles to increase fuel economy by locking the input and output members of the torque converter together.
4. A typical planetary gear set includes a sun gear in the center surrounded by planet pinions attached to a planet carrier assembly and a ring gear on the outside where internal teeth mesh with the teeth of the planet pinions.
5. Most automatic transmissions/transaxles use a compound planetary gear set to achieve the various forward gears as well as reverse.
6. Automatic transmissions/transaxles use compound planetary gear sets called Simpson, Ravigneaux, or Lapelleties.
7. Certain members of a gear set must be held to achieve a particular gear ratio and direction.

REVIEW QUESTIONS

1. Describe how a torque converter can double engine torque.
2. List the three members of a planetary gear set.
3. Explain how various gear ratios and reverse can be obtained by using a compound planetary gear set.

CHAPTER QUIZ

1. Two technicians are discussing automatic transmissions/transaxles. Technician A says that it is normal for a vehicle to move slightly when the gear selector is in the "drive" position with the brakes released. Technician B says that the stator may be defective if the vehicle moves while in gear when the engine is at idle speed. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Technician A says that a three-speed automatic transmission without a torque converter clutch will shift two times when accelerated from a stop to highway speed as long as the throttle is kept to a minimum. Technician B says that when the torque converter clutch engages, it feels as if another shift occurred. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. One automatic transmission cooler line became pinched in a minor accident. Technician A says that the transmission may overheat. Technician B says that premature wear may occur due to the lack of lube oil being returned from the cooler. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Technician A says that the automatic transmission/transaxle fluid (ATF) cooler is designed to cool the automatic transmission fluid. Technician B says that the cooler also warms the ATF when the fluid is cold. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that when an automatic transmission/transaxle shifts into overdrive, the output shaft is rotating faster (higher RPM) than the engine crankshaft. Technician B says that an overdrive ratio is a ratio where the first number is less than one. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. Two technicians are discussing lube oil. Technician A says that lube oil comes directly from the pump. Technician B says that lube oil first goes to the cooler before returning to the transmission/transaxle as lube oil. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Using a torque converter smaller than stock size could result in _____.
   a. Slower than normal acceleration
   b. Faster than normal acceleration
   c. Reduced fuel economy
   d. Both b and c
8. Which compound planetary gear set is commonly used in six-speed transmissions?
   a. Simple gear set
   b. Simpson gear set
   c. Ravigneaux gear set
   d. Lapelleties gear set
9. Which compound gear set uses a planetary gear set in front of a Ravigneaux gear set?
   a. Simple gear set
   b. Simpson gear set
   c. Ravigneaux gear set
   d. Lapelleties gear set
10. How much is engine torque increased or multiplied when a typical torque converter is at stall speed?
    a. Double
    b. Four times
    c. Eight times
    d. Ten times

CHAPTER

101 Hydraulic Components and Control Systems

OBJECTIVES: After studying Chapter 101, the reader will be able to: Prepare for the ASE general transmission/transaxle diagnosis (A2) certification test content area "A". • Explain how apply drives function in an automatic transmission/transaxle. • Describe how clutches and bands work. • Discuss one-way clutches and how they are used. • Explain how shifts are controlled in an electronically controlled automatic transmission/transaxle.

KEY TERMS: apply devices • balanced valve • check balls • clutch drum • clutch pack • clutch plates • default gear • force motors • governor valve • independent accumulator • integral accumulator • manual valve • multiple-disc clutch • one-way clutch • one-way sprag clutch • one-way valve • pressure control solenoids • pressure plate • pressure regulator valve • primary spring • reaction member • rod • servo • shift valve • sprags • strut • transmission band • variable force solenoids (VFS) • worm holes • worm tracks

APPLY DEVICES

Apply devices are the mechanical assemblies that provide holding and driving forces. Automatic transmissions typically use transmission bands, multiple-disc clutches, and one-way clutches as apply devices.

Transmission bands are holding devices. While bands always provide a holding force, they cannot provide a driving force. The planetary gear set member held by the band is known as a **reaction member**.

A **transmission band** stops and holds one planetary gear set member so that another member can react against the held member and develop output motion. The reaction member has a control surface for the band to ride on known as a drum. See Figure 101–1. The band provides holding force around the outside of the drum, closing tightly to keep it from turning. To repeat, a transmission band is a holding device and is not capable of driving any member of the planetary gear set.

Transmission bands are made of cast iron or steel with friction material lining the inside surface. Transmission design and component size dictate the type of band used. Bands fall into one of two categories:

- Single-wrap
- Double-wrap

The single-wrap band is a simple one-piece design, while the double-wrap band is a split band with overlapping ends. Bands may also be classified as either flexible or fixed depending on how well they hold their shape when they are off the drum. See Figure 101–2.

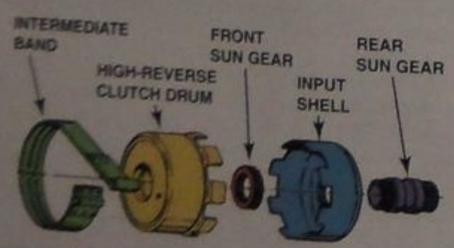


Figure 101–1 Gear set members are attached to a drum and are held stationary when the band applies.

HYDRAULIC SERVOS

A hydraulically-operated piston that travels inside a machined cylinder bore applies the transmission band. This piston and cylinder assembly is known as a **servo**. See Figure 101–3. A piston return spring normally holds the servo piston in its unapplied position. To apply the band, hydraulic fluid under pressure enters the servo cylinder and acts on the piston. The piston begins moving once hydraulic pressure overcomes spring force. A mechanical rod and linkage attaches to the piston and connects it to the band. As the piston moves, the linkage applies the band by tightening it around the drum.

Servo Linkages Servo **rods** and **struts** transfer the servo apply force to the transmission band. Rods are round metal bars and struts are flat metal plates. These may be used at either, or both, ends of the band. Linkages connect the band to the servo or an anchor. See Figure 101–4.



Figure 101–2 Transmission bands come in several designs and thicknesses.

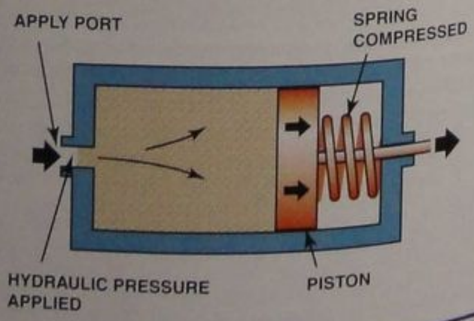


Figure 101–3 A servo uses hydraulic pressure to move a piston, which applies a band.

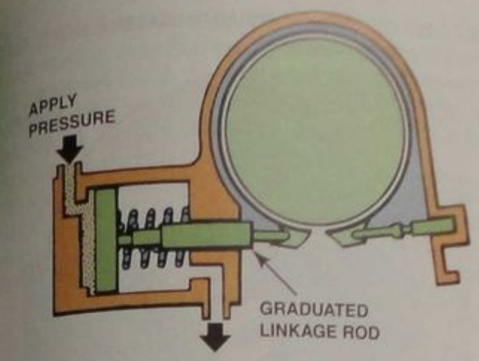


Figure 101–4 Notice that one end of the band is held stationary and the other end is attached to the servo.

ACCUMULATORS

An accumulator cushions, or dampens, hydraulic pressure surges by temporarily diverting part of the fluid flow in a hydraulic circuit into a parallel circuit or chamber. The diversion allows pressure in the main apply circuit to increase gradually and provides a smooth engagement of the band or clutch. Accumulators fit into two classifications: piston- or valve-type. Piston-type accumulators look and function much like servo pistons. In fact, some piston-type accumulators share a bore with one of the transmission servos. This common bore design is known as an **integral accumulator.** See Figure 101–5. Piston accumulators that install in a dedicated bore in the transmission case are known as **independent accumulators.**

As hydraulic pressure enters both circuits, the accumulator piston offers much less resistance than the servo piston because it represents a much lighter load. As a result, the accumulator piston moves first and absorbs any surges as the fluid fills the accumulator cylinder. Once the accumulator piston reaches the end of its travel, cushioning is complete and pressure begins to build in the servo cylinder. This pressure acts on the servo piston to apply the band.

MULTIPLE-DISC CLUTCHES

Like a transmission band, a multiple-disc hydraulic clutch is a type of apply device. Clutches have more friction area so they can develop more force and handle more torque than a band, and they are self-adjusting.

The **multiple-disc clutch** consists of plates, a piston, drum, and snap ring. The piston returns to an unapplied position via a return spring assembly. Some transmissions use a special wave-type spring to return the piston and cushion clutch applications. The entire assembly is commonly known as a **clutch pack.** See Figure 101–6.

The plates of a multiple-disc clutch assembly consist of friction discs alternated with steel discs. The friction discs have a rough surface friction material applied to both faces. The steel discs have a smooth, flat surface finish without any friction material. At times you may see them referred to as separator plates, apply plates, drive plates, or simply "steels." Collectively, the friction and steel discs are called the **clutch plates.**

Generally, the steel plates have splines on their outer edge, while the friction discs have splines on their inner edge. Each set of splines engages matching splines on a shaft, drum, planetary gear set member, or the transmission case. When the clutch applies, hydraulic pressure acting on the piston squeezes the two sets of plates together to mechanically connect the two components that engage the splines of the discs.

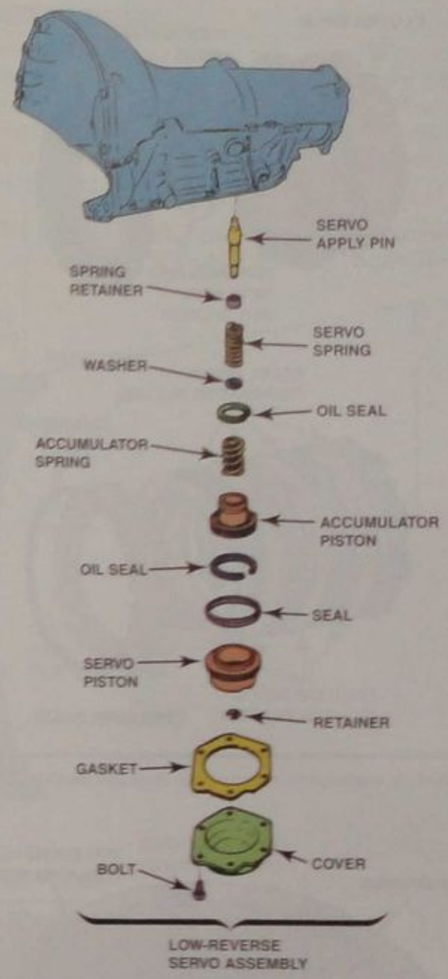


Figure 101–5 An integral accumulator is combined with a servo in a single bore.

The piston compresses the clutch plates against a thicker reaction plate known as the **pressure plate.** Pressure plates may be used at one or both ends of the clutch pack and are available in selective sizes for adjusting clutch pack clearance. The pressure plate and clutch assembly components fit into either a **clutch drum** or a machined bore in the transmission case. Snap rings retain all the clutch assembly components and are available in selective sizes for adjusting clearance. See Figure 101–7. Although a multiple-disc clutch is an apply device similar to a transmission band, it differs from a band because it can be used to drive members of planetary gear sets as well as hold them. There are two types of multiple-disc clutches:

- Holding
- Driving

Holding Clutches An example of a holding clutch is shown in Figure 101–8. In this arrangement, splines on the inner edge of the friction discs engage matching splines on the outside of the clutch drum. The steel discs, alternated with the friction discs, have splines on their outer edge that engage matching splines machined into the transmission case.

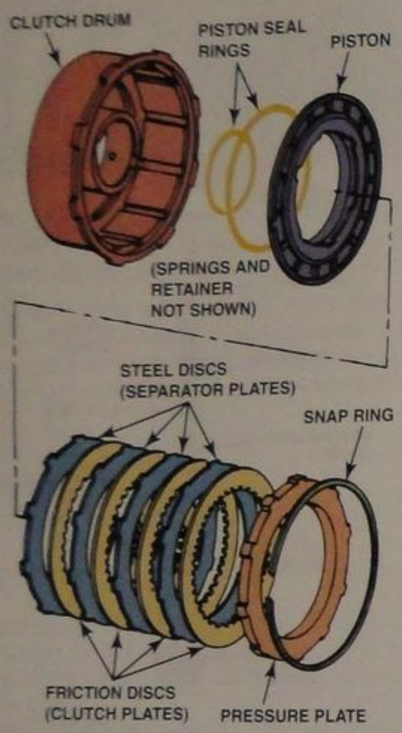


Figure 101–6 An exploded view of a multiple-disc clutch pack assembly.



Figure 101–7 A typical clutch pack assembly.

A holding clutch is an open design and usually fits into either a machined area of the case or in a special support that bolts to the case. Internal passages in the case route fluid to the apply piston.

Driving Clutches There are two types of multiple-disc driving clutches, and both types are commonly used in automotive transmissions. In one configuration, splines connect a set of friction discs to the transmission input shaft so that these discs function as the driving member. The alternating set of steel discs spline to the inside of the clutch drum and serve as the driven member. When the clutch is released, the drive discs rotate with the input shaft, but they do not drive the driven discs that spline to the drum.

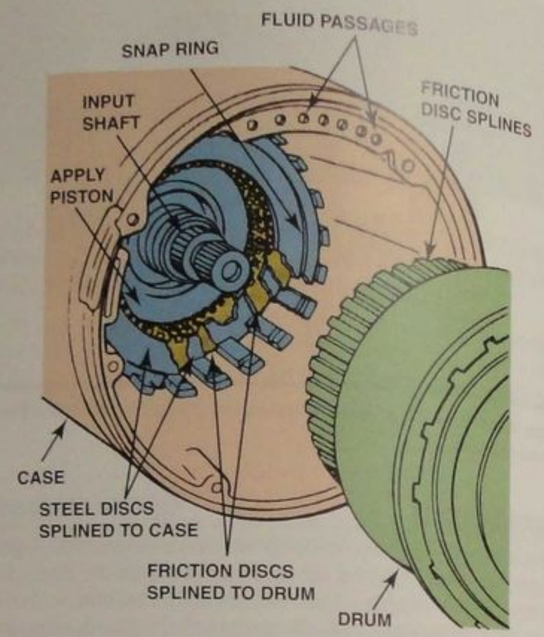


Figure 101–8 In a holding clutch, one set of discs engages splines on the transmission case and the other set engages splines on the drum. By applying the clutch, the drum is locked to the case.



Figure 101–9 Cutaway of a clutch housing on a GM 4T60 (440-T4) transaxle.

When the clutch applies, the piston takes up clearance and forces both sets of discs firmly together. Now, the input shaft and drum rotate together at the same speed and torque transfers from one gear set member to another. A passage inside the input shaft carries fluid to the clutch apply piston. See Figure 101–9.

With the second driving clutch configuration, the drum connects directly to the input shaft so the drum always rotates with the shaft. Splines connect the steel discs to the inside of the drum and the friction discs to the outside of a clutch hub. When the clutch applies, hydraulic pressure compresses the clutch pack to lock the drum and clutch hub together. The input shaft then drives the output shaft and both turn at the same speed.

Clutch Operation To apply the clutch, pressurized fluid enters the drum through an internal passage in the input shaft. The fluid acts on the piston and moves it against return spring force to clamp the clutch plates together and hold them against the pressure plate. See Figure 101–10. The friction between the discs then locks the clutch drum to the hub, causing them to turn as one unit.

To release the clutch, hydraulic fluid to the apply side of the piston is cut off and exhausted. The piston return springs, which were compressed when the clutch was applied, are now free to expand and move the piston back, allowing the clutch discs to disengage.

ONE-WAY CLUTCHES

Another type of automatic transmission device in common use is the **one-way clutch,** or overrunning clutch. Like a transmission band, a one-way clutch is always a holding device. However, it can work together with a drive clutch to provide input. One-way clutches are either roller or sprag clutches. However, the roller clutch is more common.

One-Way Roller Clutch A one-way roller clutch consists of a hub, rollers, and springs that fit inside a drum. See Figure 101–11. The

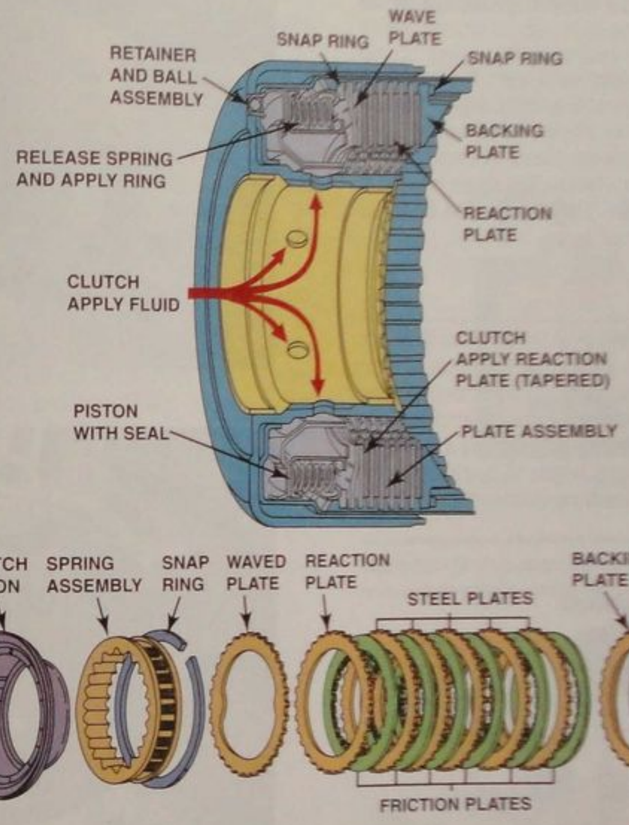


Figure 101–10 Hydraulic fluid under pressure enters the clutch housing and exerts a force on the clutch piston. The clutch piston forces the steel plates and the friction plates together, creating a shift.

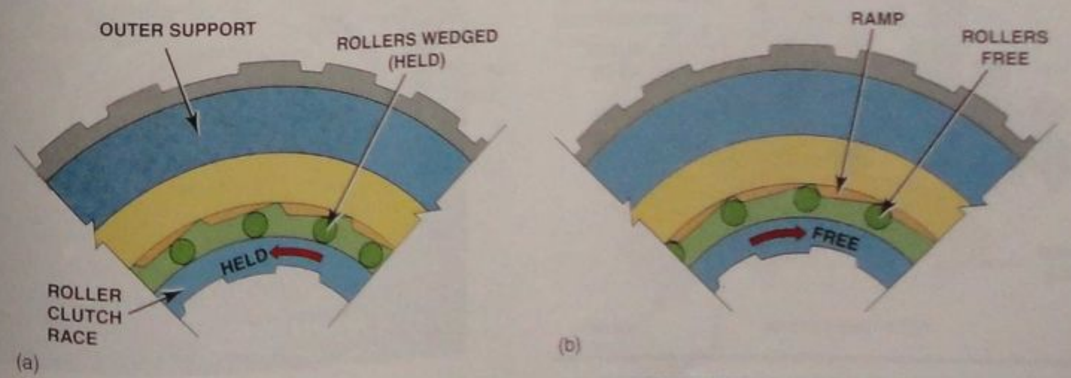


Figure 101–11 (a) A roller one-way clutch in the locked (held) position. Note how the rollers are wedged into the ramp machined into the outer support. (b) A roller one-way clutch in the released (free) position. When the inner roller clutch race rotates faster than the outer support, the rollers move out of the wedge and are free to rotate, thereby unlocking the one-way clutch.

inner circumference of the drum has a series of machined ramps, or cam cuts, to accommodate the rollers and springs. Each ramp is narrower at one end than it is at the other.

If you hold the drum while rotating the hub clockwise, the rollers will compress their springs and move toward the larger end of the ramps. This unlocks the clutch because there is enough clearance between the rollers and the drum for the hub to freewheel.

Rotate the hub counterclockwise while holding the drum. The rollers move toward the narrow end of the ramp, wedging themselves between the hub and drum to lock the clutch. With the rollers at the narrow end of the ramp there is no roller-to-drum clearance. Therefore, the hub cannot turn counterclockwise because the drum is being held.

One-Way Sprag Clutch Less commonly used is a **one-way sprag clutch** that consists of a hub and a drum separated by a number of figure-eight-shaped metal pieces called **sprags.** See Figure 101–12. Sprags lock and unlock the clutch in a manner similar to the rollers in a one-way roller clutch. The shape of a sprag provides two effective working lengths. The direction the sprag tilts determines if working length is short or long.

PUMP

Every hydraulic system requires a *pump* to supply fluid flow and pressurize the system. However, the pump itself does not develop pressure. Pressure occurs only when there is a resistance to flow. Initially, fluid flows freely when a hydraulic circuit is empty or partially filled. Once the circuit is completely full, there is a resistance to further flow. At this point, pressure begins to build up in the circuit as the pump continues to create flow.

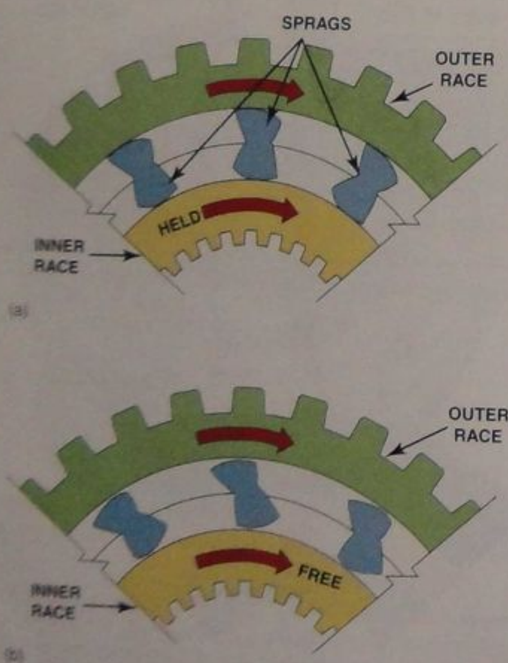


Figure 101–12 (a) The sprag is in the holding (locked) position. Note how the long portion of the sprag is wedged between the inner and outer race. (b) The sprag is released. The inner race is free to rotate faster than the outer race.

Most oil pumps mount directly behind the torque converter and are usually driven by the converter drive hub. See Figure 101–13. This connects the pump to the engine and allows it to respond quickly to engine demand. This type of oil pump operates whenever the engine is running.

Pressure Regulation Transmission oil pumps are capable of creating an excessive amount of pressure quickly, which could easily damage the transmission. Therefore, every transmission has at least one valve that opens to relieve any excess pressure the pump generates. These pressure regulator valves maintain constant pressure within the system. Valves that regulate system pressure are directly in line with the oil pump output flow. All transmission operating pressures derive from the regulated output flow of the oil pump. The *priming spring* combines with the pressure regulator valve to control mainline pressure.



Figure 101–13 (a) A gear-type pump. (b) Gerotor-type pump. (c) A vane-type pump.

Pressure Regulating Valves Pressure regulating valves control the amount of pressure that the transmission hydraulic system, or a particular hydraulic circuit, develops. An automatic transmission uses two types of valves, pressure regulator and pressure relief, to control hydraulic pressure.

The **pressure regulator valve,** or pressure control valve, is usually a spool valve and spring combination that regulates the main hydraulic system pressure. This pressure, commonly known as mainline or simply line pressure, is the working pressure for the entire hydraulic system. The pressure regulator valve is directly in line with the output flow of the transmission oil pump.

Most pressure regulator valves balance pump pressure on one side of the valve against a preset spring force acting on the other side of the valve. See Figures 101–14 and 101–15. When hydraulic pressure is greater than spring force, the valve moves in its bore far enough to uncover an exhaust port. The exhaust port provides a low-pressure path to the sump. Excess pressurized fluid flowing through this port reduces system pressure. When hydraulic pressure drops below spring pressure, the regulator valve closes the port and pressure begins to build up again.

In operation, this sequence of events opening and closing the exhaust port occurs many times per second. This achieves a steady pressure as the forces working on each end of the valve hold it in balance. Because of this action, this type of valve is sometimes called a **balanced valve.**

Electronic Pressure Regulation Electronic automatic transmissions often regulate hydraulic system pressure using computer-controlled solenoids called **pressure control solenoids, variable force solenoids (VFS),** or simply **force motors.** An onboard computer switches the solenoids on and off very quickly using pulse-width modulation (PWM). This pulsed switching positions an internal ball valve in the solenoid, which opens and closes the hydraulic circuit it regulates. See Figure 101–16. Electronic pressure control allows precise hydraulic system pressure regulation and can also be used to modify the timing and feel of transmission shifting.

Flow Directing Valves Flow directing valves, or switching valves, control the direction and distribution of fluid flow in the hydraulic system. These valves may open or close passages, fill hydraulic circuits, apply or release clutches and bands, and control the direction of fluid flow from one passage or circuit to another.

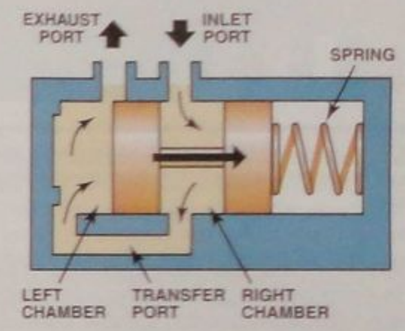


Figure 101–14 When pressure on the face of a pressure regulator valve overcomes spring force, the valve moves to open the exhaust port.

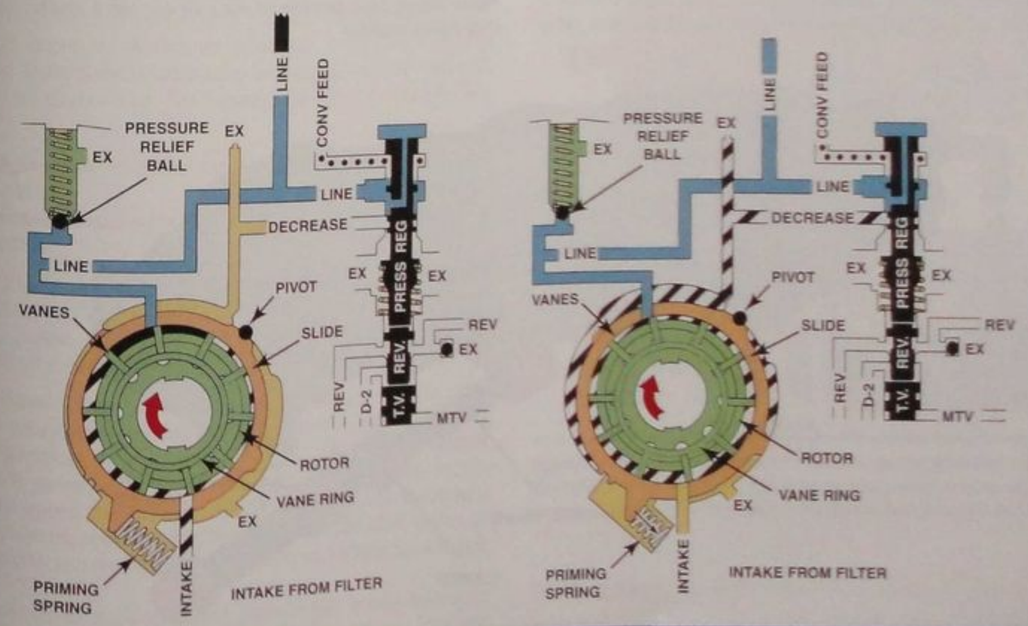


Figure 101–15 The variable pump is at the maximum pump output position until the regulator valve moves enough to decrease volume by rotating the slide against the force of the priming spring. The position of the pump constantly varies depending on the needs of the transmission/transaxle and driving conditions.

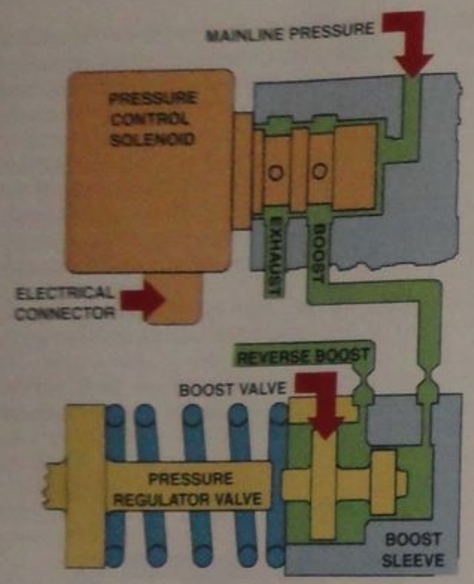


Figure 101–16 The pressure control solenoid controls mainline pressure, which is controlled by the vehicle computer by applying fluid pressure to the spring side of the pressure regulator valve.

One-Way Valves A **one-way valve** allows fluid to flow in one direction. The spring-loaded ball check valve is an example of one type of one-way valve. Valve operation is similar to that of a poppet valve. The spring holds the ball against its seat at the inlet port until fluid pressure overcomes spring force to push the ball from its seat. Fluid flows through the valve as long as hydraulic pressure exceeds the force of the spring.

Spring-loaded ball check valves are used as pressure-relief valves, and work well on bypass circuits because they provide a fast apply rate with a slow release. A second type of one-way valve is a simple gravity valve, as commonly used in transmission valve bodies.

The **check balls** in these valves are usually made of steel, but they can be nylon, rubber, or some composite material as well. Which material is used depends on the manufacturer and application. Steel balls generally hold up better, but cause greater seat wear because of their hardness. The softer composite balls are easier on seats and they cannot be magnetized. See Figure 101–17.

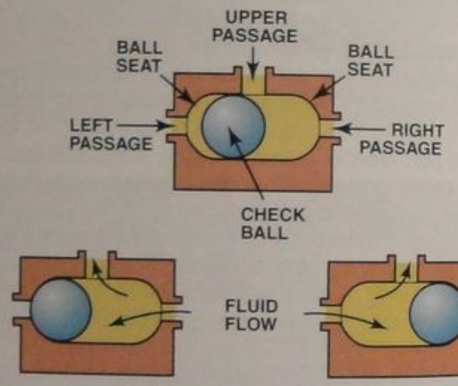


Figure 101–17 Some check balls are used in the valve body to allow hydraulic circuits to share a common passage.

Manual Valve The **manual valve** is the primary flow-directing valve in an automatic transmission. See Figure 101–18. This valve connects to a shift lever in the transmission, which in turn connects to the gear selector lever through a mechanical linkage. The driver controls manual valve position through the gear selector and shift linkage.

Mechanical linkage physically positions the manual valve in its bore for the particular gear range selected. This aligns the lands on the valve so they uncover ports feeding the correct hydraulic circuits. The manual valve receives mainline pressure from the pump

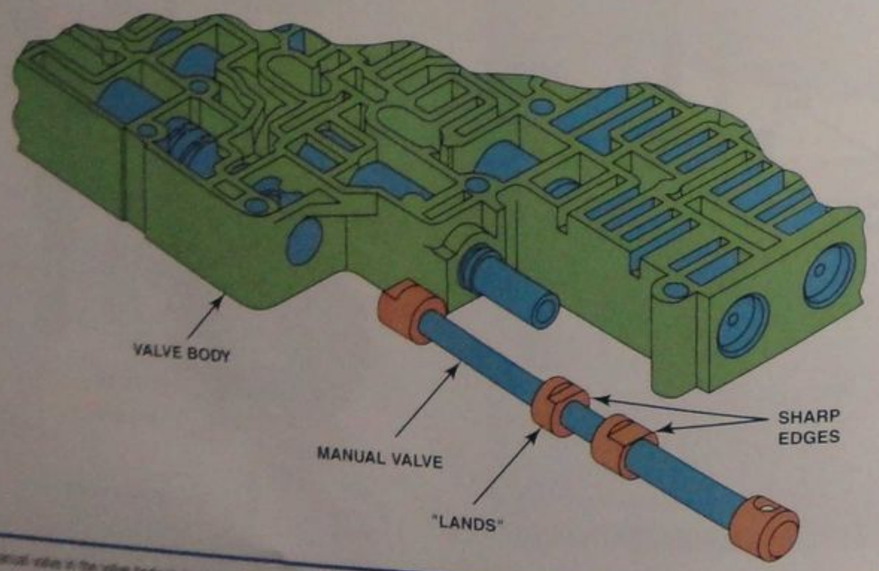


Figure 101–18 The manual valve in the valve body is moved by shift linkage. All valves in a valve body should have sharp edges on the lands. Any dirt in this area can cause shifting problems due to the close tolerances between the valves and the bores in the valve body.

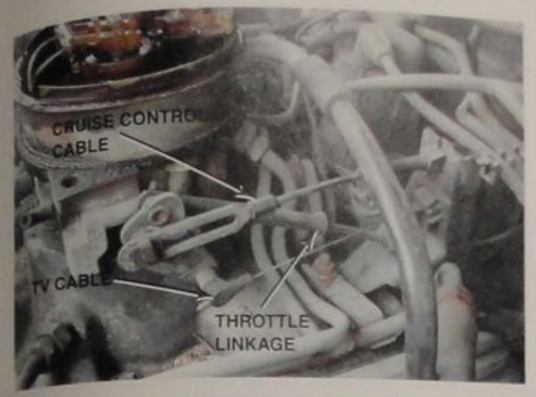


Figure 101–19 The throttle valve (TV) cable adjustment on the 700-R4 (4T60) is very sensitive and greatly affects the shifting.

output and distributes it to the hydraulic circuits uncovered by the valve lands.

Transmission Pressure Valves These valves use mainline pressure to develop other hydraulic circuit pressures within the transmission. Pressure valves are normally spool valves that link to external components.

Throttle Valve The throttle valve senses engine load and uses that operating signal to develop throttle pressure on hydraulically-shifted automatic transmissions. Some throttle valves have linkage that connects them mechanically to the throttle plates, and the throttle valve responds directly to engine load. See Figure 101–19. A low engine load develops low throttle pressure while a higher load develops higher throttle pressure. The throttle position (TP) sensor has replaced the need for these valves in electronically-shifted automotive transmissions/transaxles.

Vacuum Modulator Valve A vacuum modulator is used to convert engine manifold vacuum into a signal pressure that increases as engine vacuum decreases. A vacuum modulator is used on hydraulically shifted transmissions/transaxles to help determine the shift point based on engine load. See Figures 101–20 and 101–21. For example,

- **Light engine load**—manifold vacuum is high, shifts occur at lower speeds.
- **Heavy engine load**—manifold vacuum is low, shifts occur at higher speeds.

The manifold absolute pressure (MAP) sensor and throttle position (TP) sensor serve in place of the vacuum modulator valve in measuring engine load on computer-controlled electronically-shifted automatic transmissions/transaxles.

Governor Valve The **governor valve** monitors vehicle road speed and uses that operating signal to develop governor pressure. The governor valve normally follows transmission output shaft rotation speed, which increases with vehicle speed. As the output shaft speed increases, governor pressure also increases. Governor pressure opposes throttle pressure at the shift valves to control upshifts and downshifts in relation to vehicle speed. See Figure 101–22.

Pressure valves develop rather than simply route hydraulic pressures. Electronic transmissions often replace these pressure valves with solenoids that can develop hydraulic pressure directly from electronic speed sensor signals.



Figure 101–20 (a) A cutaway of a modulator valve. A vacuum line runs from the intake manifold to the modulator valve where changes in engine load (vacuum) move the diaphragm in the valve. The diaphragm is connected to a valve in the valve body to delay the shift points whenever the engine is under a heavy load (low vacuum). The screw at the end allows the service technician to make minor corrections to the shift points. This is a replacement modulator valve. Most original equipment modulator valves are not adjustable. (b) This modulator valve is cut away to show the altitude compensating aneroid bellows.

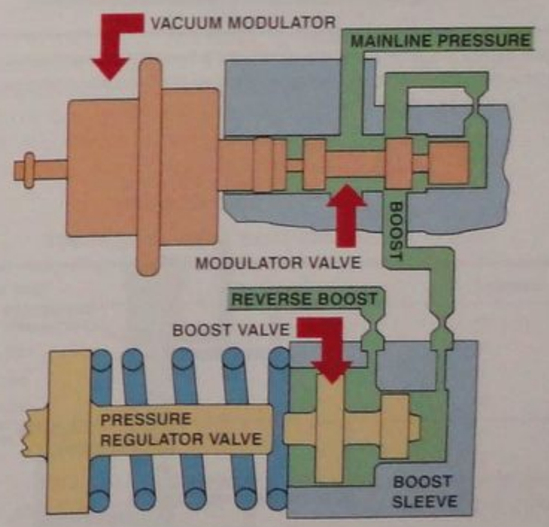


Figure 101–21 The vacuum modulator moves the modulator spool valve in the valve body that applies mainline pressure to the boost sleeve of the pressure regulator valve. Because this force is acting in the same direction as the pressure regulator spring, the mainline pressure is increased.

Shift Valves A **shift valve** is a spring-loaded spool valve that controls the transmission upshift and downshift circuits. See Figure 101–23. Throttle pressure works against one side of the valve, while governor pressure works against the other side.

When one pressure is greater than the other, the valve moves to the upshift or downshift position and the valve lands uncover the ports to the relative circuits. Transmission shift valves may be referred to as "snap valves" because they shift almost instantly in response to pressure differential changes. Since these valves cause upshifts and downshifts, they are also known as "event-causing valves." There are only two positions for a shift valve—fully to the right or to the left. Otherwise, hydraulic pressure could apply control devices for two gears at once and damage the transmission.

In an electronically-shifted automotive transmission/transaxle, solenoids replace shift valves. See Figure 101–24.

Valve Body Most of the valves in a transmission are located in the valve body. See Figures 101–25 and 101–26. Valve bodies can be either cast aluminum or cast iron and bolt up to the case. The valve body in most rear-wheel-drive transmissions is inside the oil pan at the bottom of the case. A transaxle valve body may be at the bottom of the case, on the backside of the torque

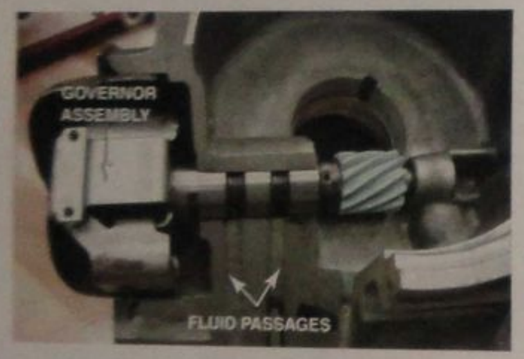


Figure 101–22 A governor assembly is used on older automatic transmissions/transaxles to control shift points based on vehicle speed as determined by the drive gear on the output shafts that rotate the governor assembly.



Figure 101–24 (a) The four electric coils represent the electromagnetic part of the shift control solenoid pack on this Chrysler 41TE transaxle. (b) The cores of the shift solenoids move when the coil(s) is engaged by the vehicle or transmission control computer.

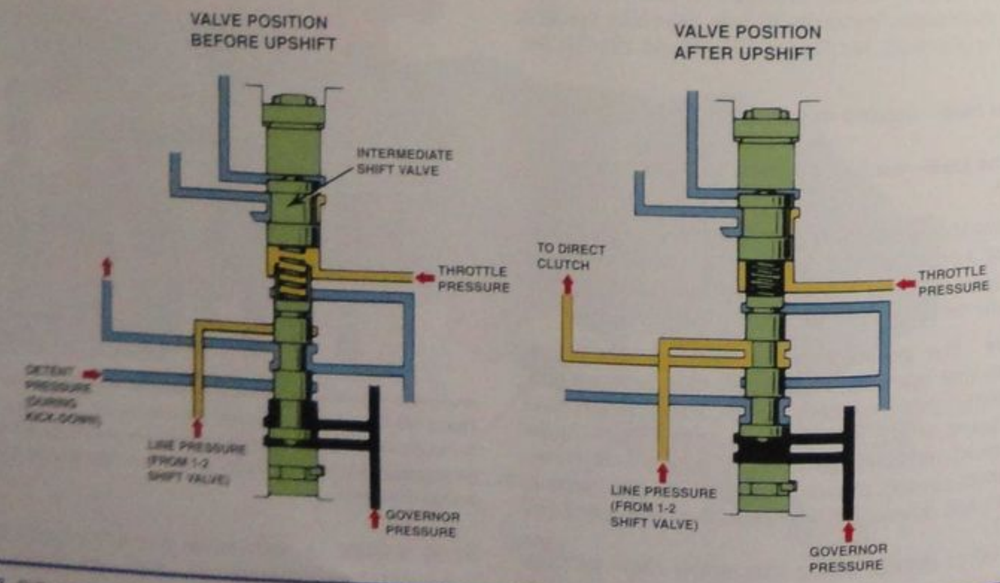


Figure 101–23 Shift valves move when there is a difference in pressure. In a hydraulically shifted transmission, the shift valves balance governor pressure against throttle pressure to determine when to upshift or downshift.

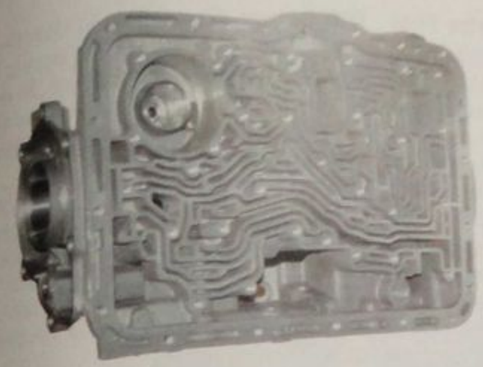


Figure 101–25 A typical valve body with all of the valves and servos removed.

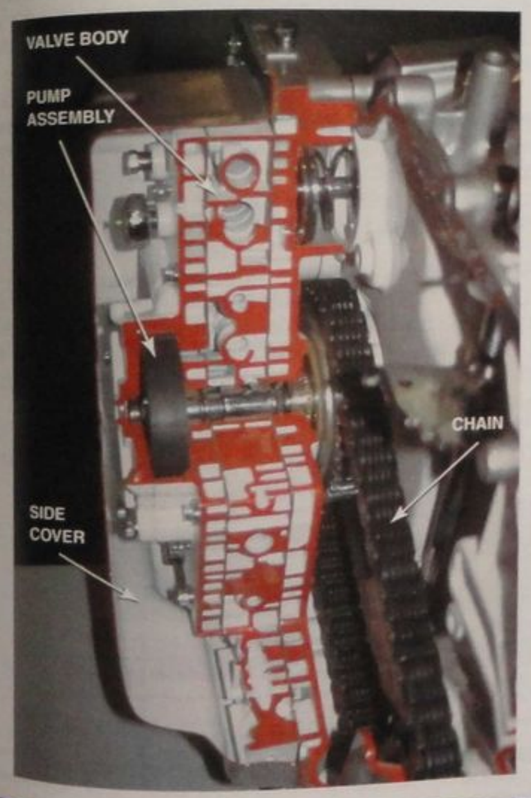


Figure 101–26 A cutaway of a valve body on a transaxle. Notice the relationship to the pump assembly and the drive chain used to transfer engine torque to the planetary gear sets. The edges of the valve body are painted red. Access to the valve body is achieved by removing the side cover.

converter housing, or on the top or side of the transaxle housing depending on the specific application.

Valve bodies have many fluid passages for the various transmission hydraulic circuits cast into them. These are sometimes called **worm holes** or **worm tracks.** Some of these passages may be widened to form pockets that contain steel, nylon, or rubber check balls.

Most valve bodies consist of two or more cast sections that bolt together with a flat metal separator plate between them. The upper section of the valve body is part of the transmission case casting. The separator plate provides rigidity and contains

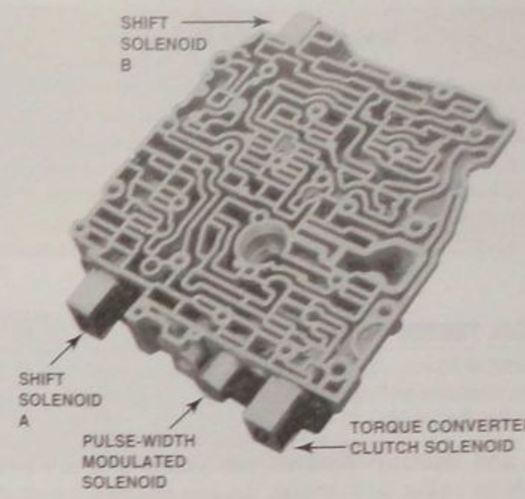


Figure 101–27 Solenoids are used to direct fluid flow through the hydraulic passages of this General Motors 4L80-E valve body.

calibrated drill holes and openings that help manage fluid flow. Valve bodies contain specialized valves and circuits that are particular to a specific transmission. Electronic solenoids are used in place of some valves on electronically-shifted transmissions/transaxles. See Figure 101–27.

Shift Solenoids Shift solenoids are computer controlled and open passages in the valve body to the clutch band to achieve a shift. Shift solenoids may be labeled 1 and 2 or A and B. Using a combination of the two shift solenoids prevents the actuation of four forward gears—one being the **default gear,** a gear that the transmission defaults to if there is a failure in the electronic or computer system. If neither solenoid is engaged, then either second or third gear is actuated, depending on the exact make and model of the transmission/transaxle. See the following charts for examples of two General Motors transmissions.

General Motors 4T60-E (Front-Wheel-Drive Transaxle)

Gear Range	Solenoid A	Solenoid B
1st gear	on	on
2nd gear	off	on
3rd gear	off	off
4th gear	on	off

In the following example, the vehicle would start out in second gear if there were a fault with the computer or wiring and the transaxle would not make any upshifts.

General Motors 4L80-E (Rear-Wheel-Drive Transmission)

Gear Range	Solenoid A	Solenoid B
1st gear	on	off
2nd gear	off	off
3rd gear	off	on
4th gear	on	on

TECH TIP ✔ **Parking Brake Before Parking Pawl**

To prevent possible damage to the transmission/transaxle case or other internal components, most experts agree that the parking brake should be applied before placing the gear selector into the park position, especially when parking on a hill. This procedure keeps the weight of the vehicle from being exerted entirely on the parking pawl and makes it easier to move the gear selector out of the park position.

TYPICAL TORQUE FLOW

The General Motors 4L60-E can provide an example of how a typical electronically-shifted rear-wheel-drive automatic transmission works. See Figure 101–28.

Park and Neutral With the gear selector level in P or N, there is no torque flow through the gear set, even though the low-reverse clutch applies in the 4L60-E. The clutch holds the reaction carrier stationary, but torque input to the gear set stops at the input housing.

The torque converter cover and impeller rotate clockwise at engine speed to hydraulically drive the turbine and mechanically drive the oil pump. The transmission input drum assembly rotates clockwise at turbine speed to drive the gear set. Turbine speed is slightly less than engine crankshaft speed. However, there is nothing connecting the input drum assembly to drive the gear sets and transfer torque at this time.

In neutral, the output shaft is free to rotate in either direction, and the vehicle can be pushed or towed. In park, a mechanical pawl engages a sprag on the reaction internal gear and locks the output shaft to the transmission case, preventing the vehicle from moving in either direction.

Overdrive First With the gear selector lever in overdrive, the transmission starts off in first gear, then upshifts into second, third, and fourth gears as the vehicle continues to accelerate. To engage first gear, the forward clutch applies, transferring engine torque from the input shaft to the input sun gear through the forward sprag clutch, and driving the sun gear clockwise.

With the input sun gear turning clockwise, the input pinion gears spin counterclockwise in the stationary carrier and attempt to drive the input internal gear and reaction carrier counterclockwise. However, the forward sprag clutch is holding, so the pinions walk clockwise inside the internal gear, turning the input carrier clockwise. Then, the input carrier drives the output shaft clockwise in gear reduction. See Figure 101–29.

The reaction internal gear turns clockwise along with the output shaft and drives the reaction pinions clockwise on the stationary reaction carrier. Pinion action drives the reaction sun gear counterclockwise. However, the reaction sun gear is not connected to a gear set member, so the reaction gear set simply freewheels. The low roller clutch prevents the reaction carrier from turning counterclockwise.

As long as the vehicle continues to accelerate in overdrive first, torque transfers through the gear set to the output shaft. During closed-throttle coasting, the clockwise torque load on the forward sprag clutch and the counterclockwise torque load on the low roller clutch is released. Both one-way clutches overrun so the gear sets freewheel on deceleration, and engine braking is not available.

Overdrive Second As the vehicle continues to accelerate in the overdrive range, the transmission upshifts to second gear by applying the 2–4 band. The band holds the reverse drum, input shell, and reaction sun gear stationary. The forward clutch remains applied, while the input shaft drives the input sun gear clockwise through the forward sprag clutch. See Figure 101–30.

As in first gear, the input sun gear rotates clockwise and drives the input pinions counterclockwise. Since the 2–4 band is holding, the input pinions walk inside the internal gear, driving the input carrier and output shaft clockwise in gear reduction.

At the same time, the output shaft drives the reaction ring and pinion gears clockwise. With the reaction sun gear held, the pinion gears walk clockwise and drive the reaction carrier clockwise with them.

Clockwise rotation of the reaction carrier transfers to the input internal gear through the reaction carrier shaft. With the input internal gear turning clockwise, the input pinions spin counterclockwise and drive the input carrier clockwise. This removes the counterclockwise torque load from the low roller clutch so that it overruns at this time. There is no engine compression braking available in overdrive second because the forward sprag clutch overruns.

Overdrive Third To automatically upshift into third gear as the vehicle continues to accelerate, the transmission releases the 2–4 band and applies the 3–4 clutch. Also, the forward clutch remains applied so the input shaft drives the input sun gear clockwise through the forward sprag clutch. See Figure 101–31.

Applying the 3–4 clutch connects the input shaft to the input internal gear, which drives the internal gear clockwise at turbine speed. Now that two members of the input gear set—sun and internal—are being driven at turbine speed, the gear set provides direct drive as it locks up and turns as a unit.

As long as the vehicle is accelerating in overdrive third, torque transfers through the planetary gear set to the output shaft. There is no engine braking because the forward one-way clutch overruns and allows the input sun gear to freewheel.

RANGE	GEAR	SHIFT SOLENOIDS "A"	SHIFT SOLENOIDS "B"	2-4 BAND	REVERSE INPUT CLUTCH	OVERRUN CLUTCH	FORWARD CLUTCH	FORWARD SPRAG CL. ASSEMBLY	3-4 CLUTCH	LOW ROLLER CLUTCH	LOW REVERSE CLUTCH
PARK		ON	ON								APPLIED
REVERSE		ON	ON		APPLIED						APPLIED
NEUTRAL		ON	ON								
D	FIRST	ON	ON				APPLIED	HOLDING		HOLDING	
	SECOND	OFF	ON	APPLIED			APPLIED	HOLDING			
	THIRD	OFF	OFF				APPLIED	HOLDING	APPLIED		
	FOURTH	ON	OFF	APPLIED			APPLIED		APPLIED		
S	FIRST	ON	ON				APPLIED	HOLDING		HOLDING	
	SECOND	OFF	ON	APPLIED			APPLIED	HOLDING			
	THIRD	OFF	OFF			APPLIED	APPLIED	HOLDING	APPLIED		
2	FIRST	ON	ON			APPLIED	APPLIED	HOLDING		HOLDING	
	SECOND	OFF	ON	APPLIED		APPLIED	APPLIED	HOLDING			
1	FIRST	ON	ON			APPLIED	APPLIED	HOLDING		HOLDING	APPLIED
	SECOND	OFF	ON	APPLIED		APPLIED	APPLIED	HOLDING			

Figure 101–28 The General Motors 4L60-E electronically shifted rear-wheel-drive automatic transmission clutch, band, and solenoid application chart.

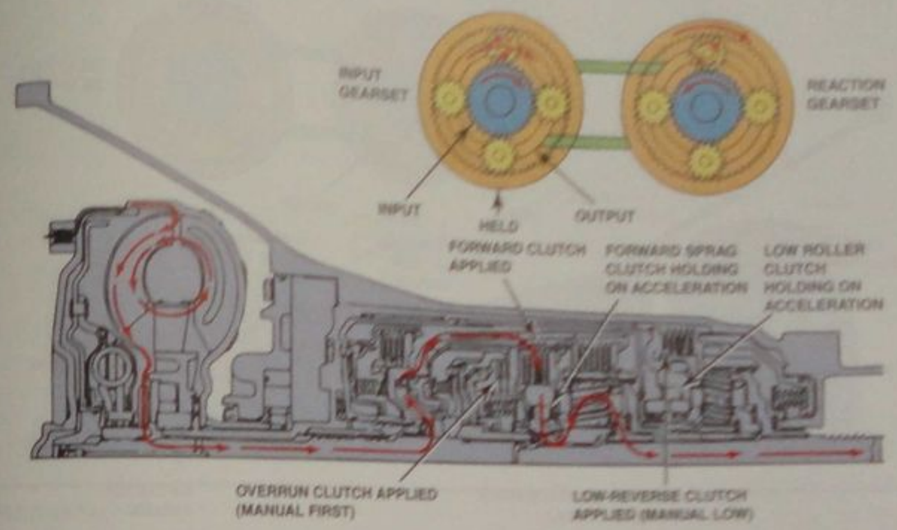


Figure 101–29 A 4L60-E torque flow in overdrive first gear.

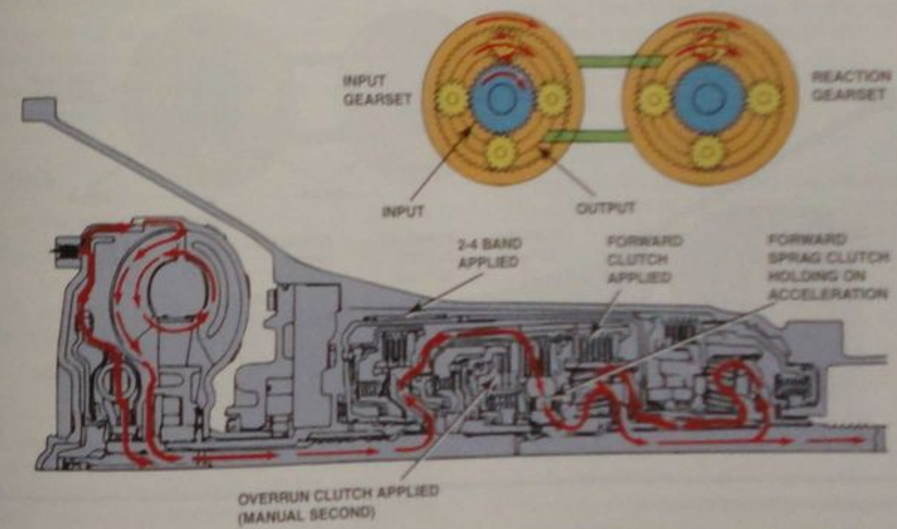


Figure 101–30 A 4L60-E torque flow in overdrive second gear.

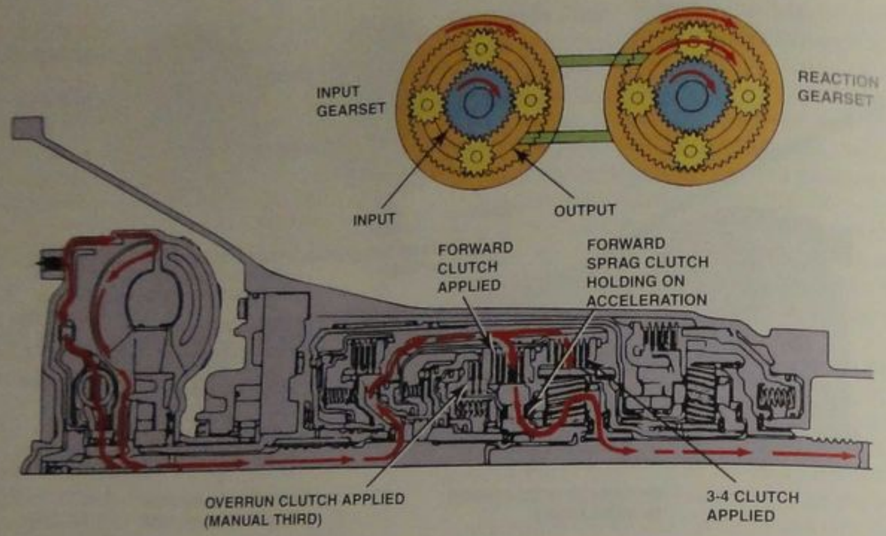


Figure 101–31 A 4L60-E torque flow in overdrive third gear.

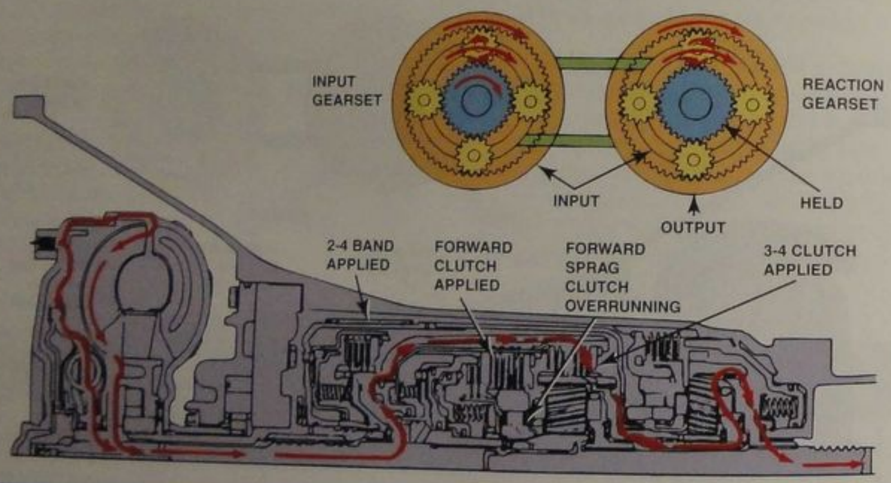


Figure 101–32 A 4L60-E torque flow in overdrive fourth gear.

Overdrive Fourth The transmission upshifts into fourth gear by applying the 2–4 band as the vehicle continues to accelerate in overdrive range. The 2–4 band holds the reverse drum and reaction sun gear stationary. Both the 3–4 and forward clutches remain applied, and the input drum continues to drive the input internal gear clockwise. See Figure 101–32.

This drives the reaction carrier clockwise, as well, since it is in common with the input internal gear. As the carrier turns, the reaction pinions walk clockwise around the stationary reaction sun gear. This drives the reaction internal gear and output shaft clockwise at an overdrive ratio.

In fourth gear, the input internal gear turns at input shaft speed, while the input carrier turns at a faster output shaft speed; both gears turn clockwise. As a result, the input pinions turn counterclockwise and drive the sun gear clockwise faster than input speed. This causes the forward sprag clutch to overrun and renders the forward friction clutch, which remains applied, ineffective.

When the transmission is operating in fourth gear, the input member, the reaction carrier, is being driven by a multiple-disc clutch, while a band prevents the held member, the reaction sun gear, from turning in either direction. Therefore, engine compression braking is available. However, due to the overdrive gear ratio, the braking effect is not noticeable to the driver.

Reverse With the gear selector lever in reverse, the low-reverse clutch applies to drive the reaction sun gear clockwise with the input shaft. The reaction carrier and input internal gear are held stationary by the applied reverse input clutch. This turns the reaction pinions counterclockwise and drives the carrier counterclockwise in gear reduction. See Figure 101–33.

In reverse gear, the input internal gear is held, while the input carrier is driven counterclockwise. This causes the input pinions to rotate clockwise and drive the input sun gear counterclockwise. However, the forward sprag clutch overruns, so the input gear set freewheels.

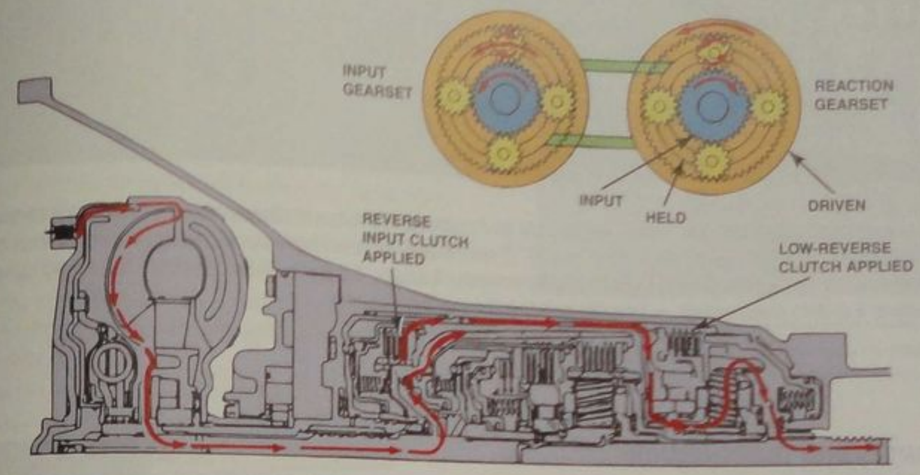


Figure 101–33 A 4L60-E torque flow in reverse.

SUMMARY

1. List three planetary gear set holding devices.
2. Describe how shift points are achieved with a hydraulically shifted automatic transmission/transaxle.
3. Explain how solenoids are used to control the shifting on electronically shifted automatic transmissions/transaxles.

REVIEW QUESTIONS

1. List the parts of a typical clutch pack assembly.
2. Explain the purpose of the priming spring used in a variable displacement vane pump.
3. List the solenoids used in a typical electronically shifted automatic transmission/transaxle.

CHAPTER QUIZ

1. Two technicians are discussing one-way clutches. Technician A says that a sprag and a roller are two types of one-way clutches. Technician B says that a one-way clutch could be installed upside down and cause the automatic transmission/transaxle to not function correctly. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Two technicians are discussing automatic transmission/transaxle oil pumps. Technician A says that a variable displacement vane-type pump is a positive displacement pump. Technician B says that a variable displacement pump is designed to pump the maximum amount of fluid when the engine is cranking and first started. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Which part controls mainline pressure in an electronically shifted automatic transmission/transaxle?
   a. Force motor
   b. Spool valve
   c. Boost valve
   d. Modulator valve
4. Two technicians are discussing the possible cause of a hydraulically shifted automotive transmission/transaxle shifting at too high a speed. Technician A says that a defective vacuum modulator (if equipped) could be the cause. Technician B says that a misadjusted TV cable (if equipped) could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Technician A says that the mainline pressure is usually higher in manual first or manual second gear than it is when the gear selector is in the drive position. Technician B says that mainline pressure is higher in reverse than when the gear selector is in the drive position. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. What is the part of the planetary gear set called that is being held by a band?
   a. Reaction member
   b. Compound gear set
   c. Simple gear set
   d. Held member
7. What is the purpose and function of an accumulator?
   a. To apply a clutch
   b. To apply a band
   c. To cushion or dampen pressure surges
   d. Either a or b
8. The steel plates in a clutch pack are commonly called _____
   a. Friction disks
   b. Reaction members
   c. Friction members
   d. Steels
9. Force motors are controlled by the computer by _____
   a. Increasing/decreasing current (amperes)
   b. PWM
   c. Increasing/decreasing voltage
   d. Changing the resistance in the circuit
10. Check balls used in the valve body are constructed of _____
    a. Steel
    b. Nylon
    c. Rubber
    d. All of the above

CHAPTER 102

Automatic Transmission/Transaxle Diagnosis and In-Vehicle Service

OBJECTIVES: After studying Chapter 102, the reader will be able to: Prepare for ASE Automatic Transmission/Transaxle (A2) certification test content area "A" (General Transmission/Transaxle Diagnosis), content area "B" (Transmission/Transaxle Maintenance and Adjustment), content area "C" (In-Vehicle Transmission/Transaxle Repair), and content area "D" (Off-Vehicle Transmission/Transaxle Repair). • Describe what to look for during a test-drive. • Explain how to perform a system pressure test. • Describe how to test a vacuum modulator.

KEY TERMS: stall test

PRELIMINARY AUTOMATIC TRANSMISSION/TRANSAXLE PROBLEM DIAGNOSIS

The first step in diagnosing any problem is to test-drive the vehicle and verify the customer complaint (concern). (See the Tech Tip, "Quick-and-Easy Automatic Transmission/Transaxle Diagnosis.") Before test-driving the vehicle, check the level and condition of the automatic transmission/transaxle fluid. Follow the procedure for checking the level as published in the owner's manual or factory information. See Figures 102–1 and 102–2. If the fluid level is low, add fluid until the proper level is achieved before test-driving the vehicle.

TECH TIP ✔ **Use Manual First Gear as a Diagnostic Aid**

If the transmission/transaxle slips during acceleration when the shift lever is placed in the *drive* position, try placing the gear selector in the manual first position. If the internal holding clutch(es) is slipping, the additional pressure applied to the clutch when the manual first gear is selected may be enough to allow the vehicle to move. If the vehicle moves when manual first gear is selected and will not move when *drive* is selected, then the clutches are worn and must be replaced.

This information is helpful during diagnosis, when learning as much information as possible about the transmission/transaxle before disassembly is important so that the known problem areas can be carefully checked.



Figure 102–1 Typical automatic transmission fluid level indicator (dipstick). The clip on this indicator keeps the dipstick from being forced upward due to pressure changes inside the transmission. The seal also helps prevent water from getting into the fluid, which can cause severe damage to the friction discs and other components inside the transmission.

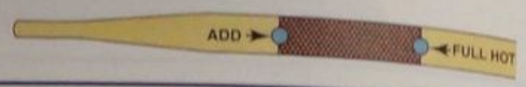


Figure 102–2 A typical automatic transmission/transaxle fluid level indicator (dipstick). The add mark usually indicates that the fluid level is down 1/2 quart (1/2 liter). Always measure the fluid level according to the instructions usually imprinted on the dipstick itself.

Road Testing After checking the fluid, perform a thorough test-drive and note the following:

- **Note how the shifts feel.** The shifts may be too harsh or too soft. This could indicate a fluid pressure problem or worn clutch or bands.
- **Note when the shifts occur.** The shifts may occur too early or too late. Either of these concerns could be caused by a defective governor or vehicle speed sensor, vacuum modulator (if so equipped), or TV cable adjustment (if so equipped). For example, a defective vacuum modulator will likely cause a delayed upshift and often a harsh downshift.

TECH TIP ✔ **Quick-and-Easy Automatic Transmission/Transaxle Diagnosis**

An experienced technician told the beginning technician that automatic transmission/transaxle diagnosis is often very easy. For example:

- *If the vehicle does not move in drive or reverse*—remove the transmission/transaxle for service because the problem is likely mechanical rather than hydraulic (valve body) or electrical (computer, solenoids, or sensors). If the unit will not power the vehicle, the unit will more than likely require removal for a thorough mechanical inspection and repair.
- *If the vehicle moves, but does not shift correctly*—the problem is likely electrical (computer, solenoid, or sensor) or hydraulic (valve body) rather than mechanical. This is usually true because if the vehicle is able to move forward and backward, the major mechanical components, though not in like-new condition, are at least able to function. Therefore, correcting the nonmechanical problem should be the technician's first consideration.

Stall Testing the Torque Converter A stall test is often performed to verify the proper operation of the torque converter.

CAUTION: Some vehicle manufacturers do not recommend performing a stall test because it can be dangerous if the brakes were to fail during the test and it places stress on the engine. Always follow the manufacturer's recommended service procedures.

Performing a stall test includes the following steps:

Step #1 Drive the vehicle until normal operating temperature is achieved.

Step #2 Check the stall speed specifications for the vehicle being serviced and connect a tachometer to the engine.

Step #3 With your left foot firmly applied to the brake pedal, move the shift selector in the drive position and depress the accelerator pedal to the floor. Observe the maximum engine speed. This engine speed is the stall speed. See Figure 102–3.

Step #4 Release the accelerator as soon as possible to avoid the possibility of overheating the automatic transmission fluid. Repeat the test with the gear selector in reverse.

Step #5 Compare the results with the specifications.

- *If the engine speed is higher than specifications*, a holding clutch or band is slipping.
- *If the engine speed is lower than specifications*, the torque converter is defective (one-way clutch or stator is slipping) or the engine is not producing normal output.

Both conditions can result in reduced vehicle performance and slow acceleration.

NOTE: There are many other possible causes of poor performance or slow acceleration beside a fault with the automatic transmission/transaxle. The stall test is just one test that can be performed to help narrow the problem to the root cause.

REAL WORLD FIX **The Stalling Lumina**

The owner of a Chevrolet Lumina complained that the vehicle would occasionally stall when slowing to a stop. The problem only occurred after at least 20 miles and occurred more frequently in warm weather. The owner also indicated even though this vehicle was equipped with an automatic transmission it felt like the clutch not being depressed on a manual transmission. Thankfully, the service technician was aware of this common problem and installed a new torque converter clutch solenoid. See Figure 102–4. When the original solenoid got hot, it became stuck in the applied position. Even though the voltage was removed from the solenoid when the brakes were applied, the solenoid and the torque converter clutch (TCC) remained applied.

REAL WORLD FIX **The Rough Idle Story**

The owner of a Chevrolet pickup truck equipped with a V-6 engine complained of a rough idle. The idle was smooth when the transmission was in park or neutral but became rough when the gear selector was placed in any drive gear position. The service technician could not find the cause of the problem but did notice that the engine seemed to be under a heavy load at idle speed due to the MAP sensor reading. The customer was questioned again about the possibility of a previous repair that may have had an effect on the idle. The customer said that the automatic transmission had been replaced recently but didn't think that could have an effect on the rough idle problem. A quick check of the stall speed indicated a much lower stall speed than normal—1400 RPM versus 1850 RPM normal stall speed. Obviously, either the torque converter was defective or a torque converter for a V-8 was installed in the V-6 truck. After returning to the transmission shop and getting a replacement torque converter installed, the rough idle problem was solved.



Figure 102–3 This four-cylinder General Motors vehicle has a stall speed of about 2350 RPM. Notice that the gear selector is in drive and the speedometer is reading zero.

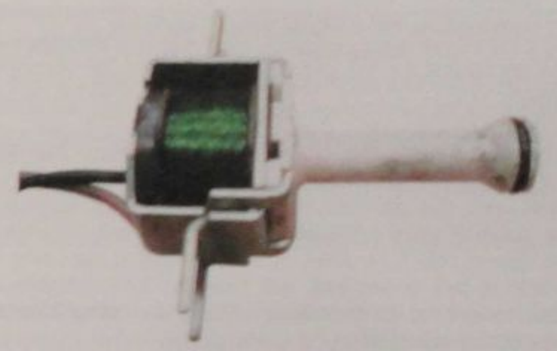


Figure 102–4 Typical torque converter clutch (TCC) solenoid. This TCC solenoid on a General Motors vehicle can be replaced without having to remove the transmission/transaxle from the vehicle.

TECH TIP ✔ **Vibration—Engine or Transmission?**

A vibration is often difficult to diagnose. One method is to separate (unbolt) the torque converter from the engine drive plate. Push the torque converter as far toward the transmission/transaxle as possible, then start the engine. If the vibration is gone, the problem is due to a fault in the torque converter, pump assembly, or other component that is constantly rotating with the engine running. If the vibration is still present, then the cause is due to an engine or accessory problem.

Torque Converter Clutch Diagnosis The torque converter clutch is usually applied above 30 mph (48 km/h) when the automatic transmission/transaxle is in second, third, or overdrive gear, depending on the vehicle speed and the throttle position. It is often difficult to distinguish between a normal shift and the application of the torque converter clutch. The torque converter clutch (TCC) may not even be applying due to a fault in the computer sensors, wiring, or the TCC solenoid.

NOTE: If the torque converter clutch does not apply, a drop in fuel economy of 3 to 4 miles per gallon is commonly reported. If the TCC fails to apply on an automatic transmission/transaxle, the automatic transmission fluid is likely to become overheated due to the torque converter operating under the increased load of an overdrive gear ratio. The higher fluid temperature can cause the automatic transmission/transaxle to fail.

To test for proper operation of the torque converter clutch, simply drive the vehicle and watch either the tachometer on the dash or connect a scan tool to observe the engine RPM.

Step #1 Drive the vehicle until the engine has reached normal operating temperature.

Step #2 Drive the vehicle on a flat, level road away from any traffic above 50 MPH (80 km/h).

Step #3 While maintaining constant speed with your right foot on the accelerator, gently apply the brake pedal with your left foot to open the electrical circuit for the torque converter clutch through the brake switch. The TCC will disengage and the RPM should increase about 150 to 250 RPM and then drop back when the brake pedal is released. This RPM change is your proof that the TCC is, in fact, working.

If the torque converter clutch is not operating, consult the factory information for the steps necessary to find and correct the problem.

Scan Tool Testing the Automatic Transmission/Transaxle

A scan tool can display information about the various sensors and components that can assist the service technician in determining the cause of many automatic transmission/transaxle problems. See Figure 102–5. A weak or missing engine can cause the vehicle to lack power, jerk, and hesitate. These symptoms are often blamed on an incorrectly shifting or slipping automatic transmission/transaxle.

Diagnostic Trouble Codes (DTCs) Obviously, if there are any DTCs stored in the memory of the vehicle computer, a problem has been detected that should be corrected before further testing.



Figure 102–5 A Tech-2 scan tool being used to check for diagnostic trouble codes (DTCs) and data stream information that may affect the operation of the automatic transmission/transaxle.

Scan Data A properly operating engine should display the following readings with the engine at idle and operating in closed loop:

- **Engine coolant temperature (ECT)**—between 180° to 215°F (82° to 102°C).
- **Throttle position (TP) sensor**—usually between 0.5 to 4.5 volts and varying directly with throttle movement.
- **Fuel injector pulse width**—1.5 to 3.5 ms.
- **O2S**—200 to 800 mV.
- **Transmission fluid temperature**—less than 275°F (135°C).
- **Brake switch**—scan data should show a change when the break pedal is pressed and released.
- **Manifold absolute pressure (MAP) sensor**—with the engine idling in park or neutral, the voltage should be within 0.88 and 1.62 volts or between 102 and 109 hertz for a Ford MAP sensor.

If any of the engine information is not within these ranges, consult the factory information for procedures to follow to determine the cause before proceeding with the analysis of the automatic transmission/transaxle.

NOTE: If the temperature of the automatic transmission fluid (ATF) is too high, the computer will modify the shift pattern (usually disabling overdrive) and engage the TCC at slower speeds in an attempt to drop the temperature of the ATF to less harmful temperatures. This computer control of the shifting may be noticeable to the driver as a fault.

Shift Solenoids Observe the operation of the command for the shift solenoids and the TCC solenoid while driving the vehicle. This information confirms that the computer is commanding the operation; it does not mean that the solenoids are working correctly. Therefore, if the scan data indicates that a particular solenoid is being commanded on and nothing occurs, then the problem more likely is a defective solenoid or a fault in the wiring to the solenoid or from the solenoid to the computer.

NOTE: Shift solenoids vary in resistance, yet may look the same. An on/off solenoid usually has twice as much electrical resistance as a pulse width modulated shift solenoid. Always double-check that the correct replacement solenoids are used.

Commanding the Shifts Many test tools can be used to actually cause the automatic transmission/transaxle to shift electrically. The tester is connected to the electrical connector at the automatic transmission/transaxle after disconnecting the factory connector. To perform this simple test, safely hoist the vehicle, start the engine, and place the gear selector in the drive position. The tester can now command the various shift solenoids to actuate. If the shift occurs when commanded, the hydraulic system is functioning. If the tester commands a shift to occur and a shift does not occur, the service technician knows that the problem is either in the solenoid itself or the hydraulic system that actuates the clutch or band to accomplish the shift.

Testing the Vacuum Modulator

A vacuum modulator is used on many hydraulically shifted automatic transmissions/transaxles. To check for proper operation of the vacuum modulator, follow these steps:

Step #1 Hoist the vehicle safely and locate the vacuum modulator (if equipped).

NOTE: The vacuum modulator used on the General Motors 4T60 (formerly called 440-T4) is located toward the front of the vehicle and is accessible from under the hood without the need to hoist the vehicle. See Figure 102–6. This vacuum modulator is not used to control shift points, but is rather used to control shift feel. Higher engine loads (lower vacuum to the vacuum modulator) result in a firmer shift; at light engine loads, the shift is softened.

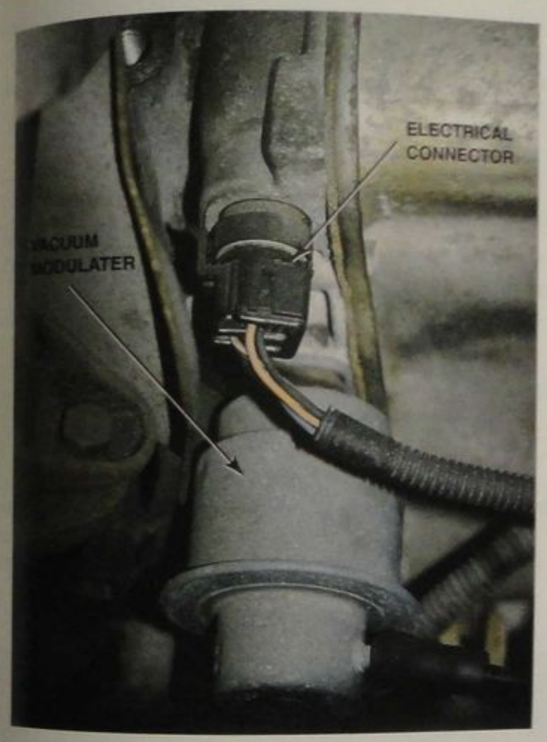


Figure 102–6 A view of a General Motors 4T60 (440-T4) automatic transaxle showing the electrical connector and the vacuum modulator.

Step #2 Remove the vacuum hose from the vacuum modulator. If automatic transmission fluid drips out when the hose is removed, the vacuum modulator is defective and must be replaced.

Step #3 Use a hand-operated vacuum pump to apply vacuum to the vacuum modulator. If the modulator is okay, the vacuum reading will hold steady and not drop. If the vacuum modulator will not hold vacuum, the modulator should be replaced.

Step #4 Connect a vacuum hose to the vacuum line from the intake manifold and have an assistant start the engine. The vacuum reading at the vacuum modulator should be 17 to 21 in. Hg with a minimum vacuum reading of 15 in. Hg to be assured of proper shifting of the automatic transmission/transaxle.

TECH TIP ✓ **White Exhaust Smoke Is Not Necessarily Due to a Blown Head Gasket**

A defective vacuum modulator can cause automatic transmission fluid (ATF) to be drawn by engine vacuum into the intake manifold. When ATF burns, it produces white smoke. The white smoke is often confused with steam. Therefore, the smart technician should check to see if the vehicle is equipped with a properly functioning vacuum modulator before continuing the diagnosis for steam coming from the tail pipe.

Range Charts All vehicle manufacturers publish range charts that indicate which holding device is applied or holding for each gear selection. Knowing which component is being used when helps the service technician determine the cause of a failure or problem. See Figure 102–7 for a sample chart for a hydraulically shifted automatic transmission.

Pressure Testing Pressure testing involves connecting a pressure gauge to pressure taps located on the outside of the automatic transmission/transaxle, as shown in Figure 102–8. After connecting the pressure gauge(s) to the transmission/transaxle, start the

RANGE	GEAR	2–4 BAND	REVERSE INPUT CLUTCH	OVERRUN CLUTCH	FORWARD CLUTCH	FORWARD SPRAG CL. ASSEMBLY	3–4 CLUTCH	LO-ROLLER CLUTCH	LO-REV. CLUTCH
PARK-NEUTRAL									
OVERDRIVE	FIRST GEAR				APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED			APPLIED	HOLDING			
	THIRD GEAR				APPLIED	HOLDING	APPLIED		
	FOURTH GEAR	APPLIED			APPLIED		APPLIED		
DRIVE	FIRST GEAR			APPLIED	APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED		APPLIED	APPLIED	HOLDING			
	THIRD GEAR			APPLIED	APPLIED	HOLDING	APPLIED		
MANUAL 2ND	FIRST GEAR			APPLIED	APPLIED	HOLDING		HOLDING	
	SECOND GEAR	APPLIED		APPLIED	APPLIED	HOLDING			
MANUAL 1ST	FIRST GEAR			APPLIED		HOLDING		HOLDING	APPLIED
REVERSE	REVERSE		APPLIED						APPLIED

Figure 102–7 A range chart for a General Motors 4L60 (formerly called the 700-R4) rear-wheel-drive transmission. Notice that the forward clutch is applied in all forward gears. Also notice that if the low-reverse clutch were to fail, it would prevent the vehicle from moving in both reverse and manual first.

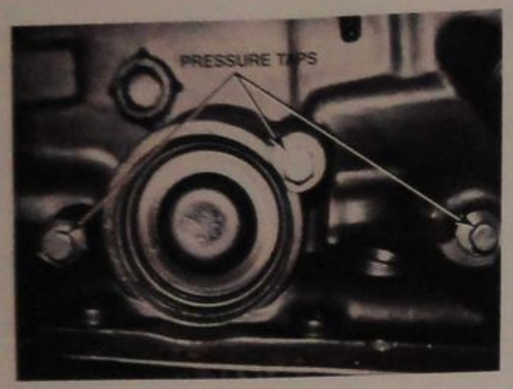


Figure 102–8 The locations (taps) for connecting a pressure gauge to measure the pressure of the various hydraulic circuits are usually on the sides of the automatic transmission/transaxle. Some may not be very accessible. Check factory service information for the exact locations for the vehicle being serviced.

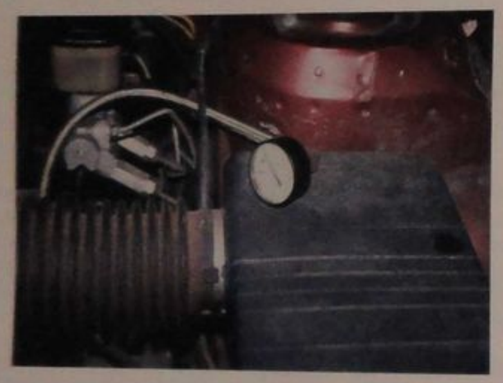


Figure 102–9 A pressure gauge connected to check mainline pressure.

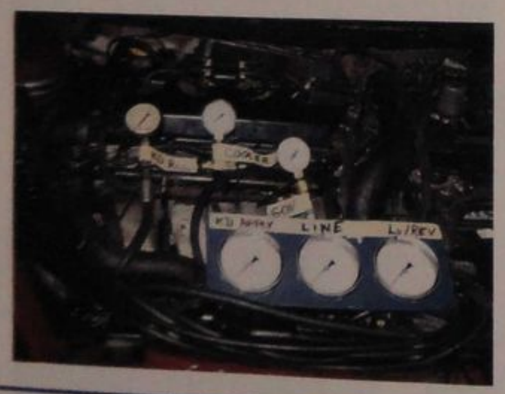


Figure 102–10 Six pressure gauges are installed on this vehicle to show students at a college how the pressures vary and how the gauges can be used to find faults or possible problem areas before the unit is removed and disassembled.

engine and select the gear being monitored. If the pressure is not within specifications, then the technician knows that the fault is internal and usually involves either removing the valve body, or in many cases, removing the automatic transmission/transaxle from the vehicle. See Figures 102–9 and 102–10.

Removing the Automatic Transmission Pan for Inspection

The inspection of the fluid and the transmission pan should be part of any thorough transmission/transaxle diagnosis. Removing the pan from an automatic transmission/transaxle can be a dirty and messy job. To make the job as easy as possible, follow these steps:

Step #1 Hoist the vehicle safely.

Step #2 Use a large drain pan and position it under the transmission pan.

Step #3 Loosen all of the oil pan bolts. ATF will start to flow out from around the gasket.

SAFETY TIP **Hot Fluid**

The automatic transmission fluid may be hot enough to cause personal injury. Wear protective clothing and avoid contact with the hot fluid.

Step #4 Remove all of the oil pan bolts except for two at one end. This will allow the pan to drop and empty most of the ATF into the drain container without falling. After most of the ATF has drained, remove the remaining bolts and remove the pan.

Step #5 Inspect the inside of the pan for excessive friction material and wear metals (such as lead and copper from bushings). Use a magnet to check for steel particles, which would indicate serious wear to major components. See Figure 102–11.

NOTE: The presence of wear metals in the pan of an automatic transmission/transaxle does not necessarily mean that a part(s) has failed or needs to be replaced. Some wear is normal. If there are a lot of metallic particles in the pan, then this may be an indication of severe gear failure that may require replacement. Use a magnet to check for steel particles. Ask the advice of an experienced transmission expert, if in doubt, about whether the wear should be considered "normal."

REAL WORLD FIX **The Customized Van Story**

The owner of a customized General Motors van equipped with an electrically shifted automatic transmission (4L80-E) complained that the automatic transmission downshifted into second gear and stayed in second gear whenever the headlights were turned on. The transmission shifted okay when the headlights were turned off. After hours of troubleshooting, including the replacement of the vehicle computer (which did not help), it was discovered that 4 volts DC were on the one wire leading from the vehicle speed (VS) sensor to the vehicle computer whenever the headlights were turned on. Obviously, there was a short-to-voltage between a light wire and the sensor wire. Instead of totally disassembling the van, it was decided to replace the wire with a new one, and the problem was solved. The 4 volts DC apparently shut down the computer. When the computer stopped controlling the shifts, both A and B solenoids were shut off. With both solenoids A and B off, the transmission was in second gear. This is the default gear or the limp-in-mode gear for this transmission. After replacing the wire, the automatic transmission returned to manual operation allowing the driver to drive at night and in the daytime.



Figure 102–11 This is a normal amount of wear material in the bottom of an automatic transmission oil pan.

Band Adjustment Some automatic transmissions/transaxles allow the technician to adjust the clearance between the band and the drum inside the unit. The procedure usually involves tightening the adjustment nut or bolt to a specified torque reading and then backing off the adjustment nut or bolt a specified number of times. See Figure 102–12. Some bands are adjusted using selective length pushrods and some bands are not adjustable at all. The band(s) should be adjusted whenever the fluid is changed or whenever recommended by the vehicle manufacturer.



Figure 102–12 Adjusting the intermediate band on a Ford A4LD transmission.

FREQUENTLY ASKED QUESTION ???

What Is Wrong When My Automatic Transmission Does Not Upshift at All?

There are several things that can cause the automatic transmission/transaxle to fail to upshift, including:

- **A defective governor** (if so equipped) will often not allow any automatic transmission/transaxle to shift out of first gear.
- **A defective vacuum modulator** (if so equipped) will often delay the shift until a very high speed is achieved.
- **A fault in the computer or sensor.** On electronically shifted automatic transmissions/transaxles, one gear, usually second or third, is selected and the unit will not shift out of that gear.

Linkage Adjustment The linkage between the shift selector and the automatic transmission should be checked for proper adjustment whenever there is a transmission-related problem. The linkage may need to be adjusted to compensate for worn linkage components. Before adjusting the linkage, check the engine and transmission/transaxle mounts carefully because a defective mount is a common reason for needing a linkage adjustment.

TECH TIP **Use Old Headlights to Check Wiring**

The proper operation of any electronically shifted automatic transmission/transaxle depends on having electrical power available to operate the solenoids. Before removing the unit from the vehicle, use a headlight to check if there is enough current being sent to the unit. Unplug the electrical connection that supplies 12 volts, usually from the ignition switch. Use a headlight and attach wires to the ground and the bright filament terminals. See Figure 102–13.

Attach one test lead from a headlight to the terminal that supplies 12 volts to the unit. Attach the other lead from the headlight to a good clean chassis or transmission ground such as the case. Turn the ignition on (KOEO) and observe the headlight.

- If there is a dim headlight, there is a voltage drop between the source (battery) and the transmission feed. Check the wires directly leaving the ignition switch. If the headlight is still dim, replace the ignition switch. See Figure 102–14.
- If the headlight is off, then there is an open circuit between the battery and the transmission/transaxle. Follow electrical troubleshooting procedures to find and repair the open circuit.
- If the headlight is bright, there is enough voltage and current being supplied to the transmission/transaxle to correctly operate all of the solenoids. See Figure 102–15.



Figure 102–13 A tester made from a headlight showing wires attached to the ground and the bright filament terminals.

SUMMARY

1. The first step in the diagnosis of an automatic transmission/transaxle problem is to verify the complaint.
2. The automatic transmission fluid level should be checked before performing a thorough road test.
3. A stall test involves accelerating the engine at wide-open throttle with the automatic transmission/transaxle gear selector in drive and your foot on the brake. The maximum attainable engine speed is called the *stall speed*.



Figure 102–14 A dim headlight indicates excessive resistance between the battery and the electrical connector to the automatic transmission/transaxle.



Figure 102–15 A bright headlight indicates that there should be sufficient current flow available at the automatic transmission/transaxle to operate all the solenoids correctly.

4. A stuck torque converter clutch solenoid can cause the engine to stall when the vehicle slows to a stop.
5. A scan tool can be helpful in the diagnosis of electronically shifted automatic transmissions/transaxles. All engine-related diagnostic trouble codes (DTCs) should be corrected before further diagnosis of the transmission/transaxle is attempted.
6. A vacuum modulator should be able to hold a vacuum applied by a hand-operated vacuum pump.
7. Most automatic transmissions/transaxles are equipped with pressure taps that allow a service technician to check mainline and other hydraulic pressures in the unit.

REVIEW QUESTIONS

1. List the tests that can be performed on an automatic transmission/transaxle to determine any faults while the unit is still in the vehicle.
2. Explain how a defective torque converter clutch solenoid can cause the vehicle to stall when the vehicle is slowing to a stop.
3. Explain how automatic transmission fluid could reach the intake manifold of the engine and be burned in the engine.
4. Describe how to perform a test of the mainline and other pressures of an automatic transmission/transaxle.

CHAPTER QUIZ

1. Technician A says that the apply and holding units are usually the same for first gear when the gear selector is in drive or manual first. Technician B says that a defective vacuum modulator could cause the automatic transmission to delay shifting until a higher-than-normal speed is achieved. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Two technicians are discussing what could be wrong with a hydraulically shifted automatic transmission/transaxle that does not shift out of first gear regardless of vehicle speed. Technician A says that a defective governor could be the cause. Technician B says that a weak pump could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
3. Two technicians are discussing an automatic transmission that will not go into any forward gear or reverse. Technician A says that a defective computer could be the cause. Technician B says that a misadjusted TV cable could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. A General Motors vehicle equipped with an electronically shifted transaxle stalls whenever slowing to a stop after being driven over 20 miles (32 km). Technician A says that the computer could be defective. Technician B says that a shift solenoid is likely to be defective. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. An electronically shifted overdrive automatic transmission is equipped with a transmission fluid temperature sensor. Technician A says that the shifts may be changed if the fluid temperature is too high. Technician B says that overdrive may be disabled if the transmission fluid temperature is too high. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
6. White smoke is observed coming from the tail pipe of the vehicle. Technician A says that a defective TV cable adjustment could be the cause. Technician B says that a defective vacuum modulator could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Why would selecting manual low be a way to check an automatic transmission/transaxle?
   a. The pressure is higher than in drive
   b. The technician does not need to drive as fast
   c. It limits engine speed and torque
   d. All of the above
8. Caution should be used when performing a stall test because _____.
   a. It could increase the temperature of the ATF
   b. It could be hazardous if the brakes fail
   c. It puts a strain on the engine
   d. All of the above
9. An electronically shifted automatic transmission operates okay in reverse, but the vehicle does not shift at all when moving forward. Technician A says that a defective torque converter is the likely cause. Technician B says that a defective shift solenoid could be the cause. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. Two technicians are discussing inspection of the transmission pan. Technician A says that some friction material at the bottom of the pan is normal. Technician B says that if any metal parts stick to a magnet that further investigation is needed to determine the cause. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technicians A and B
    d. Neither Technician A nor B

CHAPTER 103 Automatic Transmission/ Transaxle Unit Repair

OBJECTIVES: After studying Chapter 103, the reader will be able to: Discuss how to disassemble an automatic transmission/transaxle. • Explain how to properly install and check clutch packs. • Describe how to flush the cooler. • Explain how to properly reassemble an automatic transmission/transaxle. • List the steps necessary to follow when removing an automatic transmission/transaxle assembly. • Describe how to properly remove and install an aluminum pump in an automatic transmission/transaxle. • Explain how to flush an automatic transmission fluid cooler.

KEY TERMS: assembly lube • OSHA air nozzle

REMOVING THE AUTOMATIC TRANSMISSION/ TRANSAXLE FOR SERVICE

Removing an automatic transmission/transaxle from a vehicle includes many steps to avoid doing damage to the vehicle or harm to yourself. Always follow the vehicle manufacturer's recommended procedures. Most procedures include the following steps.

Step #1 Disconnect the negative (−) battery cable from the battery. This prevents the possibility of an accidental short circuit that could damage the vehicle or cause a spark that could start a fire.

Step #2 Disconnect the driveshaft or drive axle shafts.

Step #3 Disconnect all cooler lines, linkage, and electrical connections. Be sure to label each to ensure proper reinstallation.

Step #4 Disconnect the torque converter from the flex (drive) plate of the engine.

Step #5 Support the engine before disconnecting the automatic transmission/transaxle, as shown in Figure 103–1.

Step #6 Remove the transmission/transaxle mounting fasteners.

Step #7 Support the transmission/transaxle on a jack and remove the attaching bolts at the bell housing of the engine, as shown in Figure 103–2. Remove the transmission/transaxle from the vehicle.

TECH TIP ✔ **The Chain Trick**

If two slide hammers are not available to remove a cast iron pump from an automatic transmission, try using a length of chain. Attach each end of a chain to the pump and jerk the chain. The pump should come out.

CAUTION: Do not attempt this procedure with an aluminum pump or damage could result.

AUTOMATIC TRANSMISSION/ TRANSAXLE DISASSEMBLY

For best results, the automatic transmission/transaxle should be attached to a holding fixture that allows the unit to be rotated yet properly supported during disassembly and reassembly.

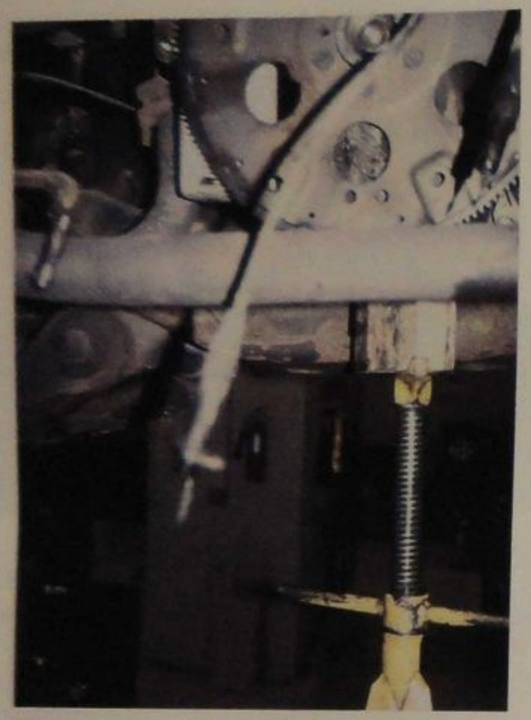
Torque Converter Check Check the torque converter for internal end play of the stator. See Figure 103–3.

NOTE: Many automotive transmission/transaxle experts recommend that the torque converter be replaced when the automatic transmission is rebuilt or replaced. This is because the torque converter is generally considered to be the "garbage pit" of the entire unit in that it often collects wear particles from the clutch and bands that can cause future problems. According to remanufacturers of torque converters, the majority of the torque converters being turned in as cores have little, if any, friction material remaining for the torque converter clutch. See Figure 103–4.

CAUTION: Never drop a torque converter. If a torque converter is accidentally dropped, even a few inches, the drop will cause the internal plastic thrust member to break. If a torque converter is dropped, it should be replaced.

Pump Assembly Remove the pump assembly using the proper removal tool to avoid damaging it. See Figures 103–5 and 103–6. Check the pump for wear as shown in Figure 103–7.

Valve Body Remove the valve body and check all valves for proper operation. See Figure 103–8. To service a valve body, disassemble all the parts and identify them for reassembly. See Figure 103–9. Save the old gaskets to match with the new ones. Clean all parts in



(a)

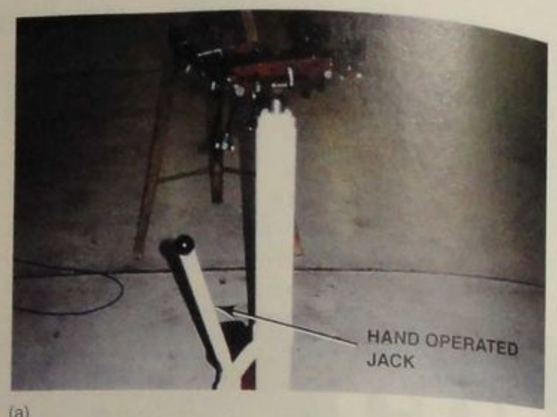


(b)

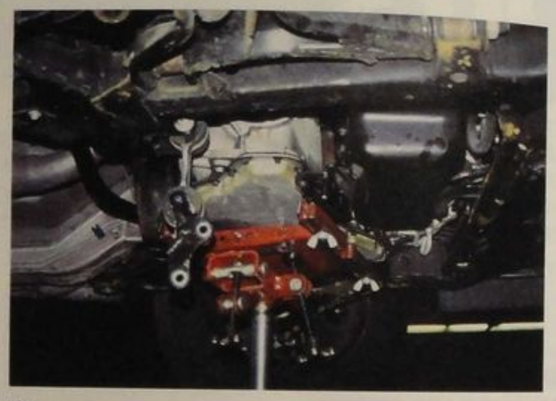
Figure 103–1 (a) A tall safety stand with a block of wood on top being used to support the engine to permit the removal of the automatic transmission without doing harm to the engine or its accessories. (b) A chain and holding fixture being used on this front-wheel-drive vehicle to support the engine when the transaxle is removed.

a solvent that removes all gum, varnish, dirt, and grease. Rinse clean parts in hot, running water, then immerse them in clean mineral spirits or a similar solvent to separate water from the parts. Finish cleaning by blow-drying with low-pressure, filtered, compressed air. Once clean, inspect the valve body and its components and look for:

- Scored, cracked, or burred plugs and valves
- Broken, bent, or worn springs
- Scored or rusted bores
- Plugged or restricted fluid passages
- Bent or rusted separator plates
- Stuck check valves
- Bent manual valves
- Cracked castings and distorted or nicked mating surfaces.



(a)



(b)

Figure 103–2 (a) A typical transmission jack. The top portion of the jack can be raised by pumping the lever on the side. (b) A transmission jack in position during the removal of the transaxle assembly.

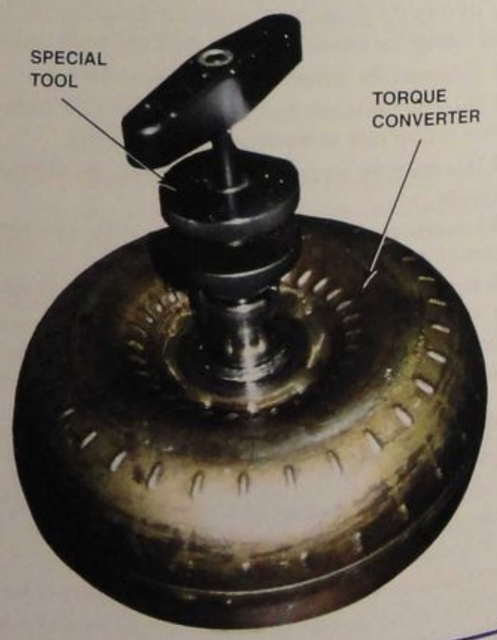


Figure 103–3 Special tool being used to help measure the end play of the stator inside the torque converter.

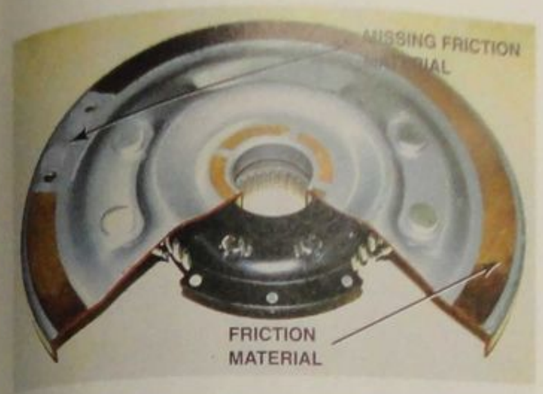


Figure 103–4 A cutaway of a torque converter clutch showing the thin paper friction material.

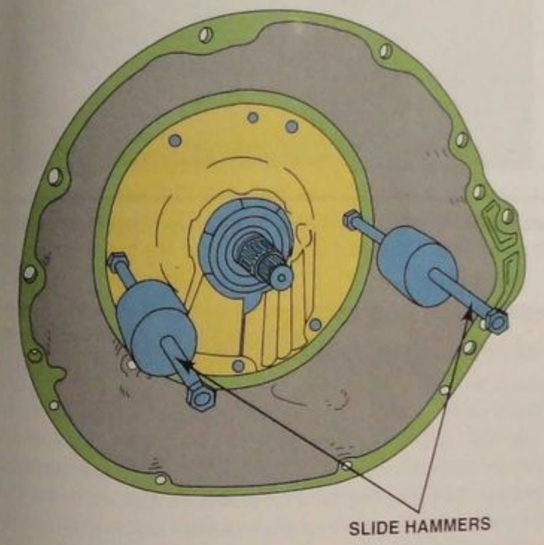


Figure 103–5 Two slide hammers are usually used to remove a cast-iron pump assembly from older automatic transmissions.

Shiny areas on valve lands indicate friction between the spool valve and body. On steel valves, these areas can be polished carefully with 400- to 600-grit wet or dry sandpaper, crocus cloth, or polishing stone. Take care not to round off the edges of the valve lands while polishing. Aluminum valves cannot be polished. If a valve needs polishing, the bore it rides in also requires servicing. Polish the valve bore by inserting and turning loosely rolled wet or dry sandpaper or crocus cloth. Avoid rounding the edge of the bore. Attach a piece of crocus cloth to a slotted dowel rod or bent welding rod to reach the bottom of a deep bore. Rewash and dry any valves and bores that are polished.

After polishing and washing, lubricate the spool valve with ATF and slide it into its bore to check fit and operation. The valve should slide back and forth freely of its own weight.

Clutch Packs Begin disassembling a clutch pack by removing the snap ring that holds the discs in the housing. Remove the snap ring from most clutches by prying one end of it free from its groove with a small screwdriver. Then, slide the screwdriver around the drum and the snap ring removes easily.

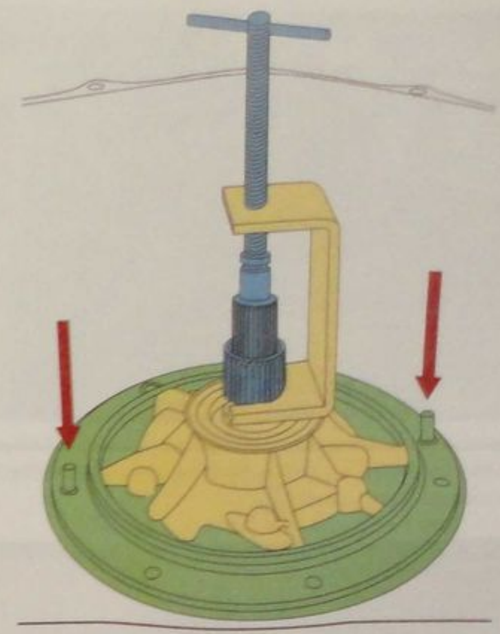


Figure 103–6 A special puller is usually specified to remove aluminum pumps from automatic transmissions/transaxles. Alignment pins (arrows) are used to properly align the gasket and pump on the case during reassembly.

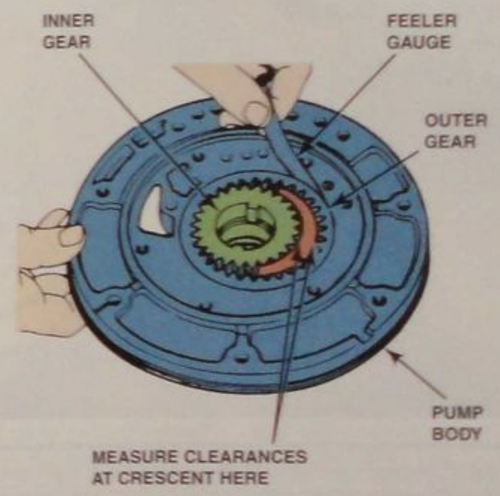


Figure 103–7 Checking a transmission pump assembly for wear using a feeler gauge. Compare the readings to factory specifications.

Friction Disc Inspection Wipe each friction disc with a dry, lint-free cloth. Inspect for:

- Excessive wear
- Cracks in the lining material
- Charred, burned, or glazed lining surface
- Pitting, flaking, or scoring
- Chips or particles embedded in the lining
- Scoring or burns on disc serrations
- Distortion

Friction discs tend to discolor in use, which is normal. However, if any friction disc shows signs of one or more of the defects

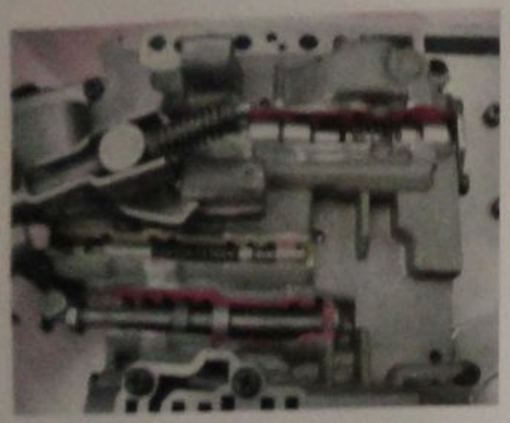


Figure 103–8 A cutaway of an auxiliary valve body showing the valves and springs that should be checked for smooth operation.



Figure 103–9 Sometimes unique tools make the job go smoother. An engine valve spring compressor is being used to compress a servo piston so the snap ring can be removed.



Figure 103–10 A compressor tool is usually necessary to compress the springs of the clutch piston to remove the snap ring.

TECH TIP ✓ **Smooth Is In; Rough Is Out**

It used to be common practice in the automatic transmission business for the rebuilder to use sandpaper to "roughen up" the surface of the steel discs to achieve a good clutch apply. This is not true now. Sanding creates grooves and sharp peaks that decrease the oil film between the paper on the friction plate and the steel plates. There should be a thin oil film between the paper and the steel to create a holding bond and make it possible for a clutch pack to apply and release thousands of times without wear. Therefore, for consistent shifts and long-lasting transmissions/transaxles, do not sand the steel discs. Used steel discs are often smoother than new steel discs due to normal wear. As long as the steel discs are not discolored, heat checked, or warped, used steel discs should be reused.

NOTE: Be sure to soak all the friction discs in ATF before assembling the clutch pack.

above, replace the entire set. Replace the set of friction discs if they do not fit freely in the clutch hub serrations or if there is wear or damage to their splines.

Steel Disc Inspection Also clean steel discs by wiping with a dry, lint-free cloth. Once clean, inspect each disc for:

- Uneven wear discoloration
- Surface scuffing or scoring
- Lining damage
- Distortion

Replace the entire set of steels if you note a rough surface or there is uneven or spotty discoloration on any of the discs. Also replace steel discs if they do not fit freely into the clutch drum serrations.

Clutch Piston Removal and Inspection To remove the snap ring holding the clutch piston in place, compress the piston return springs, which is done with a compressor tool. See Figure 103–10.

Tightening a nut onto the shaft draws the fingers of the tool down, compressing the spring, and allowing the snap ring to be removed. After removing the snap ring, release and remove the spring compressor, then remove and inspect the return springs.

Return Spring Inspection Coil springs should be straight and provide proper pressure. Check for broken, distorted, or collapsed springs. If one or more of the springs requires replacement, discard them all and install a complete set of new springs.

Some coil springs are permanently attached to their retaining collar and can only be serviced as a set. When individual coil springs are used, be sure to note their exact location. There will be vacant spring seats in some applications. This allows the manufacturer

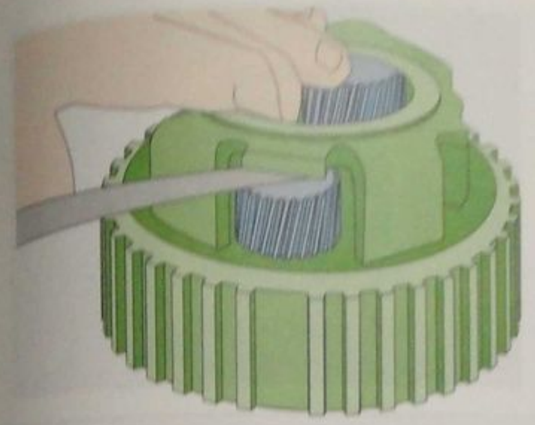


Figure 103–11 Pinion gear end play can be checked using a feeler gauge.

to use the same piston but vary the number and location of springs to precisely match spring return rate to the requirements of a particular vehicle. In these cases, reinstall return springs in *exactly the same vacancy* pattern.

Clutch Piston Inspection Remove the clutch piston from the hub. The drag of the piston seal can make it hard to remove the piston from its bore. Should this be the case, apply low-pressure compressed air through the hydraulic apply hole in the housing to force the piston from its bore.

SAFETY TIP **Always Use OSHA Approved Air Nozzles**

Compressed air can be very dangerous. The Occupational Safety and Health Administration (OSHA) has specified an air nozzle that diverts some air outward that helps reduce the full force of the compressed air able to be applied to a clutch pack. Be sure to always use an OSHA approved air nozzle.

Do not use high air pressure and be careful to avoid pinching your hand or dropping the piston as it pops from its bore. Once you remove the piston, check for:

- Cracks or scoring in the piston bore
- Nicks, scores, burrs, or signs of wear on the piston
- Seal damage
- Fluid passage obstructions or restrictions

If the piston contains a check valve, make sure it is functional. Remove and discard seals.

Hubs, Drums, Shells, and Planetaries Clutch hubs, drums, and shells transfer the torque load to the various combinations of planetary gear set members to provide different gear ratios. Hubs, drums, shells, and planetaries are *hard parts* that do not wear out under normal conditions, so they can be reused unless they are damaged. Wash with solvent, dry with compressed air, and then inspect. Planetary gear sets should be checked for proper pinion gear end play and compared to factory specifications. See Figure 103–11.

REASSEMBLING AN AUTOMATIC TRANSMISSION/TRANSAXLE

Air Pressure Checks Reassembly of an automatic transmission/transaxle involves assembling the various subassemblies, such as a

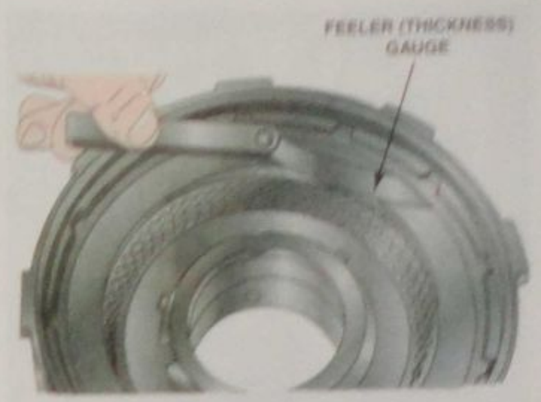


Figure 103–12 All clutch packs should be checked with a feeler (thickness) gauge to be certain that the clearance is within factory specifications.



Figure 103–13 Checking clutch pack clearance using a dial indicator. This method is used when a feeler gauge cannot be inserted to check for proper clearance.

clutch pack, before final assembly is completed. See Figures 103–12 and 103–13 for how to check for proper clutch pack clearance. Air pressure checks are used to verify that components such as clutch packs perform correctly. Use a rubber-tipped air nozzle and regulate the air supply to about 35 PSI (240 kPa). Use the factory service information regarding where to air check and what the results should be. A typical result is a dull thud or clunk heard when air pressure is applied to a clutch pack or servo piston. See Figure 103–14. When the air pressure is removed, the unit should release. If there is a seal leak, air can usually be heard hissing from around the seal.

All bushings should be inspected and replaced if necessary, as shown in Figure 103–15. Follow the vehicle manufacturer's recommended procedures. For example, a special clamp is often necessary to properly assemble a pump, as shown in Figure 103–16. Special tools are often specified by the vehicle manufacturer. These tools allow the service technician to disassemble and reassemble the transmission/transaxle more easily and without doing any harm. See Figure 103–17. Also perform all end play checks during assembly to ensure that the unit was properly assembled and that the proper internal clearances are achieved. See Figure 103–18.

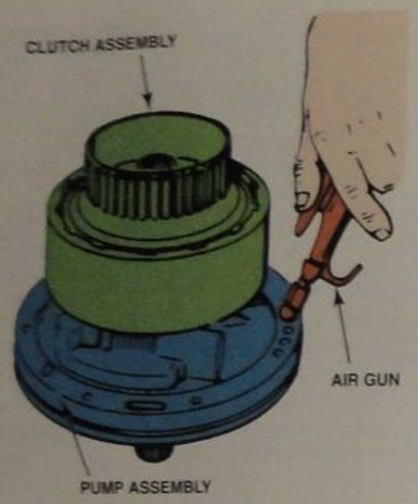


Figure 103–14 Air testing a clutch pack on the bench before it is installed into the transmission/transaxle.



Figure 103–15 A typical brass bushing used in an automatic transmission/transaxle assembly.



Figure 103–16 Using an alignment clamp to assemble both pump halves. To ensure proper alignment, many experts recommend lightly tapping around the outside edges of the pump while tightening the clamp.

CAUTION: When assembling the valve body, double-check that all the valves move by gently prying each valve with a plastic tool. If any valve is stuck, carefully clean with a cirrous cloth and avoid rounding the sharp edges of the valves. Also avoid using gasket sealer that could clog small passages.

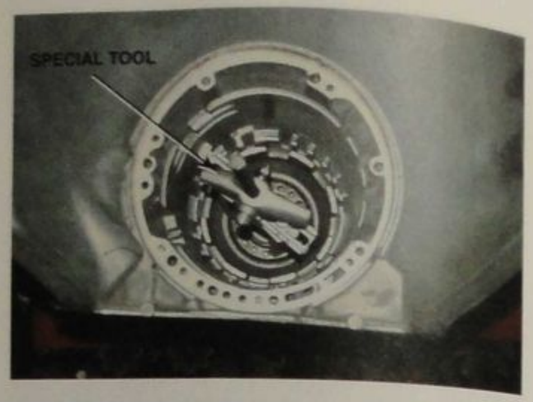


Figure 103–17 A special clamp makes removal and reinstallation of the clutch pack easier.

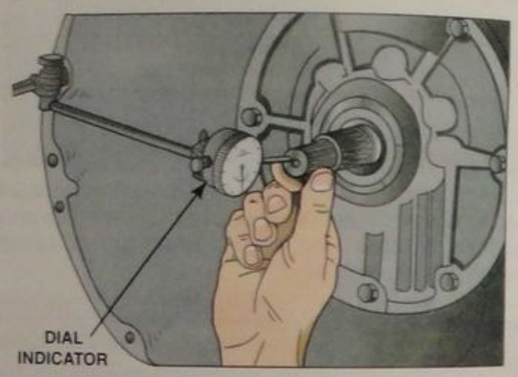


Figure 103–18 A dial indicator being used to measure the end play of the input shaft. If the end play is not within factory specifications, the unit may not have been assembled correctly.

Valve Body Checks The valve body can be checked using a tester especially designed to check valve bodies. See Figure 103–19. Adapters are available for all commonly serviced automatic transmissions/transaxles, and the pressure gauges that are part of the tester are used to monitor the movement and flow through the valve body. This unit also heats the automatic transmission fluid so that the valve body is being tested under the same conditions as will be occurring in the vehicle. It is easier to repair a fault with the valve body than wait until the valve body and the transmission are installed in the vehicle.

TECH TIP ✔ **Change the Bolts and Washers**

Whenever reassembling an automatic transmission, always replace the pump bolts and washers to avoid the possibility of a leak. A leak in the area of the pump can cause quite a headache for the technician because the entire assembly must be removed from the vehicle again to fix it.

Flushing the Cooler and Torque Converter All vehicle manufacturers recommend that the automatic transmission fluid cooler be flushed or replaced when a replacement or overhauled automatic transmission/transaxle is installed in a vehicle. Debris from the old unit could quickly cause excessive wear in the replacement unit if not thoroughly flushed. Most commercial flushing units use compressed air and a solvent or ATF to flush the cooler. See Figure 103–20 for an example of a setup used to flush a torque converter before being installed into the vehicle.

CAUTION: Most experts agree that water-based flushing solutions should be avoided. The water may contaminate the new fluid when the cooler lines are reattached and the ATF flows through the cooler.

To flush the cooler, determine which cooler line from the transmission/transaxle is flowing to the cooler. See the following chart for the placement of many of the cooler-out lines on the most commonly used transmissions/transaxles.

NOTE: At least two quarts (liters) of ATF should flow through the cooler every 30 seconds or the cooler and/or the lines are restricted.

Cooler-Out Lines

Transmission	Cooler-Out Line on the Transmission/Transaxle
General Motors	
125 (3T40)	Bottom
180	Bottom
200/200-4R	Top
325/325-4L	Bottom
350	Bottom
400 (4L80)	Bottom
440-T4 (4T60)	Bottom
700-R4 (4L60)	Bottom
Ford	
A4LD	Bottom
AOD	Top
ATX	Bell housing end
AXOD	Top
C3, C4, C5, C6	Front
Chrysler	
904, 727	Front
FWD	Bottom
Import Brand	
Honda	Over the bell housing
Jatco (RWD)	Front
Mitsubishi	Inner
Renault	Top
Nissan RL3F01A	Top
Nissan RL4F02A	Front
Subaru	Top of the differential
Toyota FWD	Top
Toyota RWD	Front

Dyno Testing the Automatic Transmission/Transaxle A rebuilt automatic transmission/transaxle can be tested on a dynamometer powered by an electric motor as shown in Figure 103–21 or by a gasoline engine as shown in Figure 103–22. Most dynamometers are equipped with pressure gauges as well as provide a load so the operation of the unit can be checked before being installed in the vehicle.



Figure 103–19 Valve body tester.



Figure 103–20 Setup used to flush a torque converter.



Figure 103–21 A motor-driven dynamometer being used to check the operation of a 4R70E transaxle.



Figure 103–22 A gasoline engine-powered dynamometer being set up to test a rear-wheel-drive transmission.

REINSTALLING THE AUTOMATIC TRANSMISSION/TRANSAXLE

After the unit has been reassembled and all end play checks indicate that the unit is properly assembled, reinstall the automatic transmission/transaxle in the vehicle. Many experts recommend that new transmission/transaxle mounts be installed to assure proper driveshaft/drive axle shaft angles.

NOTE: New mounts are particularly important if the unit was leaking automatic transmission fluid (ATF). The ATF can soften and deteriorate the rubber used in the mounts.

Before installing the unit into the vehicle, flush the torque converter with clean ATF. Carefully install the torque converter onto the input shaft being sure to fully engage the pump gear.

Carefully install the unit and use a torque wrench to torque the bolts to the bell housing. Attach the torque converter to the flex (drive) plate. Reattach all electrical connections. Lower the vehicle and add enough ATF to properly fill the unit. Consult factory information for the recommended amount to avoid under- or overfilling.

ROAD TEST

Start the engine and check the level of the ATF. Carefully test-drive the vehicle checking for proper operation and shift points. Hoist the vehicle and check for any possible ATF leaks before returning the vehicle to the customer.

TECH TIP ✔ **Avoid Using Red Assembly Lube**

Assembly lube is used during the reassembly of automatic transmissions. If red assembly lube is used on seals, it may look like an automatic transmission fluid leak when the transmission gets hot and the lube melts. If you use blue, green, brown, or clear assembly lube, then the color will immediately identify it as assembly lube. See Figure 103–23.

Many transmissions have been disassembled because the service technician thought that the red liquid dripping from parts of the transmission was automatic transmission fluid, while in fact it was just assembly lube that melted and ran when the transmission reached normal operating temperature.



Figure 103–23 Blue assembly lube.

TECH TIP ✔ **Install a Transmission Cooler**

An auxiliary transmission fluid cooler is recommended by most experts to help keep the temperature from becoming excessive, especially when towing or performing other heavy-duty vehicle operation. See Figure 103–24.

Most experts recommend that the cooler be connected so that the hot fluids travel through the auxiliary cooler and then through the factory cooler and return to the transmission/transaxle. Using this method of plumbing allows the radiator to warm the transmission fluid in cold weather as well as provide additional cooling of the fluid when the fluid temperature is high.



Figure 103–24 An auxiliary transmission cooler installed on a Chevrolet tow vehicle.

TECH TIP ✔ **If the Torque Converter Is Dropped, Replace It**

Torque converters include plastic thrust plates which are very strong under the compressive forces of normal torque converter operation. However, if a torque converter is dropped, even from a distance of less than six inches (15 cm), the thrust washer can easily break, ruining the torque converter. Even though torque converters look strong and feel heavy, handle them as if they are glass.

PHOTO SEQUENCE 6T70 Transaxle Disassembly and Assembly



P103–1 The GM 6T70 6 forward speed transaxle was a joint venture with Ford and therefore is similar to the 6F50.



P103–2 A unique thin torque converter is used to help reduce the overall length of the transaxle.



P103–3 After removing the torque converter, the housing is being removed.



P103–4 The final drive assembly is exposed after the housing has been removed.



P103–5 The final drive is easily lifted out after the housing has been removed.



P103–6 Note the tapered roller bearing used in the final drive assembly component.



P103–7 The transaxle is rotated and the plastic side cover is removed.



P103–8 Under the side cover is the valve body and integrated solenoid assembly.



P103–9 Under the plastic electrical solenoid assembly is the valve body assembly.



P103–10 Removing the valve body assembly.



P103–11 Turning the assembly around, showing the end cover.



P103–12 Removing the end cover shows the clutch packs and planetary gear set.

(continued)



P103–13 Removing the first of five clutch packs (two driving and three holding).



P103–14 A typical clutch pack in a 6T70 showing the selective thickness steel used to determine clutch pack clearance.



P103–15 A view down into the case where multiple clutch packs are found.



P103–16 The output planetary gear set with four pinions used on 6T70 units. The 6T75 version uses a five pinion carrier and a reinforced case.



P103–17 Reassembly of the clutches. Check service information for specified clutch pack clearance.



P103–18 Notice that the final drive is equipped with tapered roller bearings and this means that the preload must be adjusted.



P103–19 A special set of spacers and blocks used to determine the preload needed. A feeler gauge is then used to measure the clearance.



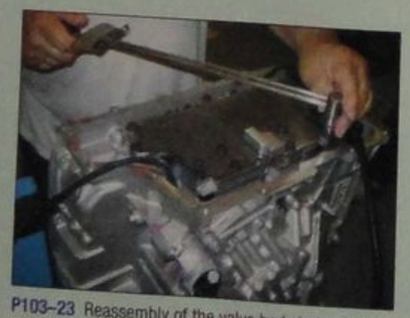
P103–20 Following the procedure in service information, the designated thickness of shim is selected, which is placed under the bearing race in the bearing packet.



P103–21 The selective shim and race before the race is driven into position.



P103–22 Driving the race into position using the specified driver.



P103–23 Reassembly of the valve body being sure that all fasteners are tightened to factory specifications.



P103–24 The solenoid assembly is replaced as an assembly only if defective and all the fasteners need to be torqued to factory specifications.

SUMMARY

1. The transmission pan should be carefully inspected for evidence of excessive wear material. Use a magnet to check for any particles of steel that could be the result of serious internal damage such as a defective planetary gear set.
2. The engine should be properly supported before the automatic transmission/transaxle is removed from the vehicle.
3. When reassembling an automatic transmission/transaxle, the clutch pack clearances should be checked with a feeler gauge and air checked.
4. End play should be checked according to the vehicle manufacturer's recommendations. This check is also used as a double check for the service technician that the unit was properly assembled.
5. All vehicle manufacturers recommend that the automatic transmission fluid cooler be flushed when rebuilding or replacing an automatic transmission/transaxle.

REVIEW QUESTIONS

1. List the procedures to follow to remove an automatic transmission/transaxle from a vehicle.
2. Describe two methods of checking a clutch pack.
3. Explain why it is important to perform an end play check of an automatic transmission/transaxle during the reassembly process.
4. Explain why it is important to flush the automatic transmission fluid cooler when a rebuilt or replacement automatic transmission/transaxle is being installed in a vehicle.

CHAPTER QUIZ

1. Technician A says that the torque converter should be separated from the flex (drive) plate before removing the automatic transmission/transaxle. Technician B says that any wear material in the bottom of the oil pan means that the unit should be overhauled. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. Air pressure checking is used to test _____.
   a. Clutch packs
   b. TV adjustment
   c. Vacuum modulators
   d. Governors
3. Technician A says that all friction and steel plates in a clutch pack should be replaced during an overhaul. Technician B says that the automatic transmission fluid cooler should always be flushed when a unit is rebuilt or replaced. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Slide hammers or a special puller are used to remove what component?
   a. An extension housing
   b. A filter
   c. A pump
   d. Rear seal
5. What part must be replaced if dropped?
   a. Pump
   b. Torque converter
   c. Extension housing
   d. Pan
6. Technician A says that the sharp edges of spool valves should be rounded using 400-grit sandpaper. Technician B says that all valve body parts should be cleaned and then dried using low-pressure, filtered compressed air. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Steel discs should be _____ before being installed.
   a. Sanded
   b. Surface roughed up
   c. Cleaned
   d. All of the above
8. Friction discs should be _____ before being installed.
   a. Sanded
   b. Soaked in ATF
   c. Surface roughed up
   d. All of the above
9. How much transmission fluid should flow through the cooler?
   a. Two quarts every 30 seconds
   b. One quart per minute
   c. Two quarts per minute
   d. Two pints per minute
10. Why should red assembly lube be avoided?
    a. Can harm friction disks
    b. Too slippery
    c. Clogs filters
    d. Looks like an ATF leak when it melts

APPENDIX 1

ASE Correlation Chart

Engine Repair (A1)

ASE Task List	Textbook Page No.
A. General Engine Diagnosis (17 questions)	
1. Verify the driver's complaint and/or road test the vehicle; determine necessary action.	160, 163, 178, 201, 202, 204, 205
2. Determine if the no-crank, no-start, or hard starting condition is an ignition system, cranking system, fuel system, or engine mechanical problem.	433
3. Inspect the engine assembly for fuel, oil, coolant, and other leaks; determine necessary action.	160, 172, 203, 204, 222, 310, 311
4. Listen to engine noises; determine necessary action.	204, 205, 206, 241, 243, 245, 249, 250, 257, 258
5. Diagnose the cause of excessive oil consumption, coolant consumption, unusual engine exhaust color, odor, and sound; determine necessary action.	163, 178, 185, 200, 202, 232, 244, 259
6. Perform engine vacuum tests; determine necessary action.	208, 209
7. Perform cylinder power balance tests; determine necessary action.	201, 208, 212
8. Perform cylinder compression tests; determine necessary action.	212, 213
9. Perform cylinder leakage tests; determine necessary action.	207, 214
B. Cylinder Head and Valve Train Diagnosis and Repair (18 questions)	
1. Remove cylinder heads, disassemble, clean, and prepare for inspection according to manufacturers' procedures.	214, 216, 218
2. Visually inspect cylinder heads for cracks, gasket surface areas for warpage, corrosion, and leakage, and check passage condition.	219, 220, 223, 230
3. Inspect and test valve springs for squareness, pressure, and free height comparison; replace as necessary.	234, 235, 238
4. Inspect valve spring retainers, rotators, locks, and valve lock grooves.	239, 240
5. Replace valve stem seals.	239, 240
6. Inspect valve guides for wear; check valve guide height and stem-to-guide clearance; determine needed repairs.	239, 240
7. Inspect valves; resurface or replace according to manufacturers' procedures.	227, 236
8. Inspect and resurface valve seats according to manufacturers' procedures.	227, 236
9. Check valve face-to-seat contact and valve seat concentricity (runout).	236, 237, 238
10. Check valve spring installed (assembled) height and valve stem height; service valve and spring assemblies as necessary.	234, 235
11. Inspect pushrods, rocker arms, rocker arm pivots, and shafts for wear, bending, cracks, looseness, and blocked oil passages; repair or replace as required.	143, 144, 183, 207, 216, 230
12. Inspect and replace hydraulic or mechanical lifters/lash adjusters.	143, 144, 182, 183, 206, 221, 237
13. Adjust valves on engines with mechanical or hydraulic lifters.	313
14. Inspect and replace camshaft drives (includes checking gear wear and backlash, sprocket and chain wear, overhead cam drive sprockets, drive belts, belt tension, tensioners, and cam sensor components).	209, 241, 242, 243, 244, 252, 254, 305, 307
15. Inspect and measure camshaft journals and lobes.	241, 247, 249, 251
16. Inspect and measure camshaft bore for wear, damage, out-of-round, and alignment; repair or replace according to manufacturers' specifications.	290, 295

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17. Time camshaft(s) to crankshaft.	243, 247
18. Reassemble and install cylinder heads and gaskets; replace and tighten fasteners according to manufacturers' procedures.	214, 216, 218
C. Engine Block Diagnosis and Repair (18 questions)	
1. Disassemble engine block and clean and prepare components for inspection.	214–219
2. Visually inspect engine block for cracks, corrosion, passage condition, core and gallery plug holes, and surface warpage; determine necessary action.	222, 223
3. Inspect and repair damaged threads where allowed; install core and gallery plugs.	51, 54–60, 295
4. Inspect and measure cylinder walls; remove cylinder wall ridges; hone and clean cylinder walls; determine need for further action.	270, 275, 276, 277, 302
5. Visually inspect crankshaft for surface cracks and journal damage; check oil passage condition; measure journal wear; check crankshaft sensor reluctor ring (where applicable); determine necessary action.	286, 287, 289, 290, 291, 291, 297
6. Inspect and measure main bearing bores and cap alignment and fit.	286, 287, 289, 290, 291, 297
7. Install main bearings and crankshaft; check bearing clearances and end play; replace/retorque bolts according to manufacturers' procedures.	286, 287, 289, 290, 291, 297
8. Inspect camshaft bearings for unusual wear; remove and replace camshaft bearings; install camshaft, timing chain, and gears; check end play.	290, 291, 292
9. Inspect auxiliary (balance, intermediate, idler, counterbalance, or silencer) shaft(s) and support bearings for damage and wear; determine necessary action.	183, 244, 290, 307
10. Inspect, measure, service, repair, or replace pistons, piston pins, and pin bushings; identify piston and bearing wear patterns that indicate connecting rod alignment problems; determine necessary action.	266, 300–303
11. Inspect connecting rods for damage, alignment, bore condition, and pin fit; determine necessary action.	263–265
12. Inspect, measure, and install or replace piston rings; assemble piston and connecting rod; install piston/rod assembly; check bearing clearance and sideplay; replace/retorque fasteners according to manufacturers' procedures.	260, 261, 262, 278, 300
13. Inspect, reinstall, or replace crankshaft vibration damper (harmonic balancer).	217, 218
14. Inspect crankshaft flange and flywheel mating surfaces; inspect and replace crankshaft pilot bearing/bushing (if applicable); inspect flywheel/flexplate for cracks and wear (includes flywheel ring gear); measure flywheel runout; determine necessary action.	203, 248, 1210–1211, 1215, 1218
15. Inspect and replace pans, covers, gaskets, and seals.	258–267, 279, 287, 291, 292, 294–314
16. Assemble engine parts using formed-in-place (tube-applied) sealants or gaskets.	258–267, 279, 287, 291, 292, 294–314
D. Lubrication and Cooling Systems Diagnosis and Repair (9 questions)	
1. Perform oil pressure tests; determine necessary action.	205
2. Disassemble, inspect, measure, and repair oil pump (includes gears, rotors, housing, and pick-up assembly), pressure relief devices, and pump drive; replace oil filter.	181–183, 206, 216, 241, 242
3. Perform cooling system tests; determine necessary action.	171
4. Inspect, replace, and adjust drive belts, tensioners, and pulleys.	176, 204, 205
5. Inspect and replace engine cooling and heater system hoses.	160–172, 177
6. Inspect, test, and replace thermostat, bypass, and housing.	164–167
7. Inspect coolant; drain, flush, and refill cooling system with recommended coolant; bleed air as required.	167–170
8. Inspect and replace water pump.	172–174
9. Inspect, test, and replace radiator, heater core, pressure cap, and coolant recovery system.	168, 169
10. Clean, inspect, test, and replace fan (both electrical and mechanical), fan clutch, fan shroud, air dams and cooling related temperature sensors.	173–176

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11. Inspect, test, and replace auxiliary oil coolers.	169, 170, 171
E. Fuel, Electrical, Ignition, and Exhaust Systems Inspection and Service (8 questions)	
1. Inspect, clean, or replace fuel and air induction system components, intake manifold, and gaskets.	709–714, 716
2. Inspect, service, or replace air filters, filter housings, and intake ductwork.	709–714, 716
3. Inspect turbocharger/supercharger; determine necessary action.	194–200
4. Test battery; charge as necessary.	410–414
5. Remove and replace starter.	428, 429
6. Inspect and replace positive crankcase ventilation (PCV) system components.	750, 751
7. Visually inspect and reinstall primary and secondary ignition system components; time distributor.	676–678, 684, 685, 687–693
8. Inspect, service, and replace exhaust manifold.	186–188, 191–193

Automatic Transmission/Transaxle (A2)

ASE Task List	Textbook Page No.
A. General Transmission/Transaxle Diagnosis (25 Questions)	
1. Mechanical/Hydraulic Systems (11 questions)	
1. Evaluate driver's concern and road test vehicle to verify mechanical/hydraulic system problems; determine necessary action.	160, 163, 178, 201, 202, 204, 205
2. Diagnose noise and vibration problems; determine necessary action.	1315
3. Diagnose unusual fluid usage, type, level, and condition problems; determine necessary action.	128, 129, 133, 135, 136
4. Perform pressure tests; determine necessary action.	1314, 1317
5. Perform stall tests; determine necessary action.	1314–1315
6. Perform torque converter clutch (lock-up converter) mechanical/hydraulic system tests; determine necessary action.	1315–1316, 1320
7. Diagnose mechanical and vacuum control systems; determine necessary action.	1316–1317, 1318
2. Electronic Systems (14 questions)	
1. Evaluate driver's concern and road test vehicle to verify electronic system problems; determine necessary action.	160, 163, 178, 201, 202, 204, 205
2. Perform pressure tests on transmissions equipped with electronic pressure control determine necessary action.	1314, 1317
3. Perform torque converter clutch (lock-up converter) electronic system tests; determine necessary action.	1315–1316, 1320
4. Diagnose electronic transmission control systems using appropriate test equipment; determine necessary action.	1316
5. Verify proper operation of starting and charging systems; check battery, connections, and vehicle grounds.	410–414, 437, 445–448
B. Transmission/Transaxle Maintenance and Adjustment (5 questions)	
1. Inspect, adjust, and replace manual valve shift linkage, transmission range sensor/ switch, and park/neutral position switch (inhibitor/neutral safety switch).	1319
2. Inspect, adjust, and replace cables or linkages for throttle valve (TV), kickdown, and accelerator pedal.	1319
3. Replace fluid and filter(s); verify proper fluid level.	128, 129, 133, 135, 136
C. In-Vehicle Transmission/Transaxle Repair (9 questions)	
1. Inspect, adjust, and replace vacuum modulator, valve, lines, and hoses.	1314, 1316, 1317, 1318

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2. Inspect, adjust, repair, and replace governor cover, seals, sleeve/bore, valve, weight, springs, retainers, and gear.	1314, 1319
3. Inspect and replace external seals and gaskets.	1319
4. Inspect and repair or replace extension housing, bushing, and driveshaft yoke.	1321–1325, 1329, 1330
5. Check condition of engine cooling system; inspect, test, and flush or replace transmission cooler, lines, and fittings.	1321, 1326, 1327
6. Inspect and replace speedometer/speed sensor drive gear, driven gear, and retainers.	1315
7. Inspect valve body mating surfaces, bores, valves, springs, sleeves, retainers, brackets, check balls, screens, spacers, and gaskets; replace as necessary.	1321–1323
8. Check and adjust valve body bolt torque.	1321–1323
9. Inspect servo bore, piston, seals, pin, spring, and retainers; repair or replace as necessary and adjust bands.	1324–1325
10. Inspect accumulator bore, piston, seals, spring, and retainers; repair or replace as necessary.	1324–1325
11. Inspect parking gear, inspect and replace parking pawl, shaft, spring, and retainer.	1325–1330
12. Inspect, test, adjust, repair, or replace electrical/electronic components and circuits including computer, solenoids, sensors, relays, terminals, connectors, switches, and harnesses.	1325–1330
13. Inspect, replace, and align power train mounts.	1319, 1328
D. Off-Vehicle Transmission/Transaxle Repair (11 questions)	
1. Removal, Disassembly, and Assembly (3 questions)	
1. Remove and replace transmission/transaxle; inspect engine core plugs, rear crankshaft seal, transmission dowel pins, and dowel pin holes.	1321–1322
2. Disassemble, clean, and inspect transmission case and sub-assemblies.	1321–1325, 1329, 1330
3. Assemble after repair.	1325–1330
4. Inspect converter flex (drive) plate, converter attaching bolts, converter pilot, converter pump drive surfaces, and crankshaft bore.	1321, 1328
2. Gear Train, Shafts, Bushings, Oil Pump, and Case (4 questions)	
1. Inspect, measure, and replace oil pump components.	1323
2. Check bearing preload; determine needed service.	1321–1330
3. Check end play; inspect, measure, and replace thrust washers and bearings as needed.	1321–1330
4. Inspect and replace shafts.	1321–1330
5. Inspect oil delivery circuit, including seal rings, ring grooves, sealing surface areas, feed pipes, orifices, and encapsulated check valves (balls).	
6. Inspect and replace bushings.	1321–1330
7. Inspect and measure planetary gear assembly; replace parts as necessary.	1321–1330
8. Inspect, repair, and replace case bores, passages, bushings, vents, mating surfaces, thread condition, and dowel pins.	1319, 1325–1330
9. Inspect, repair, or replace transaxle drive chains, sprockets, gears, bearings, and bushings.	1321–1330
10. Inspect, measure, repair, adjust, or replace transaxle final drive components.	1321–1330
3. Friction and Reaction Units (4 questions)	
1. Inspect hydraulic clutch pack assembly; replace parts as necessary.	1321–1330
2. Measure and adjust clutch pack clearance.	1321–1330
3. Air test the operation of clutch and servo assemblies.	1321–1330
4. Inspect one-way clutch assemblies; replace parts as necessary.	1321–1330
5. Inspect and replace bands and drums (housings/cylinders).	1321–1330

Manual Drive Train and Axles (A3)

ASE Task List	Textbook Page No.
A. Clutch Diagnosis and Repair (6 questions)	
1. Diagnose clutch noise, binding, slippage, pulsation, chatter, pedal feel/effort, and release problems; determine needed repairs.	1213–1216
2. Inspect, adjust, and replace clutch pedal linkage, cables, and automatic adjuster mechanisms, brackets, bushings, pivots, and springs.	1206–1210, 1212
3. Inspect, adjust, replace, and bleed hydraulic clutch slave and master cylinders, lines, and hoses.	1206–1208, 1212–1217
4. Inspect, adjust, and replace release (throw-out) bearing, lever, and pivot.	1213–1217
5. Inspect and replace clutch disc and pressure plate assembly.	1217–1218
6. Inspect and replace pilot bearing.	1213–1217
7. Inspect and measure flywheel and ring gear; repair or replace as necessary.	1210–1211, 1215, 1218
8. Inspect engine block, clutch (bell) housing, and transmission case mating surfaces; determine needed repairs.	1233
9. Measure flywheel-to-block runout and crankshaft end play; determine needed repairs.	1233
10. Measure clutch (bell) housing bore-to-crankshaft runout and face squareness; determine needed repairs.	1233
11. Inspect, replace, and align powertrain mounts.	1240, 1254, 1258, 1261
B. Transmission Diagnosis and Repair (6 questions)	
1. Diagnose transmission noise, hard shifting, jumping out of gear, and fluid leakage problems; determine needed repairs.	1233
2. Inspect, adjust, and replace transmission external shifter assembly, shift linkages, brackets, bushings/grommets, pivots, and levers.	1235–1237
3. Inspect and replace transmission gaskets, sealants, seals, and fasteners; inspect sealing surfaces.	1235–1237
4. Remove and replace transmission; inspect transmission.	1230, 1231
5. Disassemble and clean transmission components; reassemble transmission.	1231–1234, 1235–1237
6. Inspect, repair, and/or replace transmission shift cover and internal shift forks, bushings, levers, shafts, sleeves, detent mechanisms, interlocks, and springs.	1235–1237
7. Inspect and replace input (clutch) shaft, bearings, and retainers.	1206–1210, 1212
8. Inspect and replace main shaft, gears, thrust washers, bearings, and retainers/snap rings.	1231–1234, 1235–1237
9. Inspect and replace synchronizer hub, sleeve, keys (inserts), springs, and blocking (synchronizing) rings; measure blocking ring clearance.	1235–1237
10. Inspect and replace counter (cluster) gear, shaft, bearings, thrust washers, and retainers/snap rings.	1231–1234, 1235–1237
11. Inspect and replace reverse idler gear, shaft, bearings, thrust washers, and retainers/snap rings.	1231–1234, 1235–1237
12. Measure and adjust shaft, gear, and synchronizer end play.	1231–1234, 1235–1237
13. Measure and adjust bearing preload.	1235–1237
14. Inspect, repair, and replace extension housing and transmission case mating surfaces, bores, bushings, and vents.	1231–1234, 1235–1237
15. Inspect and replace speedometer drive gear, driven gear, and retainers.	1231–1237
16. Inspect, test, and replace transmission sensors and switches.	1231–1237
17. Inspect lubrication devices, check fluid level, and refill with proper fluid.	1234
C. Transaxle Diagnosis and Repair (8 questions)	
1. Diagnose transaxle noise, hard shifting, jumping out of gear, and fluid leakage problems; determine needed repairs.	1233
2. Inspect, adjust, and replace transaxle external shift assemblies, linkages, brackets, bushings/grommets, cables, pivots, and levers.	1235–1237

ASE Task List	Textbook Page No.
3. Inspect and replace transaxle gaskets, sealants, seals, and fasteners; inspect sealing surfaces.	1235–1237
4. Remove and replace transaxle; inspect, replace, and align transaxle mounts.	1230, 1231
5. Disassemble and clean transaxle components; reassemble transaxle.	1231–1234, 1235–1237
6. Inspect, repair, and/or replace transaxle shift cover and internal shift forks, levers, bushings, shafts, sleeves, detent mechanisms, interlocks, and springs.	1231–1234, 1235–1237
7. Inspect and replace input shaft, bearings, and retainers.	1231–1234, 1235–1237
8. Inspect and replace output shaft, gears, thrust washers, bearings, and retainers/snap rings.	1231–1234, 1235–1237
9. Inspect and replace synchronizer hub, sleeve, keys (inserts), springs, and blocking (synchronizing) rings; measure blocking ring clearance.	1231–1234, 1235–1237
10. Inspect and replace reverse idler gear, shaft, bearings, thrust washers, and retainers/snap rings.	1231–1234, 1235–1237
11. Inspect, repair, and replace transaxle case mating surfaces, bores, bushings, and vents.	1231–1234, 1235–1237
12. Inspect and replace speedometer drive gear, driven gear, and retainers.	1231–1237
13. Inspect, test, and replace transaxle sensors and switches.	1231–1237
14. Diagnose differential assembly noise and vibration problems; determine needed repairs.	1260, 1261, 1264
15. Remove and replace differential assembly.	1267–1271
16. Inspect, measure, adjust, and replace differential pinion gears (spiders), shaft, side gears, thrust washers, and case.	1259, 1260, 1264–1265
17. Inspect and replace differential side bearings.	1259, 1260, 1264–1265
18. Measure shaft end play/preload (shim/spacer selection procedure)	1269–1271
19. Inspect lubrication devices; check fluid level and refill with proper fluid.	1234
D. Drive (Half) Shaft and Universal Joint/Constant Velocity (CV) Joint Diagnosis and Repair (Front and Rear Wheel Drive) (6 questions)	
1. Diagnose shaft and universal/CV joint noise and vibration problems; determine needed repairs.	1243, 1252–1257
2. Inspect, service, and replace shafts, yokes, boots, and universal/CV joints.	1248, 1249–1252
3. Inspect, service, and replace shaft center support bearings.	1240
4. Check and correct propeller shaft balance.	1251–1252
5. Measure shaft runout.	1251–1252
6. Measure and adjust shaft angles.	1251–1252
E. Rear Wheel Drive Axle Diagnosis and Repair (7 questions)	
1. Ring and Pinion Gears (3 questions)	
1. Diagnose noise, vibration, and fluid leakage problems; determine needed repairs.	1260, 1261, 1264
2. Inspect and replace companion flange and pinion seal; measure companion flange runout.	1264
3. Measure ring gear runout; determine needed repairs.	1266, 1267
4. Inspect and replace ring and pinion gear set, collapsible spacers, sleeves (shims), and bearings.	1267–1271
5. Measure and adjust drive pinion depth.	1270–1271
6. Measure and adjust drive pinion bearing preload (collapsible spacer or shim type).	1269–1270
7. Measure and adjust differential (side) bearing preload, and ring and pinion backlash (threaded cup or shim type).	1270–1272
8. Perform ring and pinion tooth contact pattern checks; determine needed adjustments.	1267–1270
2. Differential Case Assembly (2 questions)	
1. Diagnose differential assembly noise and vibration problems; determine needed repairs.	1260, 1261, 1264
2. Remove and replace differential assembly.	1259–1263
3. Inspect, measure, adjust, and replace differential pinion gears (spiders), shaft, side gears, thrust washers, and case.	1259, 1260, 1264–1265

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4. Inspect and replace differential side bearings.	1259, 1260, 1264–1265
5. Measure differential case runout; determine needed repairs.	1270–1272
3. Limited Slip Differential (1 question)	
1. Diagnose limited slip differential noise, slippage, and chatter problems; determine needed repairs.	1261–1265
2. Inspect, flush, and refill with correct lubricant.	1271–1273
3. Inspect, adjust, and replace clutch (cone/plate) pack.	1261–1265
4. Axle Shafts (1 question)	
1. Diagnose rear axle shaft noise, vibration, and fluid leakage problems; determine needed repairs.	1248–1252
2. Inspect and replace rear axle shaft wheel studs.	878, 898
3. Remove, inspect, and replace rear axle shafts, seals, bearings, and retainers.	882
4. Measure rear axle flange runout and shaft end play; determine needed repairs.	1252
F. Four-Wheel Drive Component Diagnosis and Repair (7 questions)	
1. Diagnose four-wheel drive assembly noise, vibration, shifting, and steering problems; determine needed repairs.	1275, 1277, 1278, 1280, 1282
2. Inspect, adjust, and repair transfer case manual shifting mechanisms, bushings, mounts, levers, and brackets.	1283, 1284, 1287
3. Remove and replace transfer case.	1277, 1280, 1284
4. Disassemble and clean transfer case and components; reassemble transfer case.	1285–1287
5. Inspect and service transfer case and internal components; check lube level.	1283
6. Inspect, service, and replace front-drive (propeller) shafts and universal/CM joints.	1248, 1249–1252
7. Inspect, service, and replace front-drive axle knuckles and driving shafts.	1283–1284
8. Inspect, service, and replace front wheel bearings and locking hubs.	1283–1284
9. Check transfer case and front axle seals and remote vents.	1283
10. Diagnose, test, adjust, and replace electrical/electronic components of 4WD systems.	1274–1277, 1280, 1281

Suspension and Steering (A4)

ASE Task List	Textbook Page No.
A. Steering Systems Diagnosis and Repair (10 Questions)	
1. Steering Columns and Manual Steering Gears (3 questions)	
1. Diagnose steering column noises and steering effort concerns (including manual and electronic tilt and telescoping mechanisms); determine needed repairs.	1118
2. Diagnose manual steering gear (non-rack and pinion type) noises, binding, vibration, freeplay, steering effort, and lubricant leakage concerns; determine needed repairs.	1159
3. Diagnose manual rack and pinion steering gear noises, binding, vibration, freeplay, steering effort, and lubricant leakage concerns; determine needed repairs.	1159
4. Inspect and replace steering column, steering shaft U-joint(s), flexible coupling(s), collapsible columns, steering wheels (includes steering wheels with air bags and/or other steering wheel mounted controls and components).	1130
5. Remove and replace manual steering gear (non-rack and pinion type) (includes vehicles equipped with air bags and/or other steering wheel mounted controls and components).	1130
6. Adjust manual steering gear (non-rack and pinion type) worm bearing preload and sector lash.	1125–1126

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7. Remove and replace manual rack and pinion steering gear (includes vehicles equipped with air bags and/or other steering wheel mounted controls and components).	1130
8. Adjust manual rack and pinion steering gear.	1130
9. Inspect and replace manual rack and pinion steering gear inner tie rod ends (sockets) and bellows boots.	1130
10. Inspect and replace manual rack and pinion steering gear mounting bushings and brackets.	1130
2. Power-Assisted Steering Units (4 questions)	
1. Diagnose power steering gear (non-rack and pinion type) noises, binding, vibration, freeplay, steering effort, steering pull (lead), and fluid leakage concerns; determine needed repairs.	1159
2. Diagnose power rack and pinion steering gear noises, binding, vibration, freeplay, steering effort, steering pull (lead), and fluid leakage concerns; determine needed repairs.	1159
3. Inspect power steering fluid level and condition; adjust level in accordance with vehicle manufacturers' recommendations.	1160, 1161
4. Inspect, adjust, align, and replace power steering pump belt(s) and tensioners.	1159, 1160
5. Diagnose power steering pump noises, vibration, and fluid leakage; determine needed repairs.	1160, 1161
6. Remove and replace power steering pump; inspect pump mounting and attaching brackets.	1163
7. Inspect and replace power steering pump seals, gaskets, reservoir, and valves.	1163
8. Inspect and replace power steering pump pulley.	1163–1164
9. Perform power steering system pressure and flow tests; determine needed repairs.	1163–1165
10. Inspect and replace power steering hoses, fittings, O-rings, and coolers.	1161
11. Remove and replace power steering gear (non-rack and pinion type) (includes vehicles equipped with air bags and/or other steering wheel mounted controls and components).	1130
12. Remove and replace power rack and pinion steering gear; inspect and replace mounting bushings and brackets (includes vehicles equipped with air bags and/or other steering wheel mounted controls and components).	1130
13. Adjust power steering gear (non-rack and pinion type) worm bearing preload and sector lash.	1125–1126
14. Inspect and replace power steering gear (non-rack and pinion type) seals and gaskets.	1163
15. Adjust power rack and pinion steering gear.	—
16. Inspect and replace power rack and pinion steering gear inner tie rod ends (sockets), and bellows boots.	1130
17. Flush, fill, and bleed power steering system.	1160, 1161
18. Diagnose, inspect, repair, or replace components of variable-assist steering systems.	1165
19. Diagnose, inspect, repair, or replace components of power steering idle speed compensation systems.	1154
3. Steering Linkage (3 questions)	
1. Inspect and adjust (where applicable) front and rear steering linkage geometry (including parallelism and vehicle ride height).	1130
2. Inspect and replace pitman arm.	1130
3. Inspect and replace center link (relay rod/drag link/intermediate rod).	1130
4. Inspect, adjust (where applicable), and replace idler arm and mountings.	1130
5. Inspect, replace, and adjust tie rods, tie rod sleeves, clamps, and tie rod ends (sockets).	1130
6. Inspect and replace steering linkage damper.	1130
B. Suspension Systems Diagnosis and Repair (13 Questions)	
1. Front Suspensions (6 questions)	
1. Diagnose front suspension system noises, body sway/roll, and ride height concerns; determine needed repairs.	1074, 1075, 1076
2. Inspect and replace upper and lower control arms, bushings, shafts, rebound, and jounce bumpers.	1074
3. Inspect, adjust, and replace strut rods/radius arms (compression/tension), and bushings.	1076, 1088

ASE Task List	Textbook Page No.
4. Inspect and replace upper and lower ball joints (with or without wear indicators).	1079
5. Inspect and replace kingpins, bearings, and bushings.	1079
6. Inspect and replace steering knuckle/spindle assemblies and steering arms.	1079
7. Inspect and replace front suspension system coil springs and spring insulators (silencers).	1074, 1075, 1076
8. Inspect and replace front suspension system leaf spring(s), leaf spring insulators (silencers), shackles, brackets, bushings, and mounts.	1074, 1089
9. Inspect, replace, and adjust front suspension system torsion bars and mounts.	1080, 1091
10. Inspect and replace stabilizer bar (sway bar) bushings, brackets, and links.	1130
11. Inspect and replace strut cartridge or assembly.	1087
12. Inspect and replace strut bearing and mount.	1087
2. Rear Suspensions (5 questions)	
1. Diagnose rear suspension system noises, body sway/roll, and ride height concerns; determine needed repairs.	1095, 1101
2. Inspect and replace rear suspension system coil springs and spring insulators (silencers).	1097, 1101
3. Inspect and replace rear suspension system lateral links/arms (track bars), control (trailing) arms, stabilizer bars (sway bars), bushings, and mounts.	1096, 1098, 1099
4. Inspect and replace rear suspension system leaf spring(s), leaf spring insulators (silencers), shackles, brackets, bushings, and mounts.	1095, 1096, 1098, 1099
5. Inspect and replace rear strut cartridge or assembly, and upper mount assembly.	1087
6. Inspect non-independent rear axle assembly for bending, warpage, and misalignment.	1097, 1101
7. Inspect and replace rear ball joints and tie rod/toe link assemblies.	1130
8. Inspect and replace knuckle/spindle assembly.	1130
3. Miscellaneous Service (2 questions)	
1. Inspect and replace shock absorbers, mounts, and bushings.	1095, 1100, 1101
2. Inspect and replace air shock absorbers, lines, and fittings.	1095, 1100, 1101
3. Diagnose and service front and/or rear wheel bearings.	868, 869, 871, 872, 873
4. Diagnose, inspect, adjust, repair, or replace components of electronically controlled suspension systems (including primary and supplemental air suspension and ride control systems).	1109, 1114
5. Inspect and repair front and/or rear cradle (crossmember/subframe) mountings, bushings, brackets, and bolts.	1096, 1098, 1100
C. Wheel Alignment Diagnosis, Adjustment, and Repair (12 questions)	
1. Diagnose vehicle wander, drift, pull, hard steering, bump steer (toe curve), memory steer, torque steer, and steering return concerns; determine needed repairs.	1165, 1166, 1167, 1182, 1183
2. Measure vehicle ride height; determine needed repairs.	1180
3. Check and adjust front and rear wheel camber on suspension systems with a camber adjustment.	1193, 1196, 1198
4. Check front and rear wheel camber on non-adjustable suspension systems; determine needed repairs.	1193, 1196, 1198
5. Check and adjust caster on suspension systems with a caster adjustment.	1193, 1196
6. Check caster on non-adjustable suspension systems; determine needed repairs.	1193, 1196
7. Check and adjust front wheel toe.	1193, 1196, 1198
8. Center steering wheel.	1194, 1195
9. Check toe-out-on-turns (turning radius/angle); determine needed repairs.	1186
10. Check SAI/KPI (steering axis inclination/king pin inclination); determine needed repairs.	1184, 1185, 1186, 1187, 1188, 1192

ASE Task List	Textbook Page No.
11. Check included angle; determine needed repairs.	1184, 1185, 1186, 1187, 1188, 1192
12. Check rear wheel toe; determine needed repairs or adjustments.	1186, 1189, 1190, 1191, 1193, 1202
13. Check rear wheel thrust angle; determine needed repairs or adjustments.	1184, 1187, 1189, 1190, 1199
14. Check front wheel setback; determine needed repairs or adjustments.	1201
15. Check front cradle (crossmember/subframe) alignment; determine needed repairs or adjustments.	1186, 1201
D. Wheel and Tire Diagnosis and Repair (5 questions)	
1. Diagnose tire wear patterns; determine needed repairs.	1015, 1016, 1024, 1037
2. Check tire condition, tread pattern, and size; check and adjust air pressure.	1029, 1030, 1033, 1034, 1035, 1036, 1038
3. Diagnose wheel/tire vibration, shimmy, and noise concerns; determine needed repairs.	1036, 1043, 1044, 1050
4. Rotate tires/wheels and torque fasteners according to manufacturers' recommendations.	1028, 1038, 1039, 1040, 1041, 1042, 1043
5. Measure wheel, tire, axle flange, and hub runout (radial and lateral); determine needed repairs.	1043, 1044
6. Diagnose tire pull (lead) problems; determine corrective actions.	1023, 1036
7. Dismount and mount tire on wheel.	1038, 1039, 1042, 1043
8. Balance wheel and tire assembly (static and/or dynamic).	1044, 1045

Brakes (A5)

ASE Task List	Textbook Page No.
A. Hydraulic System Diagnosis and Repair (14 questions)	
1. Master Cylinder (Non-ABS) (3 questions)	
1. Diagnose poor stopping or dragging caused by problems in the master cylinder; determine needed repairs.	811, 825–839
2. Diagnose poor stopping, dragging, high or low pedal, or hard pedal caused by problems in the step bore master cylinder and internal valves (e.g., volume control devices, quick take-up valve, fast-fill valve, pressure regulating valve); determine needed repairs.	825, 827–839, 912, 934, 935
3. Measure and adjust master cylinder pushrod length.	981, 984, 985
4. Check master cylinder for defects by depressing brake pedal; determine needed repairs.	830–837, 911, 923, 925
5. Diagnose the cause of master cylinder external fluid leakage.	830–837, 911, 923, 925
6. Remove master cylinder from vehicle; install master cylinder; test operation of the hydraulic system.	838–839
7. Bench bleed (check for function and remove air) all non-ABS master cylinders.	838–839
2. Fluids, Lines, and Hoses (3 questions)	
1. Diagnose poor stopping, pulling, or dragging caused by problems in the brake fluid, lines, and hoses; determine needed repairs.	825, 827–839, 912, 934, 935
2. Inspect brake lines and fittings for leaks, dents, kinks, rust, cracks, or wear; tighten loose fittings and supports.	849–859
3. Inspect flexible brake hoses for leaks, kinks, cracks, bulging, or wear; tighten loose fittings and supports.	849–859
4. Fabricate and/or replace brake lines (double flare and ISO types), hoses, fittings, and supports.	849–859
5. Select, handle, store, and install proper brake fluids (including silicone fluids).	849–851

ASE Task List	Textbook Page No.
6. Inspect brake lines and hoses for proper routing.	849–859
3. Valves and Switches (Non-ABS) (4 questions)	
1. Diagnose poor stopping, pulling, or dragging caused by problems in the hydraulic system valve(s); determine needed repairs.	811, 825–839
2. Inspect, test, and replace metering, proportioning, pressure differential, and combination valves.	845–847
3. Inspect, test, replace, and adjust load or height sensing-type proportioning valve(s).	842–846
4. Inspect, test, and replace brake warning light, switch, and wiring.	840, 847
4. Bleeding, Flushing, and Leak Testing (Non-ABS) (4 questions)	
1. Bleed (manual, pressure, vacuum, or surge method) and/or flush hydraulic system.	860–867
2. Pressure test brake hydraulic system.	860–867
B. Drum Brake Diagnosis and Repair (6 questions)	
1. Diagnose poor stopping, pulling, or dragging caused by drum brake hydraulic problems; determine needed repairs.	897, 898, 901, 903, 905–908
2. Diagnose poor stopping, noise, pulling, grabbing, dragging, or pedal pulsation caused by drum brake mechanical problems; determine needed repairs.	897, 898, 901, 903, 905–908
3. Remove, clean, inspect, and measure brake drums; follow manufacturers' recommendations in determining need to machine or replace.	898–908
4. Machine drums according to manufacturers' procedures and specifications.	950–977
5. Using proper safety procedures, remove, clean, and inspect brake shoes/linings, springs, pins, self-adjusters, levers, clips, brake backing (support) plates and other related brake hardware; determine needed repairs.	907, 908
6. Lubricate brake shoe support pads on backing (support) plate, self-adjuster mechanisms, and other brake hardware.	907, 908
7. Install brake shoes and related hardware.	907, 908
8. Pre-adjust brake shoes and parking brake before installing brake drums or drum/hub assemblies and wheel bearings.	908, 938–949
9. Reinstall wheel, torque lug nuts, and make final checks and adjustments.	908, 936
C. Disc Brake Diagnosis and Repair (13 questions)	
1. Diagnose poor stopping, pulling, or dragging caused by disc brake hydraulic problems; determine needed repairs.	923, 925, 927, 929, 931, 934, 935
2. Diagnose poor stopping, noise, pulling, grabbing, dragging, pedal pulsation or pedal travel caused by disc brake mechanical problems; determine needed repairs.	923, 925, 927, 929, 931, 934, 935
3. Retract integral parking brake caliper piston(s) according to manufacturers' recommendations.	946, 938–949
4. Remove caliper assembly from mountings; clean and inspect for leaks and damage to caliper housing.	924–933
5. Clean, inspect, and measure caliper mountings and slides for wear and damage.	930–931
6. Remove, clean, and inspect pads and retaining hardware; determine needed repairs, adjustments, and replacements.	924–933
7. Disassemble and clean caliper assembly; inspect parts for wear, rust, scoring, and damage; replace all seals, boots, and any damaged or worn parts.	924–933
8. Reassemble caliper.	924–933
9. Clean, inspect, and measure rotor with a dial indicator and a micrometer; follow manufacturers' recommendations in determining need to machine or replace.	957, 958
10. Remove and replace rotor.	873, 873
11. Machine rotor, using on-car or off-car method, according to manufacturers' procedures and specifications.	959, 966, 967
12. Install pads, calipers, and related attaching hardware; bleed system.	924–933
13. Adjust calipers with integrated parking brakes according to manufacturers' recommendations.	946, 938–949
14. Fill master cylinder to proper level with recommended fluid; inspect caliper for leaks.	849–851

ASE Task List	Textbook Page No.
15. Reinstall wheel, torque lug nuts, and make final checks and adjustments.	908, 936
D. Power Assist Units Diagnosis and Repair (4 questions)	
1. Test pedal free travel with and without engine running to check power booster operation.	978–988
2. Check vacuum supply (manifold or auxiliary pump) to vacuum-type power booster.	978–988
3. Inspect the vacuum-type power booster unit for vacuum leaks and proper operation; inspect the check valve for proper operation; repair, adjust, or replace parts as necessary.	978–988
4. Inspect and test hydro-boost system and accumulator for leaks and proper operation; repair, adjust, or replace parts as necessary.	985–988
E. Miscellaneous Systems (Wheel Bearings, Parking Brakes, Electrical, Etc.) Diagnosis and Repair (7 questions)	
1. Diagnose wheel bearing noises, wheel shimmy and vibration problems; determine needed repairs.	868–882
2. Remove, clean, inspect, repack wheel bearings, or replace wheel bearings and races; replace seals; adjust wheel bearings according to manufacturers' specifications.	868–882
3. Check parking brake system; inspect cables and parts for wear, rusting, and corrosion; clean or replace parts as necessary; lubricate assembly.	938–949
4. Adjust parking brake assembly; check operation.	938–949
5. Test the service and parking brake indicator and warning light(s), switch(es), and wiring.	938–949
6. Test, adjust, repair, or replace brake stop light switch, lamps, and related circuits.	840, 847
F. Anti-Lock Brake System (ABS) Diagnosis and Repair (11 questions)	
1. Follow accepted service and safety precautions when inspecting, testing, and servicing of ABS hydraulic, electrical, and mechanical components.	990–1002, 1003–1013
2. Diagnose poor stopping, wheel lock up, pedal feel and travel, pedal pulsation, and noise problems caused by the ABS; determined needed repairs.	996, 997, 998
3. Observe ABS warning light(s) at startup and during road test; determine if further diagnosis is needed.	995, 996, 998
4. Diagnose ABS electronic control(s), components, and circuits using self diagnosis and/or recommended test equipment; determine needed repairs.	1004–1013
5. Depressurize integral (high pressure) components of the ABS following manufacturers' recommended safety procedures.	998, 1013
6. Fill the ABS master cylinder with recommended fluid to proper level following manufacturers' procedures; inspect system for leaks.	997, 1012
7. Bleed the ABS hydraulic circuits following manufacturers' procedures.	1007, 1012, 1013
8. Perform a fluid pressure (hydraulic boost) diagnosis on integral (high pressure) ABS; determine needed repairs.	997–1002
9. Remove and install ABS components following manufacturers' procedures and specifications; observe proper placement of components and routing of wiring harness.	1004–1013
10. Diagnose, service, and adjust ABS speed sensors and circuits following manufacturers' recommended procedures (includes voltage output, resistance, shorts to voltage/ground, and frequency data).	1004–1013
11. Diagnose ABS braking problems caused by vehicle modifications (tire size, curb height, final drive ratio, etc.) and other vehicle mechanical and electrical/electronic modifications (communication, security, and radio, etc.).	1004–1013
12. Repair wiring harness and connectors following manufacturers' procedures.	360–369

Electrical/Electronic Systems (A6)

ASE Task List	Textbook Page No
A. General Electrical/Electronic System Diagnosis (13 questions)	
1. Check electrical circuits with a test light; determine needed repairs.	340, 341, 365, 366
2. Check voltages and voltage drops in electrical/electronic circuits with a voltmeter; interpret readings and determine needed repairs.	327, 330–337, 448, 449, 503, 522
3. Check current flow in electrical/electronic circuits and components with an ammeter; interpret readings and determine needed repairs.	320–322
4. Check continuity and resistances in electrical/electronic circuits and components with an ohmmeter; interpret readings and determine needed repairs.	321, 354, 356
5. Check electronic circuit waveforms using an oscilloscope; interpret readings and determine needed repairs.	351–354
6. Use scan-tool data to diagnose electronic systems; interpret readings and determine needed repairs.	446, 482, 486, 763–777
7. Check electrical/electronic circuits with jumper wires; determine needed repairs.	432, 448, 503
8. Find shorts, grounds, opens, and resistance problems in electrical/electronic circuits; determine needed repairs.	325–327, 378–380, 464
9. Measure and diagnose the cause(s) of abnormal key-off battery drain (parasitic draw); determine needed repairs.	408–415
10. Inspect, test, and replace fusible links, circuit breakers, fuses, diodes, and other current limiting devices.	325, 360, 364, 365, 367–369
11. Read and interpret electrical schematic diagrams and symbols.	361, 370, 371–378, 379, 381, 384, 404
B. Battery Diagnosis and Service (4 questions)	
1. Perform battery state-of-charge test; determine needed service.	410–414
2. Perform battery capacity (load, high-rate discharge) test; determine needed service.	411–414
3. Maintain or restore electronic memory functions.	414
4. Inspect, clean, fill, or replace battery.	404–417
5. Perform slow/fast battery charge in accordance with manufacturer's recommendations.	404–417
6. Inspect, clean, and repair or replace battery cables, connectors, clamps, and holddowns.	404–417
7. Jump start a vehicle with jumper cables and a booster battery or auxiliary power supply.	404–417
C. Starting System Diagnosis and Repair (5 questions)	
1. Perform starter current draw test; determine needed repairs.	418, 426, 428
2. Perform starter circuit voltage drop tests; determine needed repairs.	426–428
3. Inspect, test, and repair or replace switches, connectors, and wires of starter control circuits.	433
4. Inspect, test, and replace starter relays and solenoids.	433
5. Remove and replace starter.	428, 429
6. Differentiate between electrical and engine mechanical problems that cause a slow crank or no crank condition.	433
D. Charging System Diagnosis and Repair (5 questions)	
NOTE: In 1996, SAE J1930 terminology was adopted to standardize component identification. This standard adopted the name "generator" to refer to the component commonly known as an "alternator." Both terms are used interchangeable in the ASE tests.	
1. Diagnose charging system problems that cause an undercharge, a no-charge, or an overcharge condition.	437–456
2. Inspect, adjust, and replace generator (alternator) drive belts, pulleys, and tensioners.	451, 452
3. Perform charging system output test; determine needed repairs.	437, 445–448
4. Perform generator (alternator) output test; determine needed repairs.	437, 445–448
5. Inspect and test voltage regulator/field control circuit; determine needed repairs.	449, 450, 451, 453

ASE Task List	Textbook Page No.
6. Perform charging circuit voltage drop tests; determine needed repairs.	448
7. Inspect, repair, or replace connectors and wires of charging circuits.	457–458
8. Remove, inspect, and replace generator (alternator).	451, 452
E. Lighting Systems Diagnosis and Repair (6 questions)	
1. Headlights, Parking Lights, Taillights, Dash Lights, and Courtesy Lights (3 questions)	
1. Diagnose the cause of brighter than normal, intermittent, dim, continuous, or no operation of headlights.	429, 468–471
2. Inspect, test, and repair daytime running light systems.	469, 470
3. Inspect, replace, and aim headlights/bulbs, and auxiliary lights (fog lights/driving lights).	465, 466, 475, 476
4. Inspect, test, and repair or replace headlight and dimmer switches, relays, control units, sensors, sockets, connectors, and wires of headlight circuits.	464–468
5. Diagnose the cause of intermittent, slow, or no operation of retractable headlight assembly.	246–248
6. Inspect, test, and repair or replace motors, switches, relays, connectors, wires, and controllers of retractable headlight assembly circuits.	246–248
7. Diagnose the cause of brighter than normal, intermittent, dim, continuous or no operation of parking lights, taillights, and/or auxiliary lights (fog lights/driving lights).	468–471
8. Inspect, test, and repair or replace switches, relays, bulbs, sockets, connectors, wires, and controllers of parking light, taillight circuits, and auxiliary light circuits (fog lights/driving lights).	478–496
9. Diagnose the cause of intermittent, dim, no lights, continuing operation or no brightness control of instrument lighting circuits.	468–471
10. Inspect, test, and repair or replace switches, relays, bulbs, sockets, connectors, wires, controllers, and printed circuit boards of instrument lighting circuits.	464, 465, 475
11. Diagnose the cause of intermittent, dim, continuous or no operation of courtesy lights (dome, map, vanity, cargo, trunk, and hood light).	475
12. Inspect, test, and repair or replace switches, relays, bulbs, sockets, connectors, wires, and controllers of courtesy light (dome, map, vanity, cargo, trunk, and hood light) circuits.	464
2. Stoplights, Turn Signals, Hazard Lights, and Back-Up Lights (3 questions)	
1. Diagnose the cause of intermittent, dim, continuous, or no operation of stoplights (brake lights).	475
2. Inspect, test, adjust, and repair or replace switch, bulbs, sockets, connectors, wires, and controllers of stoplight (brake light) circuits.	469
3. Diagnose the cause of no turn signal and/or hazard lights, or lights with no flash on one or both sides.	472–475
4. Inspect, test, and repair or replace switches, flasher units, bulbs, sockets, connectors, wires, and controllers of turn signal and hazard light circuits.	472–475
5. Diagnose the cause of intermittent, dim, improper, continuous or no operation of back-up lights.	475
6. Inspect, test, and repair or replace switch, bulbs, sockets, connectors, wires, and controllers of back-up light circuits.	469
7. Inspect, test, repair, or replace trailer wiring harness and connector.	361, 508
F. Gauges, Warning Devices, and Driver Information Systems Diagnosis and Repair (6 questions)	
NOTE: Diagnosing causes of abnormal charging system gauge readings or warning lights limited to dash units and their electrical connections; other causes of abnormal charging system indications are covered in category D.	
1. Diagnose the cause of intermittent, high, low, or no gauge readings.	478–496
2. Inspect, test, and repair or replace gauges, gauge sending units, connectors, wires, controllers, and printed circuit boards of gauge circuits.	478–496
3. Diagnose the cause(s) of intermittent, high, low, or no readings on electronic instrument clusters.	478–496
4. Inspect, test, repair, or replace sensors, sending units, connectors, wires, and controllers of electronic instrument circuits.	478–496
5. Diagnose the cause of constant, intermittent, or no operation of warning light, indicator lights, and other driver information systems.	478–496

ASE Task List	Textbook Page No.
6. Inspect, test, and repair or replace bulbs, sockets, connectors, wires, electronic components, and controllers of warning light, indicator light and driver information system circuits.	478–496
7. Diagnose the cause of constant, intermittent, or no operation of audible warning devices.	478–496
8. Inspect, test, and repair or replace switches, relays, sensors, timers, electronic components, controllers, printed circuits, connectors, and wires of audible warning device circuits.	478–496
G. Horn and Wiper/Washer Diagnosis and Repair (3 questions)	
1. Diagnose the cause of constant, intermittent, or no operation of horn(s).	497, 498
2. Inspect, test, and repair or replace horn(s), horn relay, horn button (switch), connectors, wires, and controllers of horn circuits.	498–504
3. Diagnose the cause of wiper problems including constant operation, intermittent operation, poor speed control, no parking, or no operation of wiper.	498–504
4. Inspect, test, and replace intermittent (pulsing) wiper controls.	498–504
5. Inspect, test, and replace wiper motor, resistors, switches, relays, controllers, connections, and wires of wiper circuits.	498–504
6. Diagnose the cause of constant, intermittent, or no operation of window washer.	498–504
7. Inspect, test, and repair or replace washer motor, pump assembly, relays, switches, connectors, and wires of washer circuits.	498–504
H. Accessories Diagnosis and Repair (8 questions)	
1. Body (4 questions)	
1. Diagnose the cause of slow, intermittent, or no operation of power windows.	507–510, 512, 513–519
2. Inspect, test, and repair or replace regulators (linkages), switches, controllers, relays, motors, connectors, and wires of power window circuits.	512
3. Diagnose the cause of slow, intermittent, or no operation of power seat and driver memory controls.	512
4. Inspect, test, adjust, and repair or replace power seat gear box, cables, switches, controllers, sensors, relays, solenoids, motors, connectors, and wires of power seat circuits and driver memory controls.	507–510, 513–519
5. Diagnose the cause of poor, intermittent, or no operation of rear window defogger.	510–512
6. Inspect, test, and repair or replace switches, relays, timers, controllers, window grid, connectors, and wires of rear window defogger circuits.	510–512
7. Diagnose the cause of poor, intermittent, or no operation of electric door lock and hatch/trunk lock.	520–526
8. Inspect, test, and repair or replace switches, relays, controllers, actuators/solenoids, connectors, and wires of electric door lock/hatch/trunk circuits.	520–526
9. Diagnose the cause of poor, intermittent, or no operation of keyless and remote lock/unlock devices.	520–526
10. Inspect, test, and repair or replace components, connectors, controllers, and wires of keyless and remote lock/unlock device circuits; reprogram system.	520–526
11. Diagnose the cause of slow, intermittent, or no operation of electrical sunroof and convertible/retractable top.	377
12. Inspect, test, and repair ore replace motors, switches, controllers, relays, connectors, and wires of electrically-operated sunroof and convertible/retractable top circuits.	377
13. Diagnose the cause of poor, intermittent, or no operation of electrically operated/heated mirror.	510–512
14. Inspect, test, and repair or replace motors, heated mirror grids, switches, controllers, relays, connectors, and wires of electrically operated/heated mirror circuits.	510–512
2. Miscellaneous (4 questions)	
1. Diagnose the cause of poor sound quality, noisy, erratic, intermittent, or no operation of the audio system, remove and reinstall audio system component (unit).	414–416, 536–545
2. Inspect, test, and repair or replace speakers, amplifiers, remote controls, antennas, leads, grounds, connectors, and wires of sound system circuits.	414–416, 536–545
3. Inspect, test, and repair or replace switches, relays, motor, connectors, and wires of power antenna circuits.	414–416, 536–545
4. Inspect, test, and replace noise suppression components.	414–416, 536–545

ASE Task List	Textbook Page No.
5. Inspect, test, and repair or replace case, fuse, connectors, relays, and wires of cigar lighter/power outlet circuits.	326, 363
6. Inspect, test, and repair or replace clock, connectors, and wires of clock circuits.	363, 416
7. Diagnose the cause of unregulated, intermittent, or no operation of cruise control.	508, 509, 510, 523
8. Inspect, test, adjust, and repair or replace speedometer cables, regulator, servo, hoses, switches, relays, electronic controller, speed sensors, connectors, and wires of cruise control circuits.	508, 509, 510, 523
9. Diagnose the cause of false, intermittent, or no operation of anti-theft system.	507, 521, 522, 523, 524
10. Inspect, test, and repair or replace components, controllers, switches, relays, connectors, sensors, and wires of anti-theft system circuits.	507, 521, 522, 523, 524
11. Diagnose the causes(s) of the supplemental restraint/airbag warning light staying on or flashing.	526–535
12. Disarm and enable the airbag system for vehicle service following manufacturers' recommended procedures.	526–535
13. Inspect, test, repair, or replace the airbag(s), controller, sensors, connectors, and wires of the airbag system circuit(s).	526–535
14. Diagnose the cause of improper operation of motorized seat belts.	507–510, 513–519
15. Inspect, test, and repair or replace motors, solenoids, switches, tracks, controllers, connectors, and wires of motorized seat belts.	507–510, 513–519

Heating and Air Conditioning (A7)

ASE Task List	Textbook Page No.
A. A/C System Diagnosis and Repair (12 questions)	
1. Diagnose the cause of unusual operating noises of the A/C system; determine needed repairs.	110, 116, 160, 163, 178, 201, 202, 204, 205
2. Identify system type and conduct performance test on the A/C system; determine needed repairs.	575, 576–578
3. Diagnose A/C system problems indicated by refrigerant flow past the sight glass (for systems using a sight glass); determine needed repairs.	575, 576–578
4. Diagnose A/C system problems indicated by pressure gauge readings; determine needed repairs.	577, 581, 582
5. Diagnose A/C system problems indicated by sight, sound, smell, and touch procedures; determine needed repairs.	575, 578, 580
6. Leak test A/C system; determine needed repairs.	578–580
7. Identify, and recover A/C system refrigerant.	581–587
8. Evacuate A/C system.	581–587
9. Clean A/C system components and hoses.	581–587
10. Charge A/C system with refrigerant (liquid or vapor).	581–587
11. Identify lubricant type; inspect level in A/C system.	581–587
B. Refrigeration System Component Diagnosis and Repair (10 questions)	
1. Compressor and Clutch (5 questions)	
1. Diagnose A/C system problems that cause the protection devices (pressure, thermal, and control modules) to interrupt system operation; determine needed repairs.	575–580
2. Inspect, test, and replace A/C system pressure and thermal protection devices.	575–580
3. Inspect, adjust, and replace A/C compressor drive belts, pulleys, and tensioners.	586
4. Inspect, test, service, and replace A/C compressor clutch components or assembly.	586, 587
5. Identify required lubricant type; inspect and correct level in A/C compressor.	586, 587
6. Inspect, test, service, or replace A/C compressor.	586, 587
7. Inspect, repair, or replace A/C compressor mountings.	586, 587

ASE Task List	Textbook Page No.
2. Evaporator, Condenser, and Related Components (5 questions)	
1. Inspect, repair, or replace A/C system mufflers, hoses, lines, filters, fittings, and seals.	586
2. Inspect A/C condenser for air flow restrictions.	587
3. Inspect, test, and replace A/C system condenser and mountings.	587
4. Inspect and replace receiver/drier or accumulator/drier.	585–588
5. Inspect, test, and replace expansion valve(s).	560, 564
6. Inspect and replace orifice tube(s).	560, 564, 577, 578, 579, 580
7. Inspect, test, or replace evaporator(s).	587
8. Inspect, clean, and repair evaporator housing, and water drain.	587
9. Inspect, test, and replace evaporator pressure/temperature control systems and devices.	575, 576, 577, 578, 587
10. Identify, inspect, and replace A/C system service valves (gauge connections).	575, 576, 577, 583
11. Inspect and replace A/C system high pressure relief device.	583
C. Heating and Engine Cooling Systems Diagnosis and Repair (5 questions)	
1. Diagnose the cause of temperature control problems in the heater/ventilation system; determine needed repairs.	575–580
2. Diagnose window fogging problems; determine needed repairs.	575–580
3. Perform cooling system tests; determine needed repairs.	160–172, 177
4. Inspect and replace engine cooling and heater system hoses.	160–172, 177
5. Inspect, test, and replace radiator, pressure cap, coolant recovery system, and water pump.	171
6. Inspect, test, and replace thermostat, bypass, and housing.	164–167
7. Identify, inspect, recover coolant; flush, and refill system with proper coolant.	167–170
8. Inspect, test, and replace fan, (both electrical and mechanical), fan clutch, fan belts, fan shroud, and air dams.	173–176
9. Inspect, test, and replace heater coolant control valve (manual, vacuum, and electrical types).	574, 575
10. Inspect, flush, and replace heater core.	574, 575, 581, 587
D. Operating Systems and Related Controls Diagnosis and Repair (16 questions)	
1. Electrical (8 questions)	
1. Diagnose the cause of failures in the electrical control system of heating, ventilating, and A/C systems; determine needed repairs.	575–580
2. Inspect, test, repair, and replace A/C-heater blower motors, resistors, switches, relay/modules, wiring, and protection devices.	497, 504, 505, 506
3. Inspect, test, repair, and replace A/C compressor clutch coil, relay/modules, wiring, sensors, switches, diodes, and protection devices.	397, 563, 564, 565, 569, 575, 577, 585, 586
4. Inspect, test, repair, replace, and adjust A/C-related engine control systems.	575–580
5. Inspect, test, repair, replace, and adjust load sensitive A/C compressor cut-off systems.	575–580
6. Inspect, test, repair, and replace engine cooling/condenser fan motors, relays/modules, switches, sensors, wiring, and protection devices.	574, 575
7. Inspect, test, adjust, repair and replace electric actuator motors, relays/modules, switches, sensors, wiring, and protection devices.	567–571
8. Inspect, test, service, or replace heating, ventilating, and A/C control panel assemblies.	567–571
2. Vacuum/Mechanical (4 questions)	
1. Diagnose the cause of failures in the vacuum and mechanical switches and controls of the heating, ventilating, and A/C systems; determine needed repairs.	575–580
2. Inspect, test, service, or replace heating, ventilating, and A/C control panel assemblies.	575–580
3. Inspect, test, adjust, and replace heating, ventilating, and A/C control cables and linkages.	575–580
4. Inspect, test, and replace heating, ventilating, and A/C vacuum actuators (diaphragms/motors) and hoses.	575–580

ASE Task List	Textbook Page No.
5. Identify, inspect, test, and replace heating, ventilating, and A/C vacuum reservoir, check valve, and restrictors.	575–580
6. Inspect, test, adjust, repair, or replace heating, ventilating, and A/C ducts, doors, and outlets.	575–580
3. Automatic and Semi-Automatic Heating, Ventilating, and A/C Systems (4 questions)	
1. Diagnose temperature control system problems; determine needed repairs.	567–571
2. Diagnose blower system problems; determine needed repairs.	567–571
3. Diagnose air distribution system problems; determine needed repairs.	567–571
4. Diagnose compressor clutch control system; determine needed repairs.	567–571
5. Inspect, test, adjust, or replace climate control temperature and sun-load sensors.	567–571
6. Inspect, test, adjust, and replace temperature blend door actuator(s).	567–571
7. Inspect, test, and replace low engine coolant temperature blower control system.	567–571
8. Inspect, test, and replace heater water valve and controls.	567–571
9. Inspect, test, and replace electric and vacuum motors, solenoids, and switches.	567–571
10. Inspect, test, and replace ATC control panel.	567–571
11. Inspect, test, adjust, or replace ATC microprocessor (climate control computer/programmer).	567–571
12. Check and adjust calibration of ATC system.	567–571
E. Refrigerant Recovery, Recycling, Handling, and Retrofit (7 questions)	
1. Maintain and verify correct operation of certified equipment.	573, 580, 581, 582, 587
2. Identify, and recover A/C system refrigerant.	581–587
3. Recycle or properly dispose of refrigerant.	581–587
4. Label and store refrigerant.	581–587
5. Test recycled refrigerant for non-condensable gases.	581–587
6. Follow federal and local guidelines for retrofit procedures.	581–587

Engine Performance (A8)

ASE Task List	Textbook Page No.
A. General Engine Diagnosis (12 questions)	
1. Verify driver's complaint, perform visual inspection, and/or road test vehicle; determine needed action.	109
2. Research applicable vehicle information, such as engine management system operation, vehicle service history, service precautions, and technical service bulletins.	110, 116
3. Diagnose the cause of unusual engine noise and/or vibration problems; determine needed action.	204, 205, 206, 241, 243, 245, 249, 250, 257, 258
4. Diagnose the cause of unusual exhaust color, odor, and sound; determine needed action.	163, 178, 185, 200, 202, 232, 244, 259
5. Perform engine manifold vacuum or pressure tests; determine needed action.	208, 209
6. Perform cylinder power balance test; determine needed action.	201, 208, 212
7. Perform cylinder cranking compression test; determine needed action.	212, 213
8. Perform cylinder leakage test; determine needed action.	207, 214
9. Diagnose engine mechanical, electrical, electronic, fuel, and ignition problems with an oscilloscope and/or engine analyzer; determine needed action.	760–777, 351–354, 537, 678, 681, 688
10. Prepare and inspect vehicle and analyzer for exhaust gas analysis; interpret HC and CO exhaust gas readings.	735–743

ASE Task List	Textbook Page No.
11. Verify correct valve adjustment on engines with mechanical or hydraulic lifters.	313
12. Verify correct camshaft timing; determine needed action.	209, 243, 244, 252, 254, 305, 307
13. Verify proper engine operating temperature, check coolant level and condition, perform cooling system pressure test; determine needed repairs.	163, 164, 170, 171, 175, 177
14. Inspect, test, and replace mechanical/electrical fans, fan clutch, fan shroud/ducting, and fan control devices.	173–176
B. Ignition System Diagnosis and Repair (12 questions)	
1. Diagnose ignition-related problems such as no-starting, hard starting, engine misfire, poor driveability, spark knock, power loss, poor mileage, and emissions problems on vehicles with distributor and distributorless ignition systems; determine needed repairs.	675–692
2. Check for possible ignition system related diagnostic trouble codes (DTC).	618–623
3. Inspect, test, repair, or replace ignition primary circuit wiring and components.	676–678
4. Inspect, test, and service distributor.	676–678, 680, 681, 685–687, 691
5. Inspect, test, service, repair, or replace ignition system secondary circuit wiring and components.	684, 685, 687–693
6. Inspect, test, and replace ignition coil(s).	676, 681–693
7. Check, and adjust if necessary, ignition system timing and timing advance/retard.	686–688
8. Inspect, test, and replace ignition system pick-up sensor or triggering devices.	677–688
9. Inspect, test, and replace ignition control module.	677–688
C. Fuel, Air Induction, and Exhaust System Diagnosis and Repair (13 questions)	
1. Diagnose fuel system related problems, including hot or cold no-starting, hard starting, poor driveability, incorrect idle speed, poor idle, flooding, hesitation, surging, engine misfire, power loss, stalling, poor mileage, dieseling and emissions problems on vehicles with injection-type or carburetor-type fuel systems; determine needed action.	695–706
2. Check for possible fuel or induction system related diagnostic trouble codes (DTCs).	618–623
3. Perform fuel system pressure, volume, or fuel pump current draw tests; determine needed action.	704–706, 732
4. Inspect fuel tank, filler neck, and gas cap; inspect and replace fuel lines, fittings, and hoses; check fuel for contaminants and quality.	704–706
5. Inspect, test, and replace mechanical and electrical fuel pumps and pump control systems; inspect, service, and replace fuel filters.	704–706, 732
6. Inspect, test, and repair or replace fuel pressure regulation system and components of injection-type fuel systems.	704–706, 732
7. Inspect, test, adjust and repair or replace cold enrichment, acceleration enrichment, and deceleration fuel reduction or shut-off components.	——
8. Remove, clean, and replace throttle body; make related adjustments.	709–714, 716
9. Inspect, test, clean, and replace fuel injectors.	710, 711
10. Inspect, service, and repair or replace air filtration system components.	595
11. Inspect throttle body, air induction system, intake manifold and gaskets for vacuum leaks/unmetered air.	709–714, 716
12. Check/adjust idle speed and fuel mixture where applicable.	723, 728, 729, 732
13. Remove, clean, inspect, test, and repair or replace fuel system vacuum and electrical components and connections.	709–714, 716
14. Inspect, service, and replace exhaust manifold, exhaust pipes, mufflers, resonators, catalytic converters, tail pipes, and heat shields.	186–188, 191–193
15. Perform exhaust system back-pressure test; determine needed action.	159, 190, 211
16. Inspect, test, clean, and repair or replace turbocharger/supercharger and system components.	194–200
D. Emissions Control Systems Diagnosis and Repair (10 questions)	
1. Positive Crankcase Ventilation (1 question)	
1. Test and diagnose emissions or driveability problems caused by positive crankcase ventilation (PCV) system.	744–762
2. Inspect, service, and replace positive crankcase ventilation (PCV) filter/breather cap, valve, tubes, orifices, and hoses.	750, 751
2. Exhaust Gas Recirculation (3 questions)	
1. Test and diagnose emissions or driveability problems caused by the exhaust gas recirculation (EGR) system.	748
2. Check for possible exhaust gas recirculation (EGR) related diagnostic trouble codes (DTCs).	618–623

ASE Task List	Textbook Page No.
3. Inspect, test, service, and replace components of the EGR system, including EGR tubing, exhaust passages, vacuum/pressure controls, filters, hoses, electrical/electronic sensors, controls, solenoids, and wiring of exhaust gas recirculation (EGR) systems.	745–748, 756
3. Exhaust Gas Treatment (3 questions)	
1. Test and diagnose emissions or driveability problems caused by the secondary air injection or catalytic converter systems.	773, 751–753
2. Check for possible secondary air injection system or catalytic converter related diagnostic trouble codes.	751–753
3. Inspect, test, service, and replace mechanical components and electrical/electronically-operated components and circuits of secondary air injection systems.	751–753
4. Inspect and test the catalytic converter(s).	753–758
4. Evaporative Emissions Controls (3 questions)	
1. Test and diagnose emissions or driveability problems caused by the evaporative emissions control system.	758–762
2. Check for possible evaporative emission related diagnostic trouble codes (DTCs).	758–762, 772–774
3. Inspect, test, and replace mechanical and electrical components and hoses of evaporative emissions control systems.	758–762
E. Computerized Engine Controls Diagnosis and Repair (19 questions)	
1. Retrieve and record stored diagnostic trouble codes.	618–623
2. Diagnose the causes of emissions or driveability problems resulting from failure of computerized engine controls with stored diagnostic trouble codes.	721–734
3. Diagnose the causes of emissions or driveability problems resulting from failure of computerized engine controls with no stored diagnostic trouble codes.	721–734, 744–761
4. Use a scan tool or digital multimeter (DMM) to inspect, test, and adjust, computerized engine control system sensors, actuators, circuits, and powertrain control module (PCM).	351–354, 537, 678, 681, 688, 763–777
5. Measure and interpret voltage, voltage drop, amperage, and resistance using digital multimeter (DMM) readings.	351–354, 537, 678, 681, 688, 763–777
6. Test, remove, inspect, clean, service, and repair or replace power and ground distribution circuits and connections.	610, 615
7. Practice recommended precautions when handling static sensitive devices and/or replacing the powertrain control module (PCM).	608–617
8. Diagnose driveability and emissions problems resulting from failures of interrelated systems (cruise control, security alarms, torque controls, suspension controls, traction controls, torque management, A/C, non-OEM installed accessories, and similar systems).	744–761
9. Diagnose the causes of emissions or driveability problems resulting from computerized spark timing controls; determine needed repairs.	721–734
10. Verify, repair, and clear diagnostic trouble codes (DTCs).	618–623
F. Engines Electrical Systems Diagnosis and Repair (4 questions)	
1. Battery (1 question)	
1. Test and diagnose emissions or driveability problems caused by battery condition and connections.	744–761
2. Test and diagnose the cause(s) of abnormal key-off battery drain; determine needed repairs.	408–415
2. Starting System (1 question)	
1. Perform starter current draw test; determine needed action.	418, 426, 428
2. Perform starter circuit voltage drop tests; determine needed action.	426–428
3. Inspect, test, and repair or replace components and wires in the starter control circuit.	433
3. Charging System (2 questions)	
1. Test and diagnose charging system problems that cause an undercharge, overcharge, or a no-charge condition, or engine performance problems; determine needed action.	744–761
2. Inspect, adjust, and replace alternator (generator) drive belts, pulleys, and fans.	451, 452
3. Inspect, test, and repair or replace charging circuit connectors and wires.	448

APPENDIX 2

NATEF Task List

Engine Repair (A1)

For every task in Engine Repair, the following safety requirement must be strictly enforced:
Comply with personal and environmental safety practices associated with clothing; eye protection; hand tools; power equipment; proper ventilation; and the handling, storage, and disposal of chemicals/materials in accordance with local, state, and federal safety and environmental regulations.

I. Engine Repair	Textbook Page No.	Worksheet Page No.
A. General Engine Diagnosis; Removal and Reinstallation (R & R)		
1. Complete work order to include customer information, vehicle identifying information, customer concern, related service history, cause, and correction. (P–1)	11	6, 24
2. Identify and interpret engine concern; determine necessary action. (P–1)	160, 163, 178, 201, 202, 204, 205	27, 39, 40, 52 65, 66
3. Research applicable vehicle and service information, such as internal engine operation, vehicle service history, service precautions, and technical service bulletins. (P–1)	109	24, 28, 29, 63, 64, 115, 119, 138
4. Locate and interpret vehicle and major component identification numbers (VIN, vehicle certification labels, and calibration decals). (P–1)	110, 116	24, 39, 40, 41, 42
5. Inspect engine assembly for fuel, oil, coolant, and other leaks; determine necessary action. (P–1)	160, 172, 203, 204, 222, 310, 311	67–71
6. Diagnose engine noises and vibrations; determine necessary action. (P–2)	204, 205, 206, 241, 243, 245, 249, 250, 257, 258	72
7. Diagnose the cause of excessive oil consumption, unusual engine exhaust color, odor, and sound; determine necessary action. (P–2)	163, 178, 185, 200, 202, 232, 244, 259	32, 73
8. Perform engine vacuum tests; determine necessary action. (P–1)	208, 209	74
9. Perform cylinder power balance tests; determine necessary action. (P–1)	201, 208, 212	75, 76
10. Perform cylinder cranking compression tests; determine necessary action. (P–1)	212, 213	77
11. Perform cylinder leakage tests; determine necessary action. (P–1)	207, 214	79, 80
12. Remove and reinstall engine in a front-wheel or rear wheel drive vehicle (OBDII or newer); reconnect all attaching components and restore the vehicle to running condition. (P–2)	215, 226	81, 82
13. Install engine covers using gaskets, seals, and sealers as required. (P–1)	175, 203, 221	147, 149
B. Cylinder Head and Valve Train Diagnosis and Repair		
1. Visually inspect cylinder head(s) for cracks; check gasket surface areas for warpage and leakage; check passage condition. (P–2)	214, 216, 218	83, 88, 91
2. Remove and reinstall cylinder heads and gaskets; tighten according to manufacturer's specifications and procedures. (P–1)	219, 220, 223, 230	85, 125, 144
3. Inspect valve springs for squareness and free height comparison; determine necessary action. (P–3)	234, 235, 238	100, 101
4. Replace valve stem seals on an assembled engine; inspect valve spring retainers, locks, and valve grooves; determine necessary action. (P–2)	239, 240	104
5. Inspect valve guides for wear; check valve stem-to-guide clearance; determine necessary action. (P–3)	238, 239, 240	93
6. Inspect valves and valve seats; determine necessary action. (P–3)	227, 236	98
7. Check valve face-to-seat contact and valve seat concentricity (runout); determine necessary action. (P–3)	236, 237, 238	99

I. Engine Repair	Textbook Page No.	Worksheet Page No.
8. Check valve spring assembled height and valve stem height; determine necessary action. (P–3)	234, 235	105
9. Inspect pushrods, rocker arms, rocker arm pivots and shafts for wear, bending, cracks, looseness, and blocked oil passages (orifices); determine necessary action. (P–2)	143, 144, 183, 207, 216, 230	107
10. Inspect hydraulic or mechanical lifters; determine necessary action. (P–2)	143, 144, 182, 183, 206, 221, 237	108
11. Adjust valves (mechanical or hydraulic lifters). (P–1)	313	109
12. Inspect camshaft drives (including gear wear and backlash, sprocket and chain wear); determine necessary action. (P–2)	241, 242	110, 111
13. Inspect and replace timing belts (chains), overhead camdrive sprockets, and tensioners; check belt/chain tension; adjust as necessary. (P–1)	209, 243, 244, 252, 254, 305, 307	113, 151, 152
14. Inspect camshaft for runout, journal wear, and lobe wear. (P–2)	241, 247, 249, 251	112
15. Inspect camshaft bearing surface for wear, damage, out-of-round, and alignment; determine necessary action. (P–3)	290, 295	114
16. Establish camshaft(s) timing and cam sensor indexing according to manufacturer's specifications and procedures. (P–1)	243, 247	116
C. Engine Block Assembly Diagnosis and Repair		
1. Disassemble engine block; clean and prepare components for inspection and reassembly. (P–2)	214–219	87
2. Inspect engine block for visible cracks, passage condition, core and gallery plug condition, and surface warpage; determine necessary action. (P–2)	222, 223	124, 128
3. Perform common fastener and thread repair to include, remove broken bolt, restore internal and external threads, and repair internal threads with thread insert. (P–2)	51, 54–60, 295	89
4. Inspect and measure cylinder walls/sleeves for damage, wear, and ridges; determine necessary action. (P–2)	270, 275, 276, 277, 302	126
5. Deglaze and clean cylinder walls. (P–2)	276, 277	127
6. Inspect and measure camshaft bearings for wear, damage, out-of-round, and alignment; determine necessary action. (P–3)	290, 291, 292	136
7. Inspect crankshaft for end play, straightness, journal damage, keyway damage, thrust flange and sealing surface condition, and visual surface cracks; check oil passage condition; measure journal wear; check crankshaft sensor reluctor ring (where applicable); determine necessary action. (P–2)	286, 287, 289, 290, 291, 297,	153
8. Inspect main and connecting rod bearings for damage and wear; determine necessary action. (P–2)	278, 279, 281, 282, 284, 287, 288, 292, 296	139
9. Identify piston and bearing wear patterns that indicate connecting rod alignment and main bearing bore problems; determine necessary action. (P–3)	274, 275, 276	117, 153
10. Inspect and measure pistons; determine necessary action. (P–2)	300–303	123
11. Remove and replace piston pin. (P–3)	266	118
12. Inspect, measure, and install piston rings. (P–2)	260, 261, 262, 278, 300	120, 121
13. Inspect auxiliary (balance, intermediate, idler, counterbalance, or silencer) shaft(s); inspect shaft(s) and support bearings for damage and wear; determine necessary action; reinstall and time. (P–2)	183, 244, 290, 307	154
14. Inspect or replace crankshaft vibration damper (harmonic balancer). (P–3)	217, 218	155
15. Assemble engine block assembly. (P–1)	258–267, 279, 287, 291, 292, 294–314	133
D. Lubrication and Cooling Systems Diagnosis and Repair		
1. Perform oil pressure tests; determine necessary action. (P–1)	205	78
2. Inspect oil pump gears or rotors, housing, pressure relief devices, and pump drive; perform necessary action. (P–2)	181–183, 206, 216, 241, 242	53, 156

I. Engine Repair	Textbook Page No.	Worksheet Page No.
3. Perform cooling system pressure tests; check coolant condition; inspect and test radiator, pressure cap, coolant recovery tank, and hoses; determine necessary action. (P–1)	171	34
4. Inspect, replace, and adjust drive belts, tensioners, and pulleys; check pulley and belt alignment. (P–1)	176, 204, 205	35, 45
5. Inspect and replace engine cooling and heater system hoses. (P–1)	160–172, 177	157
6. Inspect, test, and replace thermostat and gasket. (P–1)	164–167	158
7. Test coolant; drain and recover coolant; flush and refill cooling system with recommended coolant; bleed air as required. (P–1)	167–170	48
8. Inspect, test, remove, and replace water pump. (P–1)	172–174	159
9. Remove and replace radiator. (P–2)	168, 169	160
10. Inspect and test fans(s) (electrical or mechanical), fan clutch, fan shroud, and air dams. (P–1)	173–176	161
11. Inspect auxiliary oil coolers; determine necessary action. (P–3)	169, 170, 171	55
12. Inspect, test, and replace oil temperature and pressure switches and sensors. (P–2)	184	54
13. Perform oil and filter change. (P–1)	123–132, 136, 137	33, 57

Automatic Transmission and Transaxle (A2)

For every task in Automatic Transmission and Transaxle, the following safety requirement must be strictly enforced:

Comply with personal and environmental safety practices associated with clothing; eye protection; hand tools; power equipment; proper ventilation; and the handling, storage, and disposal of chemicals/materials in accordance with local, state, and federal safety and environmental regulations.

II. Automatic Transmission and Transaxle	Textbook Page No.	Worksheet Page No.
A. General Transmission and Transaxle Diagnosis		
1. Complete work order to include customer information, vehicle identifying information, customer concern, related service history, cause, and correction. (P–1)	11	6, 24
2. Identify and interpret transmission/transaxle concern; assure proper engine operation; determine necessary action. (P–1)	160, 163, 178, 201, 202, 204, 205	27
3. Research applicable vehicle and service information, such as transmission/transaxle system operation, fluid type, vehicle service history, service precautions, and technical service bulletins. (P–1)	109	24
4. Locate and interpret vehicle and major component identification numbers (VIN, vehicle certification labels, and calibration decals). (P–1)	110, 116	24
5. Diagnose fluid loss and condition concerns; check fluid level on transmissions with and without dip-stick; determine necessary action. (P–1)	128, 129, 133, 135, 136	667
6. Perform pressure tests; determine necessary action. (P–1)	1314, 1317	668
7. Perform stall test; determine necessary action. (P–3)	1314–1315	669
8. Perform lock-up converter system tests; determine necessary action. (P–3)	1315–1316, 1320	670
9. Diagnose mechanical and vacuum control system concerns; determine necessary action. (P–2)	1316–1317, 1318	671
10. Diagnose noise and vibration concerns; determine necessary action. (P–2)	1315	672
11. Diagnose transmission/transaxle gear reduction/multiplication concerns using driving, driven, and held member (power flow) principles. (P–1)	1314, 1315, 1316, 1317, 1319, 1320	664
12. Diagnose pressure concerns in the transmission using hydraulic principles (Pascal's Law). (P–2)	1316, 1317, 1319, 1320	665
13. Diagnose electrical/electronical concerns using principals of electricity (Ohm's Law). (P–2)	1314, 1315, 1316, 1319, 1320	673

II. Automatic Transmission and Transaxle	Textbook Page No.	Worksheet Page No.
B. Transmission and Transaxle Maintenance and Adjustment		
1. Inspect, adjust or replace throttle valve (TV) linkages or cables; manual shift linkages or cables; transmission range sensor; check gear select indicator (as applicable). (P–1)	1319	674
2. Service transmission; perform visual inspection; replace fluids and filters. (P–1)	128, 129, 133, 135, 136	666
C. In-Vehicle Transmission and Transaxle Repair		
1. Inspect, adjust, or replace (as applicable) vacuum modulator; inspect and repair or replace lines and hoses. (P–3)	1314, 1316, 1317, 1318	676
2. Inspect, repair, and replace governor assembly. (P–3)	1314, 1319	677
3. Inspect and replace external seals and gaskets. (P–2)	1319	678
4. Inspect extension housing, bushings and seals; perform necessary action. (P–3)	1318, 1325	679
5. Inspect and replace speedometer drive gear, driven gear, vehicle speed sensor (VSS), and retainers. (P–2)	1315	680
6. Diagnose electronic transmission control systems using a scan tool; determine necessary action. (P–1)	1316, 1320	675
7. Inspect, replace, and align powertrain mounts. (P–2)	1319, 1328	663
D. Off-Vehicle Transmission and Transaxle Repair		
1. Removal, Disassembly, and Reinstallation		
1. Remove and reinstall transmission and torque converter (rear-wheel drive). (P–2)	1321–1322	681
2. Remove and reinstall transaxle and torque converter assembly. (P–1)	1321–1322	682
3. Disassemble, clean, and inspect transmission/transaxle. (P–1)	1321–1325, 1329, 1330	683
4. Inspect, measure, clean, and replace valve body (includes surfaces, bores, springs, valves, sleeves, retainers, brackets, check-balls, screens, spacers, and gaskets). (P–2)	1321–1323	684
5. Inspect servo bore, piston, seals, pin, spring, and retainers; determine necessary action. (P–3)	1324–1325	685
6. Inspect accumulator bore, piston, seals, spring, and retainer; determine necessary action. (P–3)	1324–1325	686
7. Assemble transmission/transaxle. (P–1)	1325–1330	687
8. Inspect, leak test, and flush cooler, lines, and fittings. (P–1)	1321, 1326, 1327	688
2. Oil Pump and Converter		
1. Inspect converter flex plate, attaching parts, pilot, pump drive, and seal areas. (P–2)	1321, 1328	689
2. Measure torque converter endplay and check for interference; check stator clutch. (P–2)	1322, 1323	690
3. Inspect, measure, and reseal oil pump assembly and components. (P–1)	1323	691
3. Gear Train, Shafts, Bushings and Case		
1. Measure endplay or preload; determine necessary action. (P–1)	1330	692
2. Inspect, measure, and replace thrust washers and bearings. (P–2)	1329, 1330	693
3. Inspect oil delivery seal rings, ring grooves, and sealing surface areas. (P–2)	1321–1330	694
4. Inspect bushings; determine necessary action. (P–2)	1321–1330	695
5. Inspect and measure planetary gear assembly (includes sun, ring gear, thrust washers, planetary gears, and carrier assembly); determine necessary action. (P–2)	1325, 1329, 1330	696
6. Inspect case bores, passages, bushings, vents, and mating surfaces; determine necessary action. (P–2)	1321–1330	697
7. Inspect transaxle drive, link chains, sprockets, gears, bearings, and bushings; perform necessary action. (P–2)	1321–1330	698
8. Inspect, measure, repair, adjust, or replace transaxle final drive components. (P–2)	1329, 1330	699
9. Inspect and reinstall parking pawl, shaft, spring, and retainer; determine necessary action. (P–3)	1321–1330	700

II. Automatic Transmission and Transaxle	Textbook Page No.	Worksheet Page No.
4. Friction and Reaction Units		
1. Inspect clutch drum, piston, check balls, springs, retainers, seals, and friction and pressure plates; determine necessary action. (P–2)	1323–1326	701
2. Measure clutch pack clearance; determine necessary action. (P–1)	1321–1330	702
3. Air test the operation of clutch and servo assemblies. (P–1)	1321–1330	703
4. Inspect roller and sprag clutch, races, rollers, spragi, springs, cages, and retainers; determine necessary action. (P–1)	1321–1330	704
5. Inspect bands and drums; determine necessary action. (P–2)	1319, 1325–1330	705

Manual Drive Train and Axles (A3)

For every task in Manual Drive Train and Axles, the following safety requirement must be strictly enforced:

Comply with personal and environmental safety practices associated with clothing; eye protection; hand tools; power equipment; proper ventilation; and the handling, storage, and disposal of chemicals/materials in accordance with local, state, and federal safety and environmental regulations.

III. Manual Drive Train and Axles	Textbook Page No.	Worksheet Page No.
A. General Drive Train Diagnosis		
1. Complete work order to include customer information, vehicle identifying information, customer concern, related service history, cause, and correction. (P–1)	11	6, 24
2. Identify and interpret drive train concern; determine necessary action. (P–1)	160, 163, 178, 201, 202, 204, 205	27
3. Research applicable vehicle and service information, such as drive train system operation, fluid type, vehicle service history, service precautions, and technical service bulletins. (P–1)	109	24
4. Locate and interpret vehicle and major component identification numbers (VIN, vehicle certification labels, calibration decals). (P–1)	110, 116	24
5. Diagnose fluid loss, level, and condition concerns; determine necessary action. (P–1)	1234	613
6. Drain and fill manual transmission/transaxle and final drive unit. (P–1)	1234	614
B. Clutch Diagnosis and Repair		
1. Diagnose clutch noise, binding, slippage, pulsation, and chatter; determine necessary action. (P–1)	1213–1216	603
2. Inspect clutch pedal linkage, cables, automatic adjuster mechanisms, brackets, bushings, pivots, and springs; perform necessary action. (P–1)	1206–1210, 1212	604
3. Inspect hydraulic clutch slave and master cylinders, lines, and hoses; determine necessary action. (P–1)	1206–1208, 1212–1217	605
4. Inspect release (throw-out) bearing, lever, and pivot; determine necessary action. (P–1)	1213–1217	606
5. Inspect and replace clutch pressure plate assembly and clutch disc. (P–1)	1217–1218	607
6. Bleed clutch hydraulic system. (P–1)	1206–1208, 1212–1217	608
7. Inspect, remove, or replace pilot bearing or bushing (as applicable). (P–1)	1217–1218	609
8. Inspect flywheel and ring gear for wear and cracks; determine necessary action. (P–1)	1210–1211, 1215, 1218	610
9. Inspect engine block, clutch (bell) housing, transmission/transaxle case mating surfaces, and alignment dowels; determine necessary action. (P–3)	1233	611
10. Measure flywheel runout and crankshaft endplay; determine necessary action. (P–2)	1210–1211, 1215, 1218	612

III. Manual Drive Train and Axles	Textbook Page No.	Worksheet Page No.
C. Transmission/Transaxle Diagnosis and Repair		
1. Remove and reinstall transmission/transaxle. (P–1)	1230, 1231	615
2. Disassemble, clean, and reassemble transmission/transaxle components. (P–1)	1231–1234, 1235–1237	616
3. Inspect transmission/transaxle case, extension housing, case mating surfaces, bores, bushings, and vents; perform necessary action. (P–3)	1233	617
4. Diagnose noise, hard shifting, jumping out of gear, and fluid leakage concerns; determine necessary action. (P–2)	1233	618
5. Inspect, adjust, and reinstall shift linkages, brackets, bushings, cables, pivots, and levers. (P–2)	1235–1237	619
6. Inspect and reinstall powertrain mounts. (P–2)	1231–1237	620
7. Inspect and replace gaskets, seals, and sealants; inspect sealing surfaces. (P–2)	1235–1237	621
8. Remove and replace transaxle final drive. (P–3)	1236–1237	622
9. Inspect, adjust, and reinstall shift cover, forks, levers, grommets, shafts, sleeves, detent mechanism, interlocks, and springs. (P–2)	1235–1237	623
10. Measure endplay or preload (shim or spacer selection procedure) on transmission/transaxle shafts; perform necessary action. (P–1)	1235–1237	624
11. Inspect and reinstall synchronizer hub, sleeve, keys (inserts), springs, and blocking rings. (P–1)	1235–1237	625
12. Inspect and reinstall speedometer drive gear, driven gear, vehicle speed sensor (VSS), and retainers. (P–2)	1231–1237	626
13. Diagnose transaxle final drive assembly noise and vibration concerns; determine necessary action. (P–3)	1232	627
14. Remove, inspect, measure, adjust, and reinstall transaxle final drive pinion gears (spiders), shaft, side gears, side bearings, thrust washers, and case assembly. (P–2)	1231–1237	627
15. Inspect lubrication devices (oil pump or slingers); perform necessary action. (P–3)	1231–1237	628
16. Inspect, test, and replace transmission/transaxle sensors and switches. (P–1)	1231–1237	629
D. Drive Shaft and Half Shaft, Universal and Constant-Velocity (CV) Joint Diagnosis and Repair		
1. Diagnose constant velocity (CV) joint noise and vibration concerns; determine necessary action. (P–1)	1243, 1252–1257	630
2. Diagnose universal joint noise and vibration concerns; perform necessary action. (P–1)	1240–1242, 1248, 1249	631
3. Remove and replace front wheel drive (FWD) front wheel bearing. (P–1)	870, 873, 1255, 1257	632
4. Inspect, service, and replace shafts, yokes, boots, and CV joints. (P–1)	1248, 1249–1252	633
5. Inspect, service, and replace shaft center support bearings. (P–3)	1240	634
6. Check shaft balance and phasing; measure shaft runout; measure and adjust driveline angles. (P–2)	1251–1252	635
E. Drive Axle Diagnosis and Repair		
1. Ring and Pinion Gears and Differential Case Assembly		
1. Diagnose noise and vibration concerns; determine necessary action. (P–2)	1260, 1261, 1264	641
2. Diagnose fluid leakage concerns; determine necessary action. (P–1)	1265	642
3. Inspect and replace companion flange and pinion seal; measure companion flange runout. (P–2)	1264	643
4. Inspect ring gear and measure runout; determine necessary action. (P–2)	1266, 1267	644
5. Remove, inspect, and reinstall drive pinion and ring gear, spacers, sleeves, and bearings. (P–2)	1267–1271	645
6. Measure and adjust drive pinion depth. (P–2)	1270–1271	646
7. Measure and adjust drive pinion bearing preload. (P–2)	1269–1270	647
8. Measure and adjust side bearing preload and ring and pinion gear total backlash and backlash variation on a differential carrier assembly (threaded cup or shim types). (P–2)	1270–1272	648
9. Check ring and pinion tooth contact patterns; perform necessary action. (P–2)	1267–1270	649

III. Manual Drive Train and Axles	Textbook Page No.	Worksheet Page No.
10. Disassemble, inspect, measure, and adjust or replace differential pinion gears (spiders), shaft, side gears, side bearings, thrust washers, and case. (P–2)	1259, 1260, 1264–1265	650
11. Reassemble and reinstall differential case assembly; measure runout; determine necessary action. (P–2)	1259–1263	651
2. Limited Slip Differential		
1. Diagnose noise, slippage, and chatter concerns; determine necessary action. (P–3)	1261–1265	652
2. Clean and inspect differential housing; refill with correct lubricant. (P–2)	1271–1273	653
3. Inspect and reinstall clutch (cone or plate) components. (P–3)	1261–1265	654
4. Measure rotating torque; determine necessary action. (P–3)	1270	655
3. Drive Axle Shaft		
1. Diagnose drive axle shafts, bearings, and seals for noise, vibration, and fluid leakage concerns; determine necessary action. (P–2)	1248–1252	636
2. Inspect and replace drive axle shaft wheel studs. (P–1)	878, 898	637
3. Remove and replace drive axle shafts. (P–1)	1257	638
4. Inspect and replace drive axle shaft seals, bearings, and retainers. (P–2)	882	639
5. Measure drive axle flange runout and shaft endplay; determine necessary action. (P–2)	1252	640
F. Four-Wheel Drive/All-wheel Drive Component Diagnosis and Repair		
1. Diagnose noise, vibration, and unusual steering concerns; determine necessary action. (P–3)	1275, 1277, 1278, 1280, 1282	656
2. Inspect, adjust, and repair shifting controls (mechanical, electrical, and vacuum), bushings, mounts, levers, and brackets. (P–3)	1283, 1284, 1287	657
3. Remove and reinstall transfer case. (P–3)	1277, 1280, 1284	658
4. Disassemble, service, and reassemble transfer case and components. (P–3)	1285–1287	659
5. Inspect front-wheel bearings and locking hubs; perform necessary action. (P–3)	1283–1284	660
6. Check drive assembly seals and vents; check lube level. (P–3)	1283	661
7. Diagnose, test, adjust, and replace electrical/electronic components of four-wheel drive systems. (P–3)	1274–1277, 1280, 1281	662

Suspension and Steering (A4)

For every task in Suspension and Steering, the following safety requirement must be strictly enforced:
Comply with personal and environmental safety practices associated with clothing; eye protection; hand tools; power equipment; proper ventilation; and the handling, storage, and disposal of chemicals/materials in accordance with local, state, and federal safety and environmental regulations.

IV. Suspension and Steering	Textbook Page No.	Worksheet Page No.
A. General Suspension and Steering Systems Diagnosis		
1. Complete work order to include customer information, vehicle identifying information, customer concern, related service history, cause, and correction. (P–1)	11	6, 24, 540
2. Identify and interpret Suspension and Steering concern; determine necessary action. (P–1)	1051, 1076, 1102, 1117, 1130	27, 542, 569
3. Research applicable vehicle and service information, such as Suspension and Steering system operation, vehicle service history, service precautions, and technical service bulletins. (P–1)	109	24, 541
4. Locate and interpret vehicle and major component identification numbers (VIN, vehicle certification labels, calibration decals). (P–1)	110, 116	24

IV. Suspension and Steering	Textbook Page No.	Worksheet Page No.
B. Steering Systems Diagnosis and Repair		
1. Disable and enable supplemental restraint system (SRS). (P–1)	531	562
2. Remove and replace steering wheel; center/time supplemental restraint system (SRS) coil (clock spring). (P–1)	532, 1105	563
3. Diagnose steering column noises, looseness, and binding concerns (including tilt mechanisms); determine necessary action. (P–2)	1118	564
4. Diagnose power steering gear (non-rack and pinion) binding, uneven turning effort, looseness, hard steering, noise, and fluid leakage concerns; determine necessary action. (P–3)	1159	573, 574
5. Diagnose power steering gear (rack and pinion) binding, uneven turning effort, looseness, hard steering, noise, and fluid leakage concerns; determine necessary action. (P–3)	1159	575
6. Inspect steering shaft universal joint(s), flexible coupling(s), collapsible column, lock cylinder mechanism, and steering wheel; perform necessary action. (P–2)	1130	565
7. Adjust manual or power non-rack and pinion worm bearing preload and sector lash. (P–3)	1125–1126	566
8. Remove and replace manual or power rack and pinion steering gear; inspect mounting bushings and brackets. (P–1)	1130	567
9. Inspect and replace manual or power rack and pinion steering gear inner tie rod ends (sockets) and bellows boots. (P–1)	1130	570
10. Determine proper power steering fluid type; inspect fluid level and condition. (P–1)	1130	576
11. Flush, fill, and bleed power steering system. (P–2)	1160, 1161	577
12. Diagnose power steering fluid leakage; determine necessary action. (P–2)	1160, 1161	578
13. Remove, inspect, replace, and adjust power steering pump belt. (P–1)	1159, 1160	579
14. Remove and reinstall power steering pump. (P–3)	1163	580
15. Remove and reinstall power steering pump pulley; check pulley and belt alignment. (P–3)	1163–1164	581
16. Inspect and replace power steering hoses and fittings. (P–2)	1161	582
17. Inspect and replace pitman arm, relay (centerlink/intermediate) rod, idler arm and mountings, and steering linkage damper. (P–2)	1130	571
18. Inspect, replace, and adjust tie rod ends (sockets), tie rod sleeves, and clamps. (P–1)	1130	572
19. Test and diagnose components of electronically controlled steering systems using a scan tool; determine necessary action. (P–3)	1154	583
20. Inspect and test non-hydraulic electric-power assist steering. (P–3)	1155	584
21. Identify hybrid vehicle power steering system electrical circuits, service, and safety precautions. (P–3)	780, 781, 802	447, 450, 451, 585
C. Suspension Systems Diagnosis and Repair		
1. Front Suspension		
1. Diagnose short and long arm suspension system noises, body sway, and uneven riding height concerns; determine necessary action. (P–1)	1074, 1074, 1075, 1076	543, 544
2. Diagnose strut suspension system noises, body sway, and uneven riding height concerns; determine necessary action. (P–1)	1075	545
3. Remove, inspect, and install upper and lower control arms, bushings, shafts, and rebound bumpers. (P–3)	1074	546
4. Remove, inspect, and install strut rods (compression/tension) and bushings. (P–2)	1076, 1088	547
5. Remove, inspect, and install upper and/or lower ball joints. (P–1)	1079	548
6. Remove, inspect, and install steering knuckle assemblies. (P–2)	1073	549, 550
7. Remove, inspect, and install short and long arm suspension system coil springs and spring insulators. (P–3)	1074, 1075, 1076	551
8. Remove, inspect, install, and adjust suspension system torsion bars; inspect mounts. (P–3)	1075, 1091	552
9. Remove, inspect, and install stabilizer bar bushings, brackets, and links. (P–2)	1077	553

IV. Suspension and Steering	Textbook Page No.	Worksheet Page No.
10. Remove, inspect, and install strut cartridge or assembly, strut coil spring, insulators (silencers), and upper strut bearing mount. (P–1)	1087	554
11. Lubricate Suspension and Steering systems. (P–2)	135, 1073	37, 568
2. Rear Suspension		
1. Remove, inspect, and install coil springs and spring insulators. (P–2)	1097, 1100	556
2. Remove, inspect, and install transverse links, control arms, bushings, and mounts. (P–2)	1096, 1098, 1099	557
3. Remove, inspect, and install leaf springs, leaf spring insulators (silencers), shackles, brackets, bushings, and mounts. (P–3)	1095, 1096, 1098, 1099	558
4. Remove, inspect, and install strut cartridge or assembly, strut coil spring, and insulators (silencers). (P–2)	1087	559
3. Miscellaneous Service		
1. Inspect, remove, and replace shock absorbers. (P–1)	1095, 1100, 1101	555
2. Remove, inspect, and service or replace front and rear wheel bearings. (P–1)	868, 869, 871, 872, 873	478
3. Test and diagnose components of electronically controlled suspension systems using a scan tool; determine necessary action. (P–3)	1109, 1114	561
D. Wheel Alignment Diagnosis, Adjustment, and Repair		
1. Diagnose vehicle wander, drift, pull, hard steering, bump steer, memory steer, torque steer, and steering return concerns; determine necessary action. (P–1)	1165, 1166, 1167, 1182, 1183	586, 587, 588, 589
2. Perform prealignment inspection; perform necessary action. (P–1)	1180, 1181, 1183, 1186, 1201	586, 587, 588, 589, 590
3. Measure vehicle riding height; determine necessary action. (P–1)	1180	586, 587, 588, 589, 591
4. Check and adjust front and rear wheel camber; perform necessary action. (P–1)	1193, 1196, 1198	586, 587, 588, 589, 593
5. Check and adjust caster; perform necessary action. (P–1)	1193, 1196	586, 587, 588, 589, 595
6. Check and adjust front wheel toe and center steeling wheel. (P–1)	1194, 1195	586, 587, 588 589, 596
7. Check toe-out-on-turns (turning radius); determine necessary action. (P–2)	1186	586, 587, 588, 589, 597
8. Check SAI (steering axis inclination) and included angle; determine necessary action. (P–2)	1184, 1185, 1186, 1187, 1188, 1192	586, 587, 588, 589, 598
9. Check and adjust rear wheel toe. (P–1)	1188, 1189	586, 587, 588, 589, 599
10. Check rear wheel thrust angle; determine necessary action. (P–1)	1184, 1187, 1189, 1190, 1199	586, 587, 588, 589, 600
11. Check for front wheel setback; determine necessary action. (P–2)	1201	586, 587, 588, 589, 601
12. Check front cradle (subframe) alignment; determine necessary action. (P–3)	1186, 1201	586, 587, 588, 589, 602
E. Wheel and Tire Diagnosis and Repair		
1. Diagnose tire wear patterns; determine necessary action. (P–1)	1015, 1016, 1024, 1037	528
2. Inspect tires; check and adjust air pressure. (P–1)	1029, 1030, 1033, 1034, 1035, 1036, 1038	526
3. Diagnose wheel/tire vibration, shimmy, and noise; determine necessary action. (P–2)	1036, 1043, 1044, 1050	529

IV. Suspension and Steering	Textbook Page No.	Worksheet Page No.
4. Rotate tires according to manufacturer's recommendations. (P–1)	1028, 1038, 1039, 1140, 1041, 1042, 1043	36, 530
5. Measure wheel, tire, axle, and hub runout; determine necessary action. (P–2)	1043, 1044	531, 532
6. Diagnose tire pull (lead) problem; determine necessary action. (P–2)	1023, 1036	533
7. Balance wheel and tire assembly (static and dynamic). (P–1)	1044, 1045	534
8. Dismount, inspect, and remount tire on wheel. (P–2)	1038, 1039, 1042, 1043	535
9. Dismount, inspect, and remount tire on wheel equipped with tire pressure sensor. (P–3)	1028, 1029, 1038	536
10. Reinstall wheel; torque lug nuts. (P–1)	1039, 1040	537
11. Inspect tire and wheel assembly for air loss; perform necessary action. (P–1)	1033, 1037	538
12. Repair tire using internal patch. (P–1)	1046	539
13. Inspect, diagnose, and calibrate tire pressure monitoring system. (P–3)	1029, 1030	527

Brakes (A5)

For every task in Brakes, the following safety requirement must be strictly enforced:

Comply with personal and environmental safety practices associated with clothing; eye protection; hand tools; power equipment; proper ventilation; and the handling, storage, and disposal of chemicals/materials in accordance with local, state, and federal safety and environmental regulations.

V. Brakes	Textbook Page No.	Worksheet Page No.
A. General Brake Systems Diagnosis		
1. Complete work order to include customer information, vehicle identifying information, customer concern, related service history, cause, and correction. (P–1)	11	6, 24
2. Identify and interpret brake system concern; determine necessary action. (P–1)	160, 163, 178, 201, 202, 204, 205	27, 453
3. Research applicable vehicle and service information, such as brake system operation, vehicle service history, service precautions, and technical service bulletins. (P–1)	109	24
4. Locate and interpret vehicle and major component identification numbers (VIN, vehicle certification labels, calibration decals). (P–1)	110, 116	24
B. Hydraulic System Diagnosis and Repair		
1. Diagnose pressure concerns in the brake system using hydraulic principles (Pascal's Law). (P–1)	825, 827–839, 912, 934, 935	457
2. Measure brake pedal height; determine necessary action. (P–2)	833–836	458
3. Check master cylinder for internal and external leaks and proper operation; determine necessary action. (P–2)	830–837, 911, 923, 925	459
4. Remove, bench bleed, and reinstall master cylinder. (P–1)	838–839	460
5. Diagnose poor stopping, pulling or dragging concerns caused by malfunctions in the hydraulic system; determine necessary action. (P–1)	811, 825–839	461
6. Inspect brake lines, flexible hoses, and fittings for leaks, dents, kinks, rust, cracks, bulging or wear; tighten loose fittings and supports; determine necessary action. (P–2)	849–859	468
7. Fabricate and/or install brake lines (double flare and ISO types); replace hoses, fittings, and supports as needed. (P–2)	849–859	469
8. Select, handle, store, and fill brake fluids to proper level. (P–1)	849–851	470

V. Brakes	Textbook Page No.	Worksheet Page No.
9. Inspect, test, and/or replace metering (hold-off), proportioning (balance), pressure differential, and combination valves. (P–2)	845–847	462, 463, 464
10. Inspect, test, and adjust height (load) sensing proportioning valve. (P–3)	842–846	465
11. Inspect, test, and/or replace components of brake warning light system. (P–3)	840, 847	466
12. Bleed (manual, pressure, vacuum or surge) brake system. (P–1)	860–867	471, 472, 473, 474, 475
13. Flush hydraulic system. (P–3)	866	476
C. Drum Brake Diagnosis and Repair		
1. Diagnose poor stopping, noise, vibration, pulling, grabbing, dragging, or pedal pulsation concerns; determine necessary action. (P–1)	897, 898, 901, 903, 905–908	483
2. Remove, clean (using proper safety procedures), inspect, and measure brake drums; determine necessary action. (P–1)	898–908	503
3. Refinish brake drum. (P–1)	950–977	504
4. Remove, clean, and inspect brake shoes, springs, pins, clips, levers, adjusters/self-adjusters, other related brake hardware, and backing support plates; lubricate and reassemble. (P–1)	907, 908	484–487
5. Remove, inspect, and install wheel cylinders. (P–2)	886, 891, 901–903, 908	488
6. Pre-adjust brake shoes and parking brake before installing brake drums or drum/hub assemblies and wheel bearings. (P–1)	908, 938–949	489
7. Install wheel, torque lug nuts, and make final checks and adjustments. (P–1)	908, 936	490
D. Disc Brake Diagnosis and Repair		
1. Diagnose poor stopping, noise, vibration, pulling, grabbing, dragging, or pedal pulsation concerns; determine necessary action. (P–1)	923, 925, 927, 929, 931, 934, 935	492
2. Remove caliper assembly from mountings; clean and inspect for leaks and damage to caliper housing; determine necessary action. (P–1)	924–933	493
3. Clean and inspect caliper mounting and slides for wear and damage; determine necessary action. (P–1)	930–931	494
4. Remove, clean, and inspect pads and retaining hardware; determine necessary action. (P–1)	924–933	495
5. Disassemble and clean caliper assembly; inspect parts for wear, rust, scoring, and damage; replace seal, boot, and damaged or worn parts. (P–2)	924–933	496
6. Reassemble, lubricate, and reinstall caliper, pads, and related hardware; seat pads, and inspect for leaks. (P–1)	924–933	497
7. Clean, inspect, and measure rotor with a dial indicator and a micrometer; follow manufacturer's recommendations in determining need to machine or replace. (P–1)	957, 958	505
8. Remove and reinstall rotor. (P–1)	872, 873	506
9. Refinish rotor on vehicle. (P–1)	966, 967	507
10. Refinish rotor off vehicle. (P–1)	959–967	508
11. Adjust calipers equipped with an integrated parking brake system. (P–3)	946, 938–949	499
12. Install wheel, torque lug nuts, and make final checks and adjustments. (P–1)	908, 936	498
E. Power Assist Units Diagnosis and Repair		
1. Test pedal free travel with and without engine running; check power assist operation. (P–2)	978–988	509
2. Check vacuum supply (manifold or auxiliary pump) to vacuum-type power booster. (P–2)	978–988	510
3. Inspect the vacuum-type power booster unit for vacuum leaks; inspect the check valve for proper operation; determine necessary action. (P–2)	978–988	511
4. Inspect and test hydraulically assisted power brake system for leaks and proper operation; determine necessary action. (P–3)	978–988	512
5. Measure and adjust master cylinder pushrod length. (P–3)	985	513

V. Brakes	Textbook Page No.	Worksheet Page No.
F. Miscellaneous (Wheel Bearings, Parking Brakes, Electrical, Etc.) Diagnosis and Repair		
1. Diagnose wheel bearing noises, wheel shimmy, and vibration concerns; determine necessary action. (P–1)	868–882	477
2. Remove, clean, inspect, repack, and install wheel bearings and replace seals; install hub and adjust wheel bearings. (P–1)	868–882	478
3. Check parking brake cables and components for wear, rusting, binding, and corrosion; clean, lubricate, or replace as needed. (P–2)	938–949	500
4. Check parking brake operation; determine necessary action. (P–1)	938–949	501
5. Check operation of parking brake indicator light system. (P–3)	938–949	502
6. Check operation of brake stop light system; determine necessary action. (P–1)	840, 847	467
7. Replace wheel bearing and race. (P–1)	870, 873, 1255, 1257	479
8. Inspect and replace wheel studs. (P–1)	878, 898	480
9. Remove and reinstall sealed wheel bearing assembly. (P–2)	870, 873, 1255, 1257	481
G. Antilock Brake and Traction Control Systems		
1. Identify and inspect antilock brake system (ABS) components; determine necessary action. (P–1)	990–1002, 1003–1013	515, 516
2. Diagnose poor stopping, wheel lock-up, abnormal pedal feel or pulsation, and noise concerns caused by the antilock brake system (ABS); determine necessary action. (P–2)	996, 997, 998	517
3. Diagnose antilock brake system (ABS) electronic control(s) and components using self-diagnosis and/or recommended test equipment; determine necessary action. (P–1)	1004–1013	518, 519
4. Depressurize high-pressure components of the antilock brake system (ABS). (P–3)	998, 1013	520
5. Bleed the antilock brake system's (ABS) front and rear hydraulic circuits. (P–2)	1007, 1012, 1013	521
6. Remove and install antilock brake system (ABS) electrical/electronic and hydraulic components. (P–3)	1004–1013	522
7. Test, diagnose, and service ABS speed sensors, toothed ring (tone wheel), and circuits using a graphing multimeter (GMM)/ digital storage oscilloscope (DSO) (includes output signal, resistance, shorts to voltage/ground, and frequency data). (P–1)	1004–1013	523
8. Diagnose antilock brake system (ABS) braking concerns caused by vehicle modifications (tire size, curb height, final drive ratio, etc.). (P–3)	1004–1013	524
9. Identify traction control/vehicle stability control system components. (P–3)	998–1001	514, 525

Electrical/Electronic Systems (A6)

For every task in Electrical/Electronic Systems, the following safety requirement must be strictly enforced:

Comply with personal and environmental safety practices associated with clothing; eye protection; hand tools; power equipment; proper ventilation; and the handling, storage, and disposal of chemicals/materials in accordance with local, state, and federal safety and environmental regulations.

VI. Electrical/Electronic Systems	Textbook Page No.	Worksheet Page No.
A. General Electrical System Diagnosis		
1. Complete work order to include customer information, vehicle identifying information, customer concern, related service history, cause, and correction. (P–1)	11	6, 24
2. Identify and interpret electrical/electronic system concern; determine necessary action. (P–1)	160, 163, 178, 201, 202, 204, 205	27, 187

VI. Electrical/Electronic Systems	Textbook Page No.	Worksheet Page No.
3. Research applicable vehicle and service information, such as electrical/electronic system operation, vehicle service history, service precautions, and technical service bulletins. (P–1)	109	24
4. Locate and interpret vehicle and major component identification numbers (VIN, vehicle certification labels, and calibration decals). (P–1)	110, 116	24
5. Diagnose electrical/electronic integrity of series, parallel, and series-parallel circuits using principles of electricity (Ohm's Law). (P–1)	325–338	164–172, 188
6. Use wiring diagrams during diagnosis of electrical circuit problems. (P–1)	361, 370, 371–378, 381	189
7. Demonstrate the proper use of a digital multimeter (DMM) during diagnosis of electrical circuit problems. (P–1)	340–346, 354–359	173
8. Check electrical circuits with a test light; determine necessary action. (P–2)	340, 341, 365, 366	174
9. Measure source voltage and perform voltage drop tests in electrical/electronic circuits using a voltmeter; determine necessary action. (P–1)	327, 330–337, 448, 449, 503, 522	175
10. Measure current flow in electrical/electronic circuits and components using an ammeter; determine necessary action. (P–1)	320–322	176
11. Check continuity and measure resistance in electrical/electronic circuits and components using an ohmmeter; determine necessary action. (P–1)	321, 354, 356	177
12. Check electrical circuits using fused jumper wires; determine necessary action. (P–2)	432, 448, 503	178
13. Locate shorts, grounds, opens, and resistance problems in electrical/electronic circuits; determine necessary action. (P–1)	325–337, 378–380, 464	190–193
14. Measure and diagnose the cause(s) of excessive key-off battery drain (parasitic draw); determine necessary action. **Sub-repair area "B2"** (P–1)	408–415	197
15. Inspect and test fusible links, circuit breakers, and fuses; determine necessary action. (P–1)	325, 360, 364, 365, 367–369	179
16. Inspect and test switches, connectors, relays, solenoid solid state devices, and wires of electrical/electronic circuits; perform necessary action. (P–1)	325, 330 375–377	180–182, 194
17. Remove and replace terminal end from connector. (P–1)	360–369	183
18. Repair connectors and terminal ends. (P–1)	360–369	184
19. Repair wiring harness (including CAN/BUS systems). (P–1)	360–369	185
20. Perform solder repair of electrical wiring. (P–1)	360–369	185
21. Identify location of hybrid vehicle high voltage circuit disconnect (service plug) location and safety procedures. (P–3)	790	448
B. Battery Diagnosis and Service		
1. Perform battery state-of-charge (conductance) test; determine necessary action. (P–1)	410–414	198
2. Perform battery capacity test; confirm proper battery capacity for vehicle application; determine necessary action. (P–1)	411–414	199
3. Maintain or restore electronic memory functions. (P–1)	414	200
4. Inspect, clean, fill, and replace battery. (P–1)	404–417	202
5. Perform slow/fast battery charge. (P–2)	404–417	203
6. Inspect and clean battery cables, connectors, clamps, and hold-downs; repair or replace as needed. (P–1)	404–417	204
7. Start a vehicle using jumper cables and a battery or auxiliary power supply. (P–1)	404–417	205
8. Identify high voltage circuits of electric or hybrid electric vehicle and related safety precautions. (P–3)	404–417	449, 452
9. Identify electronic modules, security systems, and/or radios that require reinitialization or code entry following battery disconnect. (P–2)	414–416, 536–545	201

VI. Electrical/Electronic Systems	Textbook Page No.	Worksheet Page No.
10. Identify hybrid vehicle auxiliary (12v) battery service, repair, and test procedures. (P–3)	791, 792	206
C. Starting System Diagnosis and Repair		
1. Perform starter current draw tests; determine necessary action. (P–1)	418, 426, 428	210
2. Perform starter circuit voltage drop tests; determine necessary action. (P–1)	426–428	211
3. Inspect and test starter relays and solenoids; determine necessary action. (P–2)	433	207
4. Remove and install starter in a vehicle. (P–1)	428, 429	212
5. Inspect and test switches, connectors, and wires of starter control circuits; perform necessary action. (P–2)	433	208
6. Differentiate between electrical and engine mechanical problems that cause a slow-crank or no-crank condition. (P–2)	433	213
D. Charging System Diagnosis and Repair		
1. Perform charging system output test; determine necessary action. (P–1)	437, 445–448	219
2. Diagnose charging system for the cause of undercharge, no-charge, and overcharge conditions. (P–1)	445–447	218, 220, 221
3. Inspect, adjust, or replace generator (alternator) drive belts, pulleys, and tensioners; check pulley and belt alignment. (P–1)	438, 451, 452	222
4. Remove, inspect, and install generator (alternator). (P–1)	451, 452	224
5. Perform charging circuit voltage drop tests; determine necessary action. (P–1)	448	223
E. Lighting Systems Diagnosis and Repair		
1. Diagnose the cause of brighter than normal, intermittent, dim, or no light operation; determine necessary action. (P–1)	468–471	230
2. Inspect, replace, and aim headlights and bulbs. (P–2)	465, 466	232
3. Inspect and diagnose incorrect turn signal or hazard light operation; perform necessary action. (P–2)	468–471	231
4. Identify system voltage and safety precautions associated with high intensity discharge headlights. (P–3)	467, 468	233
F. Gauges, Warning Devices, and Driver Information Systems Diagnosis and Repair		
1. Inspect and test gauges and gauge sending units for cause of intermittent, high, low, or no gauge readings; determine necessary action. (P–1)	478, 496	235–238
2. Inspect and test connectors, wires, and printed circuit boards of gauge circuits; determine necessary action. (P–3)	478, 496	239
3. Diagnose the cause of incorrect operation of warning devices and other driver information systems; determine necessary action. (P–1)	478–496	240
4. Inspect and test sensors, connectors, and wires of electronic (digital) instrument circuits; determine necessary action. (P–3)	478, 496	241
G. Horn and Wiper/Washer Diagnosis and Repair		
1. Diagnose incorrect horn operation; perform necessary action. (P–2)	497, 498	243
2. Diagnose incorrect wiper operation; diagnose wiper speed control and park problems; perform necessary action. (P–2)	498–504	244
3. Diagnose incorrect washer operation; perform necessary action. (P–2)	498–504	245
H. Accessories Diagnosis and Repair		
1. Diagnose incorrect operation of motor-driven accessory circuits; determine necessary action. (P–2)	507–510, 513–519	246–248
2. Diagnose incorrect heated glass, mirror, or seat operation; determine necessary action. (P–2)	510–512	249
3. Diagnose incorrect electric lock operation; determine necessary action. (P–2)	520–526	250
4. Diagnose incorrect operation of cruise control systems; determine necessary action. (P–3)	508, 509, 510, 523	251

VI. Electrical/Electronic Systems	Textbook Page No.	Worksheet Page No.
5. Diagnose supplemental restraint system (SRS) concerns; determine necessary action. (Note: Follow manufacturer's safety procedures to prevent accidental deployment.) (P–1)	526–535	256
6. Disarm and enable the airbag system for vehicle service. (P–1)	526–535	259
7. Diagnose radio static and weak, intermittent, or no radio reception; determine necessary action. (P–3)	414–416, 536–545	260, 261
8. Remove and reinstall door panel. (P–1)	524, 525	252
9. Diagnose body electronic system circuits using a scan tool; determine necessary action. (P–2)	446, 469, 482, 486, 489, 494	253, 257
10. Check for module communication (LAN/ CAN/ BUS) errors using a scan tool. (P–2)	482, 486, 489, 508, 521	254, 258
11. Diagnose the cause of false, intermittent, or no operation of anti-theft systems. (P–2)	521, 522, 523, 524	255

Heating and Air Conditioning (A7)

For every task in Heating and Air Conditioning, the following safety requirement must be strictly enforced:

Comply with personal and environmental safety practices associated with clothing; eye protection; hand tools; power equipment; proper ventilation; and the handling, storage, and disposal of chemicals/materials in accordance with local, state, and federal safety and environmental regulations.

VII. Heating and Air Conditioning	Textbook Page No.	Worksheet Page No.
A. A/C System Diagnosis and Repair		
1. Complete work order to include customer information, vehicle identifying information, customer concern, related service history, cause, and correction. (P–1)	11	6, 24, 269
2. Identify and interpret Heating and Air Conditioning concern; determine necessary action. (P–1)	160, 163, 178, 200, 202, 204, 205	27, 270, 297
3. Research applicable vehicle and service information, such as heating and air conditioning system operation, vehicle service history, service precautions, and technical service bulletins. (P–1)	109	24, 266
4. Locate and interpret vehicle and major component identification numbers (VIN, vehicle certification labels, calibration decals). (P–1)	110, 116	24, 263, 264
5. Performance test A/C system; diagnose A/C system malfunctions using principles of refrigeration. (P–1)	575, 576–578	271, 281
6. Diagnose abnormal operating noises in the A/C system; determine necessary action. (P–2)	549, 573, 574, 575	272
7. Identify refrigerant type; select and connect proper gauge set; record pressure readings. (P–1)	577, 581, 582	273
8. Leak test A/C system; determine necessary action. (P–1)	578–580	274
9. Inspect the condition of discharged oil; determine necessary action. (P–2)	556–558	275
10. Determine recommended oil for system application. (P–1)	557, 558, 561, 578–580	276
11. Using scan tool, observe and record related HVAC data and trouble codes. (P–1)	576, 772–777	277
B. Refrigeration System Component Diagnosis and Repair		
1. Compressor and Clutch		
1. Diagnose A/C system conditions that cause the protection devices (pressure, thermal, and PCM) to interrupt system operation; determine necessary action. (P–2)	575–580	278

VII. Heating and Air Conditioning	Textbook Page No.	Worksheet Page No.
2. Inspect and replace A/C compressor drive belts; determine necessary action. (P–1)	586	298
3. Inspect, test, and /or replace A/C compressor clutch components and/or assembly. (P–2)	586, 587	299, 300
4. Remove, inspect, and reinstall A/C compressor and mountings; determined required oil quantity. (P–1)	586, 587	301
5. Identify hybrid vehicle AC system electrical circuits, service, and safety precautions. (P–3)	781, 782, 794, 806	265
2. Evaporator, Condenser, and Related Components		
1. Determine need for an additional A/C system filter; perform necessary action. (P–3)	586	279
2. Remove and inspect A/C system mufflers, hoses, lines, fittings, O-rings, seals, and service valves; perform necessary action. (P–2)	582, 583	280
3. Inspect A/C condenser for airflow restrictions; perform necessary action. (P–1)	587	302
4. Remove, inspect, and reinstall receiver/drier or accumulator/drier; determine required oil quantity. (P–1)	585–588	303
5. Remove and install expansion valve or orifice (expension) tube. (P–1)	560, 564, 577, 578, 579, 580	304
6. Inspect evaporator housing water drain; perform necessary action. (P–3)	587	305
7. Remove, inspect, and reinstall evaporator; determine required oil quantity. (P–3)	579, 587	306
8. Remove, inspect, and reinstall condenser; determine required oil quantity. (P–3)	575, 576, 577, 578, 587	307
C. Heating, Ventilation, and Engine Cooling Systems Diagnosis and Repair		
1. Diagnose temperature control problems in the heater/ventilation system; determine necessary action. (P–2)	575–580	282
2. Perform cooling system pressure tests; check coolant condition, inspect and test radiator, pressure cap, coolant recovery tank, and hoses; perform necessary action. (P–1)	171	283
3. Inspect engine cooling and heater system hoses and belts; perform necessary action. (P–1)	160–172, 177	308
4. Inspect, test, and replace thermostat and gasket. (P–1)	164–167	284
5. Determine coolant condition and coolant type for vehicle application; drain and recover coolant. (P–1)	167–170	285
6. Flush system, refill system with recommended coolant; bleed system. (P–1)	173–176	286
7. Inspect and test cooling fan, fan clutch, fan shroud, and air dams; perform necessary action. (P–1)	173–176	287
8. Inspect and test electric cooling fan, fan control system and circuits; determine necessary action. (P–1)	173–176	288
9. Inspect and test heater control valve(s); perform necessary action. (P–2)	574, 575	289
10. Remove, inspect, and reinstall heater core. (P–3)	574, 575, 581, 587	290
D. Operating Systems and Related Controls Diagnosis and Repair		
1. Diagnose malfunctions in the electrical controls of heating, ventilation, and A/C (HVAC) systems; determine necessary action. (P–2)	575–580	267
2. Inspect and test A/C-heater blower, motors, resistors, switches, relays, wiring, and protection devices; perform necessary action. (P–1)	497, 504, 505, 506	291
3. Test and diagnose A/C compressor clutch control systems; determine necessary action. (P–1)	397, 563, 564, 565, 569, 575, 577, 585, 586	292
4. Diagnose malfunctions in the vacuum, mechanical, and electrical components and controls of the heating, ventilation, and A/C (HVAC) system; determine necessary action. (P–2)	575–580	293
5. Inspect and test A/C-heater control panel assembly; determine necessary action. (P–3)	571	294
6. Inspect and test A/C-heater control cables, motors, and linkages; perform necessary action. (P–3)	574, 575	295
7. Inspect A/C-heater ducts, doors, hoses, cabin filters and outlets; perform necessary action. (P–3)	568–574	296
8. Check operation of automatic and semi-automatic heating, ventilation, and air-conditioning (HVAC) control system; determine necessary action. (P–3)	567–571	268

VII. Heating and Air Conditioning	Textbook Page No.	Worksheet Page No.
E. Refrigerant Recovery, Recycling, and Handling		
1. Perform correct use and maintenance of refrigerant handling equipment. (P–1)	573, 580, 581, 582, 587	309
2. Identify (by label application or use of a refrigerant identifier) and recover A/C system refrigerant. (P–1)	581–587	310
3. Recycle refrigerant. (P–1)	581–587	311
4. Label and store refrigerant. (P–1)	581–587	312
5. Test recycled refrigerant for non-condensable gases. (P–1)	581–587	313
6. Evacuate and charge A/C system. (P–1)	581–587	314

Engine Performance (A8)

For every task in Engine Performance the following safety requirement must be strictly enforced:

Comply with personal and environmental safety practices associated with clothing; eye protection; hand tools; power equipment; proper ventilation; and the handling, storage, and disposal of chemicals/materials in accordance with local, state, and federal safety and environmental regulations.

VIII. Engine Performance	Textbook Page No.	Worksheet Page No.
A. General Engine Diagnosis		
1. Complete work order to include customer information, vehicle identifying information, customer concern, related service history, cause, and correction. (P–1)	11	6, 24
2. Identify and interpret engine performance concern; determine necessary action. (P–1)	109	24, 327, 329
3. Research applicable vehicle and service information, such as engine management system operation, vehicle service history, service precautions, and technical service bulletins. (P–1)	110, 116	24, 43, 316, 361, 362, 388
4. Locate and interpret vehicle and major component identification numbers (VIN, vehicle certification labels, and calibration decals). (P–1)	11	24, 322, 323, 443, 444–446
5. Inspect engine assembly for fuel, oil, coolant, and other leaks; determine necessary action. (P–2)	160, 172, 203, 204, 222, 310, 311	38, 44
6. Diagnose abnormal engine noise or vibration concerns; determine necessary action. (P–2)	204, 205, 206, 241, 243, 245, 249, 250, 257, 258	72
7. Diagnose abnormal exhaust color, odor, and sound; determine necessary action. (P–2)	163, 178, 185, 200, 202, 232, 244, 259	32, 73
8. Perform engine absolute (vacuum/boost) manifold pressure tests; determine necessary action. (P–1)	208, 209	74
9. Perform cylinder power balance test; determine necessary action. (P–1)	201, 208, 212	75, 76
10. Perform cylinder cranking compression tests; determine necessary action. (P–1)	212, 213	77
11. Perform engine running compression test; determine necessary action. (P–2)	212, 213	77
12. Perform cylinder leakage test; determine necessary action. (P–1)	207, 214	79, 80
13. Diagnose engine mechanical, electrical, electronic, fuel, and ignition concerns with an oscilloscope and/or engine diagnostic equipment; determine necessary action. (P–1)	760–777, 351–354, 537, 678, 681, 688,	330–359 389, 390, 394–397, 414
14. Prepare 4 or 5 gas analyzer; inspect and prepare vehicle for test, and obtain exhaust readings; interpret readings, and determine necessary action. (P–1)	735–743	416, 424

VIII. Engine Performance	Textbook Page No.	Worksheet Page No.
15. Verify engine operating temperature; determine necessary action. (P–1)	163, 164, 170, 171, 175, 177	47
16. Perform cooling system pressure tests; check coolant condition; inspect and test radiator, pressure cap, coolant recovery tank, and hoses; perform necessary action. (P–1)	171	46, 49
17. Verify correct camshaft timing. (P–2)	243, 247	113, 151, 152
B. Computerized Engine Controls Diagnosis and Repair		
1. Retrieve and record stored OBD I diagnostic trouble codes; clear codes. (P–3)	618–623	442
2. Retrieve and record stored OBD II diagnostic trouble codes; clear codes when applicable. (P–1)	618–623	442
3. Diagnose the causes of emissions or driveability concerns resulting from malfunctions in the computerized engine control system with stored diagnostic trouble codes. (P–1)	721–734	324–326, 417, 425
4. Diagnose emissions or driveability concerns resulting from malfunctions in the computerized engine control system with no stored diagnostic trouble codes; determine necessary action. (P–1)	721–734 744–761	324
5. Check for module communication (LAN/ CAN/ BUS) errors using a scan tool. (P–2)	763–777	321
6. Inspect and test computerized engine control system sensors, powertrain control module (PCM), actuators, and circuits using a graphing multimeter (GMM)/digital storage oscilloscope (DSO); perform necessary action. (P–1)	351–354, 537, 678, 681 688, 763–777	330–359, 389, 390, 394–397, 414
7. Obtain and interpret scan tool data. (P–1)	763–777	320, 328, 360
8. Access and use service information to perform step-by-step diagnosis. (P–1)	763–777	398, 399
9. Diagnose driveability and emissions problems resulting from malfunctions of interrelated systems (cruise control, security alarms, suspension controls, traction controls, A/C, automatic transmissions, non-OEM-installed accessories, or similar systems); determine necessary action. (P–3)	744–761	400
10. Perform active tests of actuators using scan tool; determine necessary action. (P–1)	763–777	408, 414
C. Ignition System Diagnosis and Repair		
1. Diagnose ignition system related problems such as no-starting, hard starting, engine misfire, poor driveability, spark knock, power loss, poor mileage, and emissions concerns on vehicles with electronic ignition (distributorless) systems; determine necessary action. (P–1)	675–692	363, 364, 366, 367, 368
2. Diagnose ignition system related problems such as no-starting, hard starting, engine misfire, poor driveability, spark knock, power loss, poor mileage, and emissions concerns on vehicles with distributor ignition (DI) systems; determine necessary action. (P–1)	675–692	365, 369, 370
3. Inspect and test ignition primary circuit wiring and solid state components; perform necessary action. (P–2)	676–678	371
4. Inspect, test, and service distributor. (P–3)	676–678, 680, 681, 685–687, 691	372
5. Inspect and test ignition system secondary circuit wiring and components; perform necessary action. (P–2)	684, 685, 687–693	373–378
6. Inspect and test ignition coil(s); perform necessary action. (P–1)	676, 681–693	379
7. Check and adjust ignition system timing and timing advance/retard (where applicable). (P–3)	686–688	380
8. Inspect and test ignition system pick-up sensor or triggering devices; perform necessary action (P–1)	677–688	381
D. Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair		
1. Diagnose hot or cold no-starting, hard starting, poor driveability, incorrect idle speed, poor idle, flooding, hesitation, surging, engine misfire, power loss, stalling, poor mileage, dieseling, and emissions problems on vehicles with injection-type fuel systems; determine necessary action. (P–1)	695–706	401–404
2. Check fuel for contaminants and quality; determine necessary action. (P–3)	704–706	317–319
3. Inspect and test fuel pumps and pump control systems for pressure, regulation, and volume; perform necessary action. (P–1)	704–706, 732	382–386
4. Replace fuel filters. (P–1)	702	387
5. Inspect and test cold enrichment system and components; perform necessary action. (P–3)	N/A	391, 392
6. Inspect throttle body, air induction system, intake manifold and gaskets for vacuum leaks and/or unmetered air. (P–2)	709–714, 716	393, 414, 415

VIII. Engine Performance	Textbook Page No.	Worksheet Page No.
7. Inspect and test fuel injectors. (P–1)	710, 711	405–411
8. Check idle speed. (P–2)	723, 728, 729, 732	412, 413
9. Inspect the integrity of the exhaust manifold, exhaust pipes, muffler(s), catalytic converter(s), resonator(s), tail pipe(s), and heat shield(s); perform necessary action. (P–2)	186–188, 191–193	429
10. Perform exhaust system back-pressure test; determine necessary action. (P–1)	159, 190, 211,	441
11. Test the operation of turbocharger/supercharger systems; determine necessary action. (P–3)	1994–200	63, 64
E. Emissions Control Systems Diagnosis and Repair		
1. Positive Crankcase Ventilation		
1. Diagnose oil leaks, emissions, and driveability problems resulting from malfunctions in the positive crankcase ventilation (PCV) system; determine necessary action. (P–2)	744–762	434
2. Inspect, test, and service positive crankcase ventilation (PCV) filter/breather cap, valve, tubes, orifices, and hoses; perform necessary action. (P–2)	750, 751	432, 433
2. Exhaust Gas Recirculation		
1. Diagnose emissions and driveability problems caused by malfunctions in the exhaust gas recirculation (EGR) system; determine necessary action. (P–1)	748	426–428
2. Inspect, test, service, and replace components of the EGR system, including EGR tubing, exhaust passages, vacuum/pressure controls, filters and hoses; perform necessary action. (P–1)	745–748, 756	429
3. Inspect and test electrical/electronic sensors, controls, and wiring of exhaust gas recirculation (EGR) systems; perform necessary action. (P–2)	744–748	430, 431
3. Exhaust Gas Treatment		
1. Diagnose emissions and driveability problems resulting from malfunctions in the secondary air injection and catalytic converter systems; determine necessary action. (P–2)	751–753, 773	435
2. Inspect and test mechanical components of secondary air injection systems; perform necessary action. (P–3)	751–753	436
3. Inspect and test electrical/electronically-operated components and circuits of air injection systems; perform necessary action. (P–3)	751–753	437
4. Inspect and test catalytic converter performance. (P–1)	753–758	438–440
4. Evaporative Emissions Controls		
1. Diagnose emissions and driveability problems resulting from malfunctions in the evaporative emissions control system; determine necessary action. (P–1)	758–762	418–420
2. Inspect and test components and hoses of evaporative emissions control system; perform necessary action. (P–2)	758–762	421, 422
3. Interpret evaporative emission related diagnostic trouble codes (DTCs); determine necessary action. (P–1)	758–762, 772–774	423
F. Engine Related Service		
1. Adjust valves on engines with mechanical or hydraulic lifters. (P–1)	313	109
2. Remove and replace timing belt; verify correct camshaft timing. (P–1)	209, 243, 233, 252, 254, 305, 307	113, 151 152
3. Remove and replace thermostat and gasket. (P–1)	164–167	50
4. Inspect and test mechanical/electrical fans, fan clutch, fan shroud/ducting, air dams, and fan control devices; perform necessary action. (P–1)	173–176	51
5. Perform common fastener and thread repair to include: remove broken bolt, restore internal and external threads, and repair internal threads with thread insert. (P–1)	51, 54–60, 295	89
6. Perform oil and filter changes. (P–1)	123–132, 136, 137	33, 57
7. Demonstrate proficiency in using oxy-acetylene torch to heat and cut metal. (P–3)	79–81	14
8. Identify hybrid vehicle internal combustion engine service precautions. (P–3)	787–795	445

ENGLISH GLOSSARY

3 minute charge test A method used to test batteries. Not valid for all types of batteries.

4 X 2 The term used to describe a two-wheel drive truck. The "4" indicates the number of wheels of the vehicle and the "2" indicates the number of wheels that are driven by the engine.

4 X 4 The term used to describe a four-wheel drive vehicle. The first "4" indicates the number of wheels of the vehicle and the second "4" indicates the number of wheels that are driven by the engine.

4WAL Four wheel antilock.

720° cycle The number of degrees of crankshaft rotation required to complete the four-stroke cycle.

A-arm Another name for a control arm because it often looks like the letter A.

Above ground storage tank A type of oil storage.

ABS Antilock brake system.

AC See alternating current.

AC coupling A signal that passes the AC signal component to the meter, but blocks the DC component. Useful to observe an AC signal that is normally riding on a DC signal; for example, charging ripple.

AC generator Also called an alternator.

AC/DC clamp-on DMM A type of meter that has a clamp that is placed around the wire to measure current.

AC motor An electric motor that is powered by AC (alternating current).

AC synchronous motor An electric motor that uses a three-phase stator coil with a brushless permanent magnet rotor. Another term for DC brushless motor.

Accumulator A temporary location for fluid under pressure.

Acid A substance with a pH lower than 7.

Acidic A chemical compound that produces a pH of less than 7 when dissolved in water. Acidic is the opposite of alkaline.

ACIM AC Induction Motor. See Induction motor.

Ackerman Principle The angle of the steering arms causes the inside wheel to turn more sharply than the outer wheel when making a turn. This produces toe-out on turns (TOOT).

ACM Active Control Engine Mount. ACMs are computer controlled and are designed to dampen unusual vibrations during ICE start/stop.

ACP Audio Control Protocol, a type of serial data transmission used by Ford.

Active crossover A type of crossover that uses electronic components to block certain frequencies.

Active sensor A type of wheel speed sensor that produces a digital output signal.

Actuator An electromechanical device that performs mechanical movement as commanded by a controller.

Additive A substance added in small amounts to something, such as gasoline.

Adhesive-lined heat shrink tubing A type of heat shrink tubing that shrinks to one-third of its original diameter and has glue inside.

Adjustable wrench A wrench that has a moveable jaw to allow it to fit many sizes of fasteners.

Advisor A role played by a mentor.

Advocate A role played by a mentor.

AFS Active Front headlight System. A name for the system that causes the headlights to turn when cornering.

AFV Alternative fuel vehicle.

AGM battery Absorbed glass mat. AGM batteries are lead-acid batteries, but use an absorbent material between the plates to hold the electrolyte. AGM batteries are classified as valve-regulated lead-acid (VRLA) batteries.

AGST Above ground storage tank, used to store used oil.

Ah Ampere-hour. A battery capacity rating.

AIR Air injection reaction emission control system; also called secondary air injection.

Airbag An inflatable fabric bag that deploys in the event of a collision that is severe enough to cause personal injury.

Air-blow gun A handheld nozzle attached to a compressed air hose to apply air pressure to a component or device.

Air compressor A piece of shop equipment that uses an electric motor to power an air compressor, which is stored in a pressure tank for use in the shop.

Air-fuel ratio The ratio of air to fuel in an intake charge as measured by weight.

Air gap The distance between the wheel speed sensor and the reluctor wheel.

Air management system The system of solenoids and valves that control the flow of air from the secondary air injection system.

Air ratchet An air-operated hand tool that rotates a socket.

Air spring A rubber fabric air-filled bag used to replace a spring.

Air suspension A type of suspension that uses air springs instead of steel springs.

AKI Anti-knock index. The octane rating posted on a gas pump, which is the average of the RON and MON octane ratings.

Alamite fitting See Zerk.

ALB Antilock brakes.

ALC Automatic level control.

ALCL Assembly line communications link.

ALDL Assembly line diagnostic link.

Align To bring the parts of a unit into the correct position.

Alkaline A substance with a pH of higher than 7.

Alkaline battery A battery that uses an alkaline (pH greater than 7) electrolyte solution.

All except questions A type of question asked on the ASE certification tests.

Alloy A metal that contains one or more other elements usually added to increase strength or give the base metal important properties.

Alnico A permanent-magnet alloy of aluminum, nickel, and cobalt.

Alternating current (AC) An electrical signal in which current and voltage vary in a repeating sequence.

Alternator An electric generator that produces alternating current; also called an AC generator.

Alternator whine A noise made by an alternator with a defective diode(s).

Altitude Elevation as measured in relationship to the earth's surface at sea level.

AM Amplitude modulation.

Amber ABS warning lamp The dash warning lamp that lights if a fault in the antilock braking system (ABS) is detected.

Ambient air temperature The temperature of the air surrounding an object.

American wire gauge (AWG) A method used to measure wire diameter.

Ammeter An electrical test instrument used to measure amperes (unit of the amount of current flow).

Ampere The unit of the amount of current flow. Named for André Ampère (1775–1836).

Ampere turns The unit of measurement for electrical magnetic field strength.

Amplitude The difference between the highest and lowest level of a waveform.

Analog A type of dash instrument that indicates values by use of the movement of a needle or similar device. An analog signal is continuous and variable.

Analog signal An electrical signal whose voltage varies.

Analog-to-digital (AD) converter An electronic circuit that converts analog signals into digital signals that can then be used by a computer.

ANC Active noise control. ANC is a function of the vehicle's sound system, and is designed to generate sound pulses that "cancel" undesirable noises from the engine compartment.

Anchor The curved end of a brake shoe where it contacts the anchor pin.

Anchor pin A steel stud firmly attached to the backing plate. One end of the brake shoes is either attached to or rests against it.

Anchor plate The support for the anchor pin on a drum brake backing plate.

Anhydrous ethanol Ethanol that has no water content.

Anode The positive electrode; the electrode toward which electrons flow.

ANSI American National Standards Institute, an organization that publishes safety standards for safety glasses and other personal protective equipment.

Antenna trimmer A method used to calibrate the antenna of a radio.

Anti-dive A term used to describe the geometry of the suspension that controls the movement of the vehicle during braking. It is normal for a vehicle to nose-dive slightly during braking and is designed into most vehicles.

Antifreeze A liquid such as ethylene glycol or propylene glycol that is used to lower the freeze point of the ICE coolant. Antifreeze also raises the coolant boiling point and contains inhibitors to prevent rust and corrosion inside the cooling system.

Antifriction bearings Bearings that use steel balls or rollers to reduce friction.

Anti-knock index A measure of a fuel's ability to resist engine knock, stated as a number, that is called the octane number.

Antilock braking system A system that is capable of pulsing the wheel brakes if lockup is detected to help the driver maintain control of the vehicle.

Antimony A metal added to nonmaintenance-free or hybrid battery grids to add strength.

Anti-rattle clips Metal clips used to eliminate or dampen noise in a brake system.

Anti-roll bar See stabilizer bar.

Anti-squat A term used to describe the geometry of the suspension that controls the movement of the vehicle body during acceleration. 100% anti-squat means that the body remains level during acceleration. Less than 100% indicates that the body "squats down," or lowers in the rear during acceleration.

Anti-sway bar See stabilizer bar.

API American Petroleum Institute.

API gravity An arbitrary scale expressing the specific gravity or density of liquid petroleum products, usually diesel fuel.

APO Auxiliary power outlet. APOs are 120-volt AC electrical outlets located on a vehicle such as the GM parallel hybrid truck or Ford Escape Hybrid.

APP Accelerator pedal position sensor. Also known as an accelerator pedal sensor (APS).

Apply system The part of a brake system that starts the operation of the brakes, including the brake pedal and levels, as well as the parking brake.

APRA Automotive Parts Rebuilders Association.

APS Accelerator pedal sensor. Also known as an accelerator pedal position sensor (APP).

Aramid Generic name for aromatic polyamide fibers developed in 1972. Kevlar is the Dupont brand name for aramid.

Armature The rotating unit inside a DC generator or starter, consisting of a series of coils of insulating wire wound around a laminated iron core.

Arming sensor A sensor used in an air bag circuit that is most sensitive and completes the circuit first of two sensors that are needed to deploy an air bag.

Armored brake line Steel brake line that has wire wrapped around it to provide protection against stones and other debris.

Articulation test A test specified by some vehicle manufacturers that tests the amount of force necessary to move the inner tie rod end in the ball socket assembly. The usual specification for this test is greater than 1 lb. (.5 Kg.) and less than 6 lbs. (2.7 Kg.) of force.

AS Air suspension.

Asbestosis A health condition where asbestos causes scar tissue to form in the lungs causing shortness of breath.

ASE Abbreviation for the National Institute for Automotive Service Excellence, a non-profit organization for the testing and certification of vehicle service technicians.

Aspect ratio The ratio of height to width of a tire. A tire with an aspect ratio of 60 (a 60 series tire) has a height (from rim to tread) of 60% of its cross-sectional width.

ASR Acceleration slip regulation.

ASTM American Society for Testing Materials.

ATC After top center.

ATDC After top dead center.

ATe Alfred Teves Engineering, a manufacturer of brake system components and systems.

Atkinson cycle An internal combustion engine design that limits the effective intake stroke in order to maximize the engine's expansion ratio. Atkinson-cycle engines produce less horsepower than Otto-cycle designs, but are more efficient overall.

Atmospheric pressure Pressure exerted by the atmosphere on all things based on the weight of the air (14.7 pounds per square inch at sea level).

Atom An atom is the smallest unit of matter that still retains its separate unique characteristic.

Atomize To reduce or separate into fine or minute particles.

AT-PZEV Advanced Technology Partial-Zero-Emission Vehicle.

Attenuation The decrease in amplitude of a signal.

Auto link A type of automotive fuse.

Auto range Activates automatic settings of the test tool to the input signal.

Automatic adjusters Drum brake adjusters that work to keep the proper clearance between the shoe lining and the brake drum.

Automatic level control A type of electronic suspension that uses air shocks to control the height of the vehicle at the rear.

Auxiliary battery The 12-volt battery in a hybrid electric vehicle.

Aviation tin snips Cutters designed to cut sheet metal.

AWG American wire gauge system.

Axial In line along with the axis or centerline of a part or component. Axial play in a ball-joint means looseness in the same axis as the ball-joint stud.

Axial load A force in line (same axis) as the centerline of the bearing or shaft.

Axial play Movement or play in the same axis as the centerline of the ball joint.

Axle windup The movement of the rear axle on a rear-wheel-drive vehicle equipped with a leaf spring-type suspension during acceleration.

B20 A blend of 20% biodiesel with 80% petroleum diesel.

Back pressure The exhaust system's resistance to flow. Measured in pounds per square inch (PSI).

Back spacing The distance between the back rim edge and the center section mounting pad of a wheel.

Backing plate A steel plate upon which the brake shoes are attached. The backing plate is attached to the steering knuckle or axle housing.

Backlight Light that illuminates the test tool's display from the back of the LCD.

Backlight The rear window of a vehicle.

Backside setting See back spacing.

Backup camera A camera mounts on the rear of the vehicle that is used to display what is behind a vehicle when the gear selector is placed in reverse.

Baffle A plate or shield used to direct the flow of a liquid or gas.

Bakelite A brand name of the Union Carbide Company for phenol formaldehyde resin plastic.

Balance shaft A shaft in the engine that is designed so that, as it rotates, it reduces or cancels out any vibration.

Ball bearings An anti-friction bearing that uses steel balls between the inner and outer race to reduce friction.

Ball joints A ball and socket joint used in the front suspension to allow up and down and turn motion of the front wheel.

Ball socket assembly An inner tie rod end assembly that contains a ball and socket joint at the point where the assembly is threaded on to the end of the steering rack.

Ballast resistor A variable resistor used to control the primary ignition current through the coil.

Ball-joint A flexible joint having a ball and socket type of construction used in suspension systems.

BARO sensor A sensor used to measure barometric pressure.

Barometric pressure The measure of atmospheric pressure, in inches of mercury (Hg), that reflects altitude and weather conditions.

Barrel A part of a micrometer, which has 40 threads per inch.

Barrel shaped A brake drum having a frictional surface that is larger in the center than at the open end or the rear of the drum.

Barrier hose A type of refrigerant hose that has an inner liner that helps prevent the loss of refrigerant.

BAS Belt Alternator Starter system. A hybrid electric vehicle system that uses a motor-generator connected to the ICE through an accessory drive belt.

Base The name for the section of a transistor that controls the current flow through the transistor.

Base brakes See service brakes.

Battery A chemical device that produces a voltage created by two dissimilar metals submerged in an electrolyte.

Battery cables Cables that attach to the positive and negative terminals of the battery.

Battery electrical drain test A test to determine if a component or circuit is draining the battery.

Battery module A number of individual cells (usually six) connected in series. NiMH cells produce 1.2 volts, so most NiMH battery modules produce 7.2 volts.

Battery vent The external air intake vent for the battery cooling system in a Ford Escape hybrid.

Battery voltage correction factor A computer problem that increases the fuel-injector pulse width if the battery voltage drops to compensate for the resulting slower opening of the injector(s).

Baud rate The speed at which bits of computer information are transmitted on a serial data stream. Measured in bits per second (bps).

BCI Battery Council International.

BCM Battery condition monitor module. On Honda HEVs, the BCM is responsible for providing information on high-voltage battery condition to other modules on the vehicle network.

Bead The part of a tire that is made of wire that the body plies are wrapped around.

Beam-type torque wrench A type of wrench that displays the torque being applied to a fastener by the position of a deflective pointer and a scale, indicating the amount of torque.

Bearing splitter A two-part steel device used between a bearing and a gear or other component, which is used to remove the bearing using a hydraulic press.

Bearingized A hard surface created inside a wheel cylinder or master cylinder by forcing a hardened steel ball through the bore.

Beehive holddown A type of hold-down spring used on drum brakes and shaped like a beehive.

Bell housing A bell-shape housing attached between the engine and the transmission.

Bell-mounted A brake drum with a frictional surface larger at the open end of the drum than at any other point toward the rear of the drum.

Belt Fabric or woven steel material over the body plies of a tire, and just under the tread area, to help keep the tread from squirming.

Belt-and-pulley CVT A continuously variable transmission (CVT) that uses a belt with two variable-width pulleys (variators) to provide an infinite number of gear ratios.

Bench grinder An electric motor with a grinding stone and/or wire brush attached at both ends of the armature and mounted on a bench.

Bench testing A test of a component such as a starter before being installed in the vehicle.

Bendix drive An inertia-type starter engagement mechanism not used on vehicles since the early 1960s.

BEV Battery electric vehicle.

BHP Brake horsepower. BHP is horsepower as measured on a dynamometer.

Bias In electrical terms, the voltage applied to a device or component to establish the reference point for operation.

Bias voltage In electrical terms, bias is the voltage applied to a device or component to establish the reference point for operation.

Bias-belted A bias ply tire with additional belt material just under the tread area.

Bias-ply The body plies cover the entire tire and are angled as they cross from bead to bead.

Bidirectional communication Computer communication that uses serial data as both an input and an output.

BIN number A United States federal rating of emissions. The lower the BIN number, the cleaner the exhaust emission is.

Binary system A computer system that uses a series of zeros and ones to represent to information.

Biodiesel A renewable fuel manufactured from vegetable oils, animal fats, or recycled restaurant grease.

Biomass Nonedible farm products, such as corn stalks, cereal straws, and plant wastes from industrial processes, such as sawdust and paper pulp used in making ethanol.

Bipolar transistor A type of transistor that has a base, emitter, and collector.

Bit The individual voltage signal of a serial data stream; also, the smallest unit of measurement recognized by a computer.

BJB Battery junction box. The power distribution box located near the battery in the ICE compartment.

BJI Ball joint inclination.

Bleeder screw A valve in wheel cylinders (and other locations) for bleeding air from the hydraulic system.

Bleeder valve A threaded valve used to bleed air from a brake hydraulic system.

Blend door An air mix valve located in the air distribution box of a HVAC system. The blend door blends air from the A/C evaporator with warm air from the heater core to deliver air at the desired temperature at the outlet ducts.

Block The foundation of any engine. All other parts are either directly or indirectly attached to the block of an engine.

Blow-by gases Combustion gases that leak past the piston rings into the crankcase during the compression and combustion strokes of the engine.

Blower motor An electric motor and squirrel cage type of fan that moves air inside the vehicle for heating, cooling, and defrosting.

Bluetooth A short range wireless communication standard named after a Danish king that had a bluetooth.

BNC connector Coaxial-type input connector. Named for its inventor, Neil Councilman.

BOB Break out box.

Body ply A layer of cloth that gives a tire its strength.

Bolt circle The diameter (in inches or millimeters) of a circle drawn through the center of the bolt holes in a wheel.

Bonded linings Brake linings that are glued or bonded to the brake shoes.

Boost An increase in air pressure above atmospheric. Measured in pounds per square inch (psi).

Boost converter An electronic component that increases voltage from a DC power source. Toyota's THS II system utilizes a boost converter to increase electric drive motor efficiency.

Boost system The component in the brake system used to increase the brake pedal force.

Boots Rubber dust protectors on the ends of wheel cylinder or caliper.

Bore The inside diameter of the cylinder in an engine.

Bottom dead center (BDC) The lowest position in the cylinder that a piston can travel without reversing its direction.

Bounce test A test used to check the condition of shock absorbers.

Bound electrons Electrons that are close to the nucleus of the atom.

Boxer A type of engine design that is flat and has opposing cylinders. Called a boxer because the pistons on one side resemble a boxer during engine operation. Also called a pancake engine.

BPMV Brake pressure modulator valve.

BPP Brake pedal position.

Braided ground straps Ground wires that are not insulated and braided to help increase flexibility and reduce RFI.

Brake Any device that is designed to slow or stop a mechanism or component.

Brake block Brake pad material is pressed into a brake block before being heated to become a brake pad.

Brake control system The component in a brake system that ensures that the wheel brakes are applied quickly and balanced among all four wheels for safe operation.

Brake fade A result of heat buildup. It is the reduction in braking force due to loss of friction between the brake shoes and the drum or between the disc brake pads and the rotor.

Brake fluid A non-petroleum-based fluid called polyglycol used in hydraulic brake systems.

Brake fluid level sensor A sensor used in the brake fluid reservoir to detect when brake fluid is low and turns on the red brake warning light on the dash.

Brake hardware kit Springs, clips, and other hardware items to replace the original items when the brake lining or pads are replaced.

Brake light switch A switch located on the brake pedal linkage used to turn on the rear brake lights.

Brake lines Steel tubes used to transmit brake fluid pressure.

Brake lining A friction material fastened to the brake shoes. It is pressed against the rotating brake drum to accomplish braking.

Brake pad The brake friction material used in disc brakes.

Brake pedal The pedal depressed by the driver to operate the wheel brakes.

Brake pipes Lines that carry brake fluid from the master cylinder to the wheel brakes.

Brake return springs The springs used on a drum brake to retract the linings away from the drum when the brakes are released.

Brake shoe The part of the brake system upon which the brake lining is attached.

Brake shoe holddown spring Springs or clips used to hold brake shoes against the backing plate.

Brake shoes The part of the brake system upon which the brake lining is attached.

Brake tubing Pipes used to carry brake fluid from the master cylinder to the wheel brakes.

Brake warning lights Include the red brake warning light and the amber ABS warning light.

Branches Electrical parts of a parallel circuit.

Breaker bar A handle used to rotate a socket; also called a flex handle.

Breather tube A tube that connects the left and right bellows of a rack and pinion steering gear.

Breakout box A piece of test equipment that installs between an electrical/electronic component, such as a controller, and the wiring harness.

Breather port Another name for the master cylinder replenishing port (rearward port).

Breather tube A tube that connects the left and right bellows of a rack and pinion steering gear.

Brinelling A type of mechanical failure used to describe a dent in metal such as what occurs when a shock load is applied to a bearing. Named after Johann A. Brinell, a Swedish engineer.

British thermal unit (BTU) The amount of heat required to raise 1 pound of water 1°F at sea level.

Brush-end housing The end of a starter or generator (alternator) where the brushes are located.

Brushes A copper or carbon conductor used to transfer electrical current from or to a revolving electrical part such as that used in an electrical motor or generator.

Brushless motor An electric motor that does not use brushes or a commutator. Instead, brushless motors are typically constructed with permanent magnets in the rotors and are powered by three-phase alternating current.

BTDC Before top dead center.

BTU British thermal unit. A measure of heat energy. One BTU of heat will raise the temperature of one pound of water one Fahrenheit degree.

Buffer A component or circuit used to reduce the interaction between two electronic circuits.

Bulb test A test to check the operation of certain circuits controlled by the ignition switch.

Bulkhead The panel between the engine compartment and the passenger compartment.

Bump cap A hat that is plastic and hard to protect the head from bumps.

Bump steer A term used to describe what occurs when the steering linkage is not level causing the front tires to turn inward or outward as the wheels and suspension move up and down. Automotive chassis engineers call it "roll steer."

Bump stop A rubber or urethane stop to limit upward suspension travel. Also called a strikeout bumper, suspension bumper, or compression bumper.

Burn in A process of operating an electronic device for a period from several hours to several days.

BUS A term used to describe a communication network.

Bypass port Another name for the master cylinder vent port (forward port).

Bypass tube A tube located in the engine water jacket that allows coolant to bypass the radiator and be sent directly to the water pump inlet when the thermostat is closed.

Bypassing A type of fault when brake fluid flows past cup seals and enters another chamber.

Byte Eight bits of computer information that are processed as a unit and are transmitted in sequence on the serial data stream. Also known as a "word."

CA Cranking amperes. A battery rating.

CAA Clean Air Act. Federal legislation passed in 1970 that established national air quality standards.

CAB Controller antilock brake.

Cabin filter A filter located in the air intake of the HVAC system.

CAFE Corporate average fuel economy.

Cage The support for rollers or ball bearings.

Calcium A metallic chemical element added to the grids of a maintenance-free battery to add strength.

Calendar year (CY) A calendar year is from January 1 through December 31 each year.

Calibration codes Codes used on many powertrain control modules.

California Air Resources Board (CARB) A state of California agency which regulates the air quality standards for the state.

Caliper The U-shaped housing that contains the hydraulic pistons and holds the pads on disc brake applications.

Camber The inward or outward tilt of the wheels from true vertical as viewed from the front or rear of the vehicle. Positive camber means the top of the wheel is out from center of the vehicle more than the bottom of the wheel.

Camber roll The camber angle of the front wheels due to caster.

Cam-in-block design An engine where the crankshaft is located in the block rather than in the cylinder head.

Campaign A recall where vehicle owners are contacted to return a vehicle to a dealer for corrective action.

Camshaft A shaft with lobes which open valves when being rotated through a chain, belt, or gear from the crankshaft.

(CAN) Controller Area Network A type of serial data transmission.

Candlepower Measures the amount of light produced by a bulb.

Cap screw A bolt that is threaded into a casting.

Capacitance Electrical capacitance is a term used to measure or describe how much charge can be stored in a capacitor (condenser) for a given voltage potential difference. Capacitance is measured in farads or smaller increments of farads such as microfarads.

Capacitor A condenser: an electrical unit that can pass alternating current, yet block direct current. Used in electrical circuits to control fluctuations in voltage.

Capillary action The movement of a liquid through tiny openings or small tubes.

CARB See California Air Resources Board.

Carbohydrates Chemical compounds that store energy and contain carbon, hydrogen, and oxygen atoms.

Carbon An element found in all organic materials. Carbon combines with oxygen to form carbon monoxide (CO) and carbon dioxide (CO_2).

Carbon dioxide (CO_2) A colorless, odorless, nonflammable gas produced during the combustion process. The amount (%) in the exhaust can be used to evaluate the efficiency of an engine's combustion process.

Carbon footprint The net amount of carbon emitted into the atmosphere through processes such as combustion. Burning of fossil fuels is considered to have a large carbon footprint.

Carbon monoxide (CO) A colorless, odorless, and highly poisonous gas. It is formed by the incomplete combustion of gasoline.

Carbon pile An electrical test instrument used to provide an electrical load for testing batteries and the charging circuit.

Carbonated water Water containing dissolved carbon dioxide. The carbon dioxide remains in solution when under pressure and is released when its container is opened to the atmosphere.

Carcass ply Plies of fabric in a tire that covers the entire tire from bead to bead.

Cardan joint A type of universal joint named for a 16th century Italian mathematician.

Caster The forward or backward tilt of an imaginary line drawn through the steering axis as viewed from the side of the vehicle. Positive caster is where an imaginary line would contact the road surface in front of the contact path of the tire.

Caster sweep A process used to measure caster during a wheel alignment procedure where the front wheels are rotated first inward, then outward, a specified amount.

Casting number An identification code cast into an engine block or other large cast part of a vehicle.

Castle nut A nut with notches cut out around the top to allow the installation of a cotter key to keep the nut from loosening.

CAT III An electrical measurement equipment rating created by the International Electrotechnical Commission (IEC). CAT III indicates the lowest level of instrument protection that should be in place when performing electrical measurements on hybrid electric vehicles.

Catalytic converter An emission control device located in the exhaust system that changes HC and CO into harmless H_2O and CO_2. If a three-way catalyst NOx is also divided into harmless separate nitrogen (N_2) and Oxygen (O_2).

Catalytic cracking Breaking hydrocarbon chains using heat in the presence of a catalyst.

Cathode The negative electrode.

Cavitation A process of creating a cavity or void area. Cavitation is usually used in the automotive field to describe what happens in the cooling system when water boils, creating a bubble in the system, and then cools below 212°F, which causes the bubble to collapse. When this event occurs, water rushes back into the void left by the bubble. The force of this moving water can cause noise as well as damage to cooling system parts such as water pumps.

CCA Cold Cranking Amps. A rating of a battery tested at zero degrees F.

CCC Computer command control is the name of General Motors' Computer Control System that uses a carburetor.

CCD Chrysler Collision Detection, a type of serial data transmission.

CCR Computer Command Ride.

CCVRTMR Chassis continuously variable real time dampening magneto-rheological. A type of electronic controlled suspension.

Cd Coefficient of drag. A measure of the aerodynamic efficiency of a vehicle.

Cell A group of negative and positive plates to form a cell capable of producing 2.1 V.

Cellulose ethanol Ethanol produced from biomass feedstock such as agricultural and industrial plant wastes.

Celsius A temperature scale where zero degrees is the freezing point of water (32 degrees F) and 100 degrees is the boiling point of water (212 degrees F).

CEMF Counter electromotive force.

Center bolt A bolt used to hold the leaves of a leaf spring together in the center. Also called a centering pin.

Center link The center part of a parallelogram-type steering linkage.

Center section The section of a wheel that attaches to the hub. Also called the spider.

Center support bearing A bearing used to support the center of a long drive shaft on a rear-wheel-drive vehicle. Also called a steady bearing.

Center take off rack A type of rack and pinion steering gear where the tie rods are attached to the center of the rack rather than at the ends of the rack.

Center valve A valve used in some master cylinders that allows brake fluid to flow into and out of the reservoir without causing harm to lip seals.

Centering pin See center bolt.

Centerline steering A term used to describe the position of the steering wheel while driving on a straight level road. The steering wheel should be centered or within plus or minus 3 degrees as specified by many vehicle manufacturers.

Centrifugal advance A spark advance mechanism that uses centrifugal force (outward force centrifugal force (outward force increases with rotational speed) to increase timing advance in proportion to engine speed.

Cetane rating A diesel fuel rating that indicates how easily the fuel can be ignited.

CFL Cathode fluorescent lighting.

CFR Code of Federal Regulations.

CFRC Carbon fiber reinforced carbon.

Change of state The process where a material absorbs or releases heat energy to change between solid, liquid, and gaseous states.

Channel A term used to describe a wheel brake being controlled by the antilock brake system controller.

Chapman strut A MacPherson strut-type of suspension used at the rear of the vehicle.

Charge indicator A hydrometer built into one battery cell that gives a visual indication of the state of charge.

Charging circuit Electrical components and connections necessary to keep a battery fully charged.

Charging voltage test An electrical test using a voltmeter and an ammeter to test the condition of the charging circuit.

Chassis The frame, suspension, steering, and machinery of a motor vehicle.

Chassis ground In electrical terms, a ground is the desirable return circuit path.

Chatter Sudden grabbing and releasing of the drum when brakes are applied.

Cheater bar A pipe or other object used to lengthen the handle of a ratchet or breaker bar. Not recommended to be used as the extra force can cause the socket or ratchet to break.

Check ball A steel ball used to stop the flow of fluid in one direction only.

Check engine light A dashboard warning light that is controlled by the vehicle computer. Also called the malfunction indicator light (MIL).

Chill spots Hard stops on a brake rotor or brake drum.

Chisel A sharpened tool used with a hammer to separate two pieces of an assembly.

CHMSL Centrally High Mounted Stop Light; the third brake light.

Christmas tree clips Plastic clips used to hold interior panels in place. The end that goes into a hole in the steel door panel is tapered and looks like a Christmas tree.

Circuit A circuit is the path that electrons travel from a power source, through a resistance, and back to the power source.

Circuit breaker A mechanical unit that opens an electrical circuit in the event of excessive flow.

City tax A typical payroll deduction.

CKP Crankshaft position sensor.

Clamping diode A diode installed in a circuit with the cathode toward the positive. The diode becomes forward biased when the circuit is turned off thereby reducing the high voltage surge created by the current flowing through a coil.

Class 2 A type of BUS communication used in General Motors vehicles.

Claw poles The magnetic points of a generator (alternator) rotor.

C-lock axle A type of rear differential that uses a C-lock to retain the axles.

Clock generator A crystal that determines the speed of computer circuits.

Clock in The act of recording the time when a technician reports for work or when work is started on a vehicle.

Clock time The time charged to complete a service procedure, which is determined by the actual time spent.

Clockspring A flat ribbon of wire used under the steering wire to transfer airbag electrical signals. May also carry horn and steering wheel control circuits depending on make and model of vehicle.

Close end An end of a wrench that grips all sides of the fastener.

Closed loop operation A phase of computer-controlled engine operation in which oxygen sensor feedback is used to calculate air/fuel mixture.

Clutch Any device that is made to couple one mechanism with another to cause each to rotate at the same speed.

CMOS Complementary metal oxide semiconductor.

CMP Camshaft position sensor.

CNG Compressed natural gas.

CO Carbon monoxide.

Coach A role played by a mentor.

Coal-to-liquid (CTL) A refining process in which coal is converted to liquid fuel.

Cold chisel A type of chisel used to remove rivets or to break off fasteners.

Cold climate fluid A typical power steering fluid recommended for use in cold climates.

Cold-cranking amperes (CCA) The rating of a battery's ability to provide battery voltage during cold-weather operation. CCA is the number of amperes that a battery can supply at 0°F (−18°C) for 30 seconds and still maintain a voltage of 1.2 V per cell (7.2 V for a 12-V battery).

Cold solder joint A type of solder joint that was not heated to high enough temperature to create a good electrical connection. Often a dull gray appearance rather than shiny for a good solder connection.

Coefficient of drag (Cd) A calculation of the amount of aerodynamic drag created by a vehicle's body. A higher coefficient of drag indicates more wind resistance created by the vehicle.

Coefficient of friction A measure of the amount of friction usually measured from 0 to 1. A low number (0.3) indicates low friction and a high number (0.9) indicates high friction.

Coil spring A spring steel rod wound in a spiral (helix) shape. Used in both front and rear suspension systems.

Coil-on-plug ignition system An ignition system without a distributor, where each spark plug is integrated with an ignition coil.

Collapsible column A steering column which collapses in the event of a front impact to the vehicle to help prevent injury to the driver.

Collector The name of one section of a transistor.

Color shift A term used to describe the change in the color of an HID arc tube assembly over time.

Combination circuit Another name for a series-parallel electrical circuit.

Combination wrench A wrench that is open ended at one end and has a box end at the other end.

Combination valve A valve used in the brake system that performs more than one function, such as a pressure differential switch, metering valve, and/or proportioning valve.

Combination wrench A type of wrench that has an open end at one end and a closed end at the other end of the wrench.

Combustion The rapid burning of the air-fuel mixture in the engine cylinders, creating heat and pressure.

Combustion chamber The space left within the cylinder when the piston is at the top of its combustion chamber.

Commission pay Income to a service technician determined by the number of hours that a flat-rate manual states in the time it should take multiplied by the hourly rate of the technician.

Commutator The name for the copper segments of the armature of a starter or DC generator.

Commutator-end housing The end of a starter motor that contains the commutator and brushes. Also called the brush end housing.

Companion flange The part that attaches to the driveshaft at the differential assembly.

Compensating port The port located in the master cylinder that allows excess fluid to return to the reservoir. See also vent port.

Compensation A process used during a wheel alignment procedure where the sensors are calibrated to eliminate errors in the alignment readings that may be the result of a bent wheel or unequal installation of the sensor on the wheel of the vehicle.

Complete circuit A type of electrical circuit that has continuity and current would flow if connected to power and ground.

Composite A term used to describe the combining of individual parts into a larger component. For example, a composite leaf spring is constructed of fiberglass and epoxy and a composite master brake cylinder contains both plastic parts (reservoir) and metal parts (cylinder housing).

Composite headlights A type of headlights that uses a separate, replaceable bulb.

Composite leaf spring A leaf spring made from a composite material, which usually includes fiberglass and epoxy resin.

Compound circuit Another name for a series-parallel electrical circuit.

Compound wound A type of electric motor where some field coils are wired in series and some field coils are wired in parallel with the armature.

Compression bumper See jounce bumper.

Compression ratio (CR) The ratio of the volume in the engine cylinder with the piston at bottom dead center (BDC) to the volume at top dead center (TDC).

Compression rod See strut rod.

Compression spring A spring which is part of a starter drive that acts on the starter pinion gear.

Compressor An A/C system component that compresses refrigerant vapor and circulates refrigerant throughout the system.

Computer Any device that can perform high-speed mathematical or logical calculations and otherwise process data.

Computer command control (CCC or C³) The name of General Motors' computer engine computer engine control system that uses a carburetor.

Concentric Perfectly round—the relationship of two round parts on the same center.

Condenser An A/C system component located in front of the radiator in most vehicles that removes heat from the refrigerant and causes it to change from a gas to a liquid.

Condenser (electrical) Also called a capacitor; stores an electrical charge.

Conductance The plate surface area in a battery that is available for chemical reaction. Battery condition can be assessed using a measurement of its conductance.

Conductor A material that conducts electricity and heat. A metal that contains fewer than four electrons in its atom's outer shell.

Cone A tapered metal cone with a hole in the center. Used to center a hubless brake drum or rotor on a brake lathe.

Conicity A fault in a tire that causes it to be shaped like a cone and causes a pull.

Constant velocity joint Commonly called CV joints. CV joints are drive line joints that can transmit engine power through relatively large angles without a change in the velocity as is usually the case with conventional Cardan-type U-joints.

Continuity Instrument setup to check wiring, circuits, connectors, or switches for breaks (open circuit) or short circuits (closed circuit).

Continuity light A test light that has a battery and lights if there is continuity (electrical connection) between the two points that are connected to the tester.

Control arms A suspension link that connects a knuckle or wheel flange to the body or frame of the vehicle.

Control module An electronic device used to control the operation of activities.

Control wires The wires used in a power window circuit that are used to control the operation of the windows.

Controller A term that is usually used to refer to a computer or an electronic control unit (ECU).

Convection The movement of heat from the friction surface of a brake drum or rotor to the cooler part of the drum or rotor.

Conventional ignition system Ignition system that uses a distributor; also called distributor ignition (DI).

Conventional theory The theory that electricity flows from positive (+) to negative (−).

Coolant The liquid mixture in the engine cooling system.

Coolant heat storage system A system used on the second generation Toyota Prius that stores hot coolant in order to warm the engine prior to a cold start.

Coolant recovery reservoir An external storage tank for the engine cooling system.

COP Coil-on-plug. This term describes ignition systems in which each spark plug has its own coil assembly mounted directly over top of it. Also known as coil-over-plug, coil-by-plug, or coil-near-plug ignition.

Core charge An amount of money paid when a rebuildable part is purchased and refunded when the worn or defective part is returned to the parts store.

Cotter Key A metal loop used to retain castle nuts by being installed through a hole. Size is measured by diameter and length (for example, 1/8" × 1 1/2"). Also called a cotter pin. Named for the old English verb meaning "to close or fasten."

Coulomb A measurement of electrons. A coulomb is 6.28 × 101 (6.28 billion billion) electrons.

Counter electromotive force (cemf) A voltage produced by a rotating coil such as a starter motor where the armature is being moved through a magnetic field.

Country of origin The first number of the vehicle identification number (VIN), which identifies where the vehicle was assembled.

Coupling disc See flexible coupling.

Courtesy light General term used to describe all interior lights.

Cow Catcher A large spring seat used on many General Motors MacPherson strut units. If the coil spring breaks, the cow catcher is designed to prevent one end of the spring from moving outward and cutting a tire.

CPA Connector Position Assurance. A clip used to help hold the two parts of electrical connector together.

CPU Central Processor Unit.

CR See compression ratio.

Cracking A refinery process in which hydrocarbons with high boiling points are broken into hydrocarbons with low boiling points.

Cradle A structural support for the engine and transaxle on a front-wheel-drive vehicle.

Cranking amperes A battery rating tested at 32°F (0°C).

Cranking circuit Electrical components and connections required to crank the engine to start. Includes starter motor, starter solenoid/relay, battery, neutral safety switch, ignition control switch, and connecting wires and cables.

Creeper A small platform mounted on short casters designed for a service technician to lie down and maneuver under a vehicle.

Crest The outside diameter of a bolt measured across the threads.

Crimp and seal connectors A type of electrical connector that has glue inside which provides a weather-proof seal after it is heated.

Cross camber/caster The difference of angle from one side of the vehicle to the other. Most manufacturers recommend a maximum difference side-to-side of 1/2 degree for camber and caster.

Crossflow A radiator that is designed so the coolant flows through it horizontally.

Crossover An electronic circuit that separates frequencies in a sound (audio) system.

Cross steer A type of steering linkage commonly used on light and medium trucks.

Cross-steer linkage A type of steering linkage commonly used on light and medium trucks.

Crowfoot socket A type of socket that slips onto the side of the bolt or nut. Used where direct access from the top is restricted.

CRT Cathode ray tube.

Cruise control A system that maintains the desired vehicle speed. Also called speed control.

CTL Coal-to-liquid. See Coal-to-liquid.

Cunife A magnetic alloy made from copper (Cu), nickel (Ni), and iron (Fe).

Cup Rubber seals that have a lip which forces toward where pressure is increased.

Cup The outer race or ring of a bearing.

Cuppy tire wear Scalloped tire wear usually on the inside or outside edges caused by defective or worn shock absorbers or other faults in the suspension system.

Current Electron flow through an electrical circuit; measured in amperes.

CV joint boot The covering over a constant velocity joint made from rubber, thermoplastic, or urethane.

CVT Continuously variable transmission. A transmission that is designed to utilize an infinite number of gear ratios during normal operation.

CY See calendar year.

Cycle life The number of times a battery can be charged and discharged without suffering significant degradation in its performance.

Cylinder deactivation A phase of internal combustion engine operation in which the valves of certain cylinders are disconnected from the valve train and remain closed. This allows the engine to operate on fewer cylinders for greater fuel economy and efficiency.

Cylinder hone A tool that uses an abrasive to smooth out and bring to exact measurement such things as wheel cylinders.

Cylindrical cell A battery cell that is constructed similar to a D cell.

Darlington pair Two transistors electrically connected to form an amplifier. This permits a very small current flow to control a large current flow. Named for Sidney Darlington, a physicist at Bell Laboratories from 1929 to 1971.

Data Information used as a basis for mechanical or electronic computation.

dB An abbreviation for decibel, a measure of relative noise level.

DC Direct current.

DC brushless motor An electric motor that uses a three-phase stator coil with a brushless permanent magnet rotor. Also called an AC synchronous motor.

DC coupling A signal transmission that passes both AC and DC signal components to the meter. (Also see AC coupling.)

DC motor An electric motor powered by direct current (DC).

DC-to-DC converter An electronic component found in a hybrid electric vehicle that converts high-voltage DC to 12-volts DC for charging the auxiliary battery.

Dead-blow hammer A type of hammer that has lead shot (small pellets) inside a steel housing, which is then covered with a plastic covering. Used to apply a blunt force to an object.

Deceleration sensor A sensor mounted to the body of frame of a vehicle that detects and measures the deceleration of the vehicle. Used to control the activation of the air bags and vehicle stability systems.

Decibel (dB) A unit of the magnitude of sound.

Deep cycling The full discharge and then the full recharge of a battery.

Default setup The setup that exists as long as there are no changes made to the settings.

Deflection A bending or distorting motion. Usually applied to a brake drum when it is forced out-of-round during brake application.

Degrees A degree is 1/360th of a circle.

Delta wound A type of stator winding where all three coils are connected in a triangle shape. Named for the triangle-shape Greek capital letter.

Desiccant An ingredient, such as silica gel used to remove moisture from air. Used in electronic systems that uses air shocks or springs.

Despiking diode Another name of clamping diode.

Detonation A violent explosion in the combustion chamber created by uncontrolled burning of the air-fuel mixture; often causes a loud, audible knock. Also known as spark knock or ping.

DI Distillation index. A rating of the volatility of a fuel and how well it evaporates in cold temperatures.

Diagnostic trouble code (DTC) An alphanumeric or numeric sequence indicating a fault in a vehicle operating system. Each sequence corresponds to a specific malfunction.

Diagonal pliers Pliers designed to cut wire and to remove cotter keys. Also called side cuts or dike pliers.

Diagonal split master cylinder A master cylinder for front-wheel vehicles that contains two circuits—one for the LF and LR wheel brakes and the other for the RF and LR wheel brakes.

Diaphragm A flexible cloth/rubber sheet that is stretched across an area, separating two different compartments.

DIC Driver Information Center. The instrument panel readout on a vehicle that provides extra information about vehicle operation and diagnostics.

Die grinder A handheld air-operated tool used with a grinding stone or a wire brush.

Dielectric strength Resistance to electrical penetration.

Diesohol Standard #2 diesel fuel combined with up to 15% ethanol.

Diff An abbreviation or slang for differential.

Differential A mechanical unit containing gears that provides gear reduction and a change of direction of engine power and permits the drive wheels to rotate at different speeds as is required when turning a corner.

Differential measurement (delta) Measurement of the difference between the waveform sample values at the position of the two cursors.

Digital A method of display that uses numbers instead of a needle or similar device.

Digital computer A computer that uses on and off signals only. Uses an A to D converter to change analog signals to digital before processing.

Digital signal An electrical signal that is either ON or OFF with no in between.

Dimmer switch An electrical switch used to direct the current to either bright or dim headlight filaments.

Diode An electrical device that allows current to flow in one direction only.

Diode trio A group of three diodes grouped together with one output used to put out the charge indicator lamp and provide current for the field from the stator windings on many alternators.

Direct current (DC) A constant electric current that flows in one direction only.

Direct drive A drive train that rotates the output shaft at the same speed as the input shaft. A direct drive has a gear ratio of 1:1.

Direction wires The wires from the control switch to the lift motor on a power window circuit. The direction of current flow through these wires determines which direction the window moves.

Directional stability Ability of a vehicle to move forward in a straight line with a minimum of driver control. Cross winds and road irregularities will have little effect if directional stability is good.

DIS Distributorless ignition system; also called direct-fire ignition system.

Disc brakes A type of wheel brake that squeezes two brake pads on both sides of a rotor or disc.

Discs Another name for brake rotors.

Displacement The total volume displaced or swept by the cylinders in an internal combustion engine.

Distillation The process of purification through evaporation and then condensation of the desired liquid.

Distillation curve A graph that plots the temperatures at which the various fractions of a fuel evaporate.

Distributor Electromechanical unit used to help create and distribute the high voltage disturb the function of the signal when it exceeds a certain electrical level.

Division A specific segment of a waveform, as defined by the grid on the display.

DMM Digital multimeter. A digital multimeter is capable of measuring electrical current, resistance, and voltage.

Dog tracking A term used to describe the condition where the rear wheels do not follow directly behind the front wheels. Named for the way many species of dogs run with their rear paws offset toward one side so their rear paws will not hit their front paws while running.

Doping The adding of impurities to pure silicon or germanium to form either P or N type material.

DOT Abbreviation for the Department of Transportation.

DOT 3 Rating of the most commonly specified brake fluid.

DOT 4 A brake fluid rating for polyglycol.

DOT 5 Silicone brake fluid rating.

DOT 5.1 The highest rated polyglycol brake fluid.

DOT tire code The Department of Transportation. Tire code includes numbers and letters that indicate the tire manufacturer and week and year of production.

Double Cardan A universal joint that uses two conventional Cardan joints together to allow the joint to operate at greater angles.

Double-cut file A file that has two rows of teeth that cut at an opposite angle.

Double flare A tubing end made such that the flare area has two wall thickness.

Double-trailing shoe A type of non-servo drum brake when both shoes are the same size that are applied with equal force by a pair of wheel cylinders.

Downflow radiator A radiator design in which coolant flows vertically (top to bottom).

DPDT switch Double-pole, double-throw switch.

DPST Double pole, single throw switch.

Drag link Used to describe a link in the center of the steering linkage; usually called a center link.

Drag rod See strut rod.

Drift A mild pull that does not cause a force on the steering wheel that the driver must counteract (also known as lead). Also refers to a tapered tool used to center a component in a bolt hole prior to installing the bolt.

Drive axle shaft The shaft that connects the transaxle or differential to the drive wheels.

Drive-by-wire Another term for electronic throttle control. See ETC.

Drive-end (DE) housing The end of a starter motor that has the drive pinion gear.

Drive plate A flywheel that is used on an engine equipped with an automatic transmission.

Drive shaft A shaft that transfers engine torque from the output of the transmission to the rear axle (differential) assembly.

Drive size The size in fractions of an inch of the square drive for sockets.

Driveability The general evaluation of an engine's operating qualities, including idle smoothness, cold and hot starting, throttle response, and power delivery.

Driveline angles The angles of the driveshaft at the front and rear, which are equal, plus or minus 0.5 degrees.

Driver select switch A switch which allows the driver to select the harshness of the suspension.

Driveshaft runout A measurement of the amount a driveshaft is from perfectly round when rotated.

DRL Daytime Running Lights. Lights that are on located in the front of the vehicle and come on whenever the ignition is on. In some vehicles the vehicle has to be moving before they come on. Used as a safety device on many vehicles and required in many countries such as Canada since 1990.

Dropping point The temperature at which a grease passes from a semi-solid to a liquid state under conditions specified by ASTM.

Drum brakes A type of wheel brake that uses expanding brake shoes inside a brake drum.

Dry charged Emptying the electrolyte from a fully charged lead-acid battery in order to store or ship it. Dry-charged batteries are filled with electrolyte before being put back into service.

Dry park test A test of steering and/or suspension components. With the wheels in the straight ahead position and the vehicle on flat level ground, have an assistant turn the steering wheel while looking and touching all steering and suspension components looking for any looseness.

DSO Digital Storage Oscilloscope.

Dual diameter bore master cylinder A master cylinder designed to work with low-drag calipers that uses two different bore sizes.

Dual diaphragm A type of vacuum booster that uses two parallel diaphragms.

Dual inline pins (DIP) A type of electronic chip that has two parallel lines of pins.

Dual-mass flywheel A flywheel that consists of two parts separated by springs used to absorb vibration in the drive line.

Dual master cylinder A two compartment master cylinder.

Dual overhead camshaft (DOHC) An engine design with two camshafts above each line of cylinders—one for the exhaust valves and one for the intake valves.

Dual servo brake A drum brake design where the primary (forward facing) brake shoe exerts force against the secondary (rearward facing) brake shoe during braking while the vehicle is traveling forward.

Dual split master cylinder A tapered master cylinder for a rear-wheel drive vehicle which has two different portions—one for the front wheel brakes and the other for the rear wheel brakes.

Dual-stage airbags Airbags that can deploy either with minimum force or full force or both together based on the information sent to the airbag controller regarding the forces involved in the collision.

Duo-Servo Brand name of a Bendix dual-servo drum brake.

Duration A rating system applied to engine camshafts that determines how long the valve will be open, relative to crankshaft movement in degrees.

Durometer The hardness rating of rubber products named for an instrument used to measure hardness that was developed about 1890.

Dust Cap A functional metal cap that keeps grease in and dirt out of wheel bearings. Also called a grease cap.

Duty cycle Refers to the percentage of on-time of the signal during one complete cycle.

DVOM Digiatl volt-ohm-milliammeter.

Dwell The amount of time, recorded on a dwell meter in degrees, that voltage passes through a closed switch.

Dynamic balance When the weight mass centerline of a tire is in the same plane as the centerline of the object.

Dynamic seals Seals used between two surfaces where there is movement.

Dynamic voltage Voltage measured with the circuit energized and current flowing through the circuit.

E10 A fuel blend of 10% ethanol and 90% gasoline.

E85 A fuel blend of 85% ethanol and 15% gasoline.

Earth ground The most grounded ground. A ground is commonly used as a return current path for an electrical circuit.

Easy out A tool used to extract a broken bolt.

EBCM Electronic brake control module.

EBTCM Electronic brake traction control module.

E & C Entertainment and comfort.

ECA Electronic Control Module. The name used by Ford to describe the computer used to control spark and fuel on older model vehicles.

ECB Electronically controlled braking system used on hybrid electric vehicles. Also called regenerative braking systems.

Eccentric The relationship of two round parts having different centers. A part which contains two round surfaces, not on the same center.

Eccentric distortion A fault with brake drums where the geometric centerline of the drum is different from the centerline of the axle.

Eccentric cam A plate that has a bolt offset from the center used to change camber and/or caster.

ECM Electronic control module on a vehicle.

ECU Electronic control unit on a vehicle.

eCVT Electronic continuously variable transmission.

E-diesel Standard #2 diesel fuel combined with up to 15% ethanol. Also known as diesohol.

EDR Event data recorder. The hardware and software used to record vehicle information before, during and after an airbag deployment.

EEPROM Electronically erasable programmable read-only memory.

EFI Electronic fuel injection.

EGR Exhaust gas recirculation. An emission control device to reduce NO_x (oxides of nitrogen).

EHCU Electro-hydraulic control unit.

EHPS Electro-Hydraulic Power Steering.

EI Electronic ignition. An SAE term for an ignition system that does not use a distributor.

Elastic limit The limit of movement of brake shoes due to the metal not being able to return to its original dimensions.

Elastomer Another term for rubber.

Electrical load Applying a load to a component such as a battery to measure its performance.

Electrical potential Another term to describe voltage.

Electricity The movement of free electrons from one atom to another.

Electrochemistry The term used to describe the chemical reaction that occurs inside a battery to produce electricity.

Electrode A solid conductor through which current enters or leaves a substance, such as a gas or liquid.

Electrolyte Any substance which, in solution, is separated into ions and is made capable of conducting an electric current. The acid solution of a lead-acid battery.

Electromagnet An electromagnet consists of a soft iron core surrounded by a coil of wire. Electrical current flowing through the coiled wire creates a magnetic field around the core.

Electromagnetic gauges A type of dash instrument gauge that uses small electromagnetic coils.

Electromagnetic induction The generation of a current in a conductor that is moved through a magnetic field. Electromagnetic induction was discovered in 1831 by Michael Faraday.

Electromagnetic interference (EMI) An undesirable electronic signal. It is caused by a magnetic field building up and collapsing, creating unwanted electrical interference on a nearby circuit.

Electromagnetism A magnetic field created by current flow through a conductor.

Electromotive force (EMF) The force (pressure) that can move electrons through a conductor.

Electron A negative-charged particle: 1/1800 the mass of a proton.

Electron theory The theory that electricity flows from negative (−) to positive (+).

Electronic brake proportioning The control of the rear brakes during heavy braking is controlled by the ABS controller instead of using a proportioning valve.

Electronic circuit breaker See PTC.

Electronic ignition General term used to describe any of various types of ignition systems that use electronic instead of mechanical components, such as contact points.

Electronic spark control (ESC) Means that the computer system is equipped with a knock sensor that can retard spark advance if necessary to eliminate spark knock.

Electronic spark timing (EST) The computer controls spark timing advance.

Element Any substance that cannot be separated into different substances.

EM Electric machine. A term used to describe any device, such as an electric motor, that converts mechanical energy into electrical energy or electrical energy to mechanical energy.

Emergency brake See parking brake.

E-metric A tire designation for electric vehicles, which have low rolling resistance.

EMF Electromotive force.

EMI Electromagnetic interference. An undesirable electronic signal. It is caused by a magnetic field building up and collapsing, creating unwanted electrical interference on a nearby circuit.

Emissions Gases and particles left over after the combustion event of an engine. The primary emissions of concern are hydrocarbons, carbon monoxide, and oxides of nitrogen.

Emitter The name of one section of a transistor. The arrow used on a symbol for a transistor is on the emitter and the arrow points toward the negative section of the transistor.

Endplay The movement in line with the centerline of an assembly.

Energized shoe A brake shoe that receives greater applied force from wheel rotation.

Energy Capacity for performing work.

Energy carrier Any medium that is utilized to store or transport energy. Hydrogen is an energy carrier because energy must be used to generate hydrogen gas that is used as a fuel.

Engine control module (ECM) The on-board computer of the engine management system that controls fuel and emissions, as well as diagnostics, for the vehicle's engine management system.

Engine mapping A computer program that uses engine test data to determine the best fuel-air ratio and spark advance to use at each speed of the engine for best performance.

Engine stand A floor mounted frame usually equipped with casters on which an engine can be attached and rotated.

Enleanment The act of reducing fuel delivery to the air-fuel mix to create a leaner mixture.

Enrichment The act of adding fuel to the air-fuel mix to create a richer mixture.

Entrepreneur A person who owns a business.

Environmental Protection Agency (EPA) A federal government agency that oversees the enforcement of laws related to the environment. Included in these laws are regulations on the amount and content of automotive emissions.

EPA Environmental Protection Agency.

EPAS Electric power assist steering. Also known as EPS (electric power steering).

EPM Electrical Power Management. A General Motors term used to describes a charging system control sensor and the control of the generator (alternator) output based on the needs of the vehicle.

EPR Ethylene propylene rubber.

EPROM Erasable programmable read-only memory.

EPS Electric Power Steering.

Equalizer A bracket used in a parking brake cable system to balance the force and transmit an equal amount to each rear brake assembly.

ERFS Electronic returnless fuel system. A fuel delivery system that does not return fuel to the tank.

ESC Means that the computer system is equipped with a knock sensor that can retard spark advance if necessary to eliminate spark timing advance.

ESD Electrostatic discharge. Another term for ESD is static electricity.

EST The computer controls spark timing advance.

ETC Electronic throttle control. The intake system throttle plate is controlled by a servo motor instead of a mechanical linkage. Also known as drive-by-wire.

Ethanol (grain alcohol) An octane enhancer added, at a rate of up to 10 percent, to gasoline; will increase the octane rating of the fuel by 2.5 to 3.0. Ethanol is a fuel oxygenate.

Ethyl alcohol See Ethanol.

Ethyl tertiary butyl ether (ETBE) An octane enhancer for gasoline. It is also a fuel oxygenate that is manufactured by reacting isobutylene with ethanol. The resulting either is high octane and low volatility. ETBE can be added to gasoline up to a level of approximately 13 percent.

Ethylene glycol Used with water for use as a coolant.

ETR Electronically tuned radio. A type of radio now used in all vehicles that use electronics to tune the frequencies instead of using a variable capacitor.

EV Electric vehicle. A term used to describe battery-powered vehicles.

EVA Electronic Vibration Analyzer.

Evaluator A role played by a mentor.

Evaporative (EVAP) emissions Control system used to prevent fuel vapors in the tank from entering the atmosphere as HC emissions.

Evaporator An A/C system component that absorbs heat from the air in the vehicle's passenger compartment.

Evaporator drain An outlet at the bottom of the evaporator housing that allows condensed water to flow out of the passenger compartment.

EVO Electronic variable orifice.

Exhaust gas recirculation (EGR) The process of passing a small, measured amount of exhaust gas back into the engine to reduce combustion temperatures and formation of NO_x (oxides of nitrogen).

Expander A spring used inside a sealing cup in a wheel cylinder to help prevent the lip from deforming when the brakes are rapidly released.

Experienced-based questions A type of question asked on the ASE certification tests that require the technician to determine the correct answer based on experience rather than on book knowledge.

Extension A socket wrench tool used between a ratchet or breaker bar and a socket.

External trigger An external trigger is used to actuate a scope to an external circuit.

Eye wash station A water fountain designed to rinse the eyes with a large volume of water.

F = MA A formula for inertia. The force (F) of an object in motion is equal to the mass (M) times the acceleration (A).

Fade To grow weak; brakes becoming less effective.

Fahrenheit A temperature scale developed by Gabriel Fahrenheit (1686–1736), a German physicist.

Fan clutch A device used to control the speed of the radiator fan, used with belt-driven fans.

Farad A unit of capacitance named for Michael Faraday (1791–1867), an English physicist. A farad is the capacity to store 1 coulomb of electrons at 1 volt of potential difference.

Fast-fill master cylinder Another name for a quick-take-up master cylinder used with low-drag calipers.

Federal tax A payroll deduction.

Feed controlled circuit A circuit that energizes by applying voltage; it already has a ground.

Feedback The reverse flow of electrical current through a circuit or electrical unit that should not normally be operating. This feedback current (reverse-bias current flow) is most often caused by a poor ground connection for the same normally operating circuit.

Feeler gauge A set of precision thickness steel blades used to measure a gap. Also called a thickness gauge.

FET Field effect transistor.

FFV Flex-fuel vehicle. Flex-fuel vehicles are capable of running on straight gasoline or gasoline/ethanol blends.

Fiber optics The transmission of light through special plastic that keeps the light rays parallel even if the plastic is tied in a knot.

FICA A payroll deduction (Federal Insurance Contribution Act, also known as Social Security).

Field coils Coils or wire wound around metal pole shoes to form the electromagnetic field inside an electric motor.

Field housing The part of a starter that supports the field coils.

Field poles The magnets used as field coils in a starter motor.

Filament The light-producing wire inside a light bulb.

Files A metal smoothing tool.

Filler port A term sometimes used to identify the replenishing port (rear port) of a master cylinder.

Filler vent A breather hole in the filler cap on the master cylinder.

Filter Electrical device that only passes or blocks certain signal frequencies. An application can be removing noise from a signal.

Fire blanket A fire-proof wool blanket used to cover a person who is on fire and smother the fire.

Fire extinguisher classes The types of fires that a fire extinguisher is designed to handle is referred to as fire class.

First-class lever A type of lever where the fulcrum is between the weight and the force.

Fischer-Tropsch A refining process that converts coal, natural gas, or other petroleum products into synthetic motor fuels.

Fitting wrench A wrench that is used to remove the fitting holding a brake line or other line. Also called a line wrench or flare-nut wrench.

Five-wheel alignment An alignment that not only includes the four wheels that are on the ground, but also includes the steering wheel.

Fixed brake caliper A type of disc brake caliper that has pistons on both sides of the rotor.

Fixed joint A type of CV joint used at the wheel end of the drive axle shaft.

Flagging The act of recording the time and the description of the work completed on a vehicle.

Flare nut wrench A type of wrench used to remove brake lines.

Flash codes Diagnostic trouble codes that are retrieved using a jumper wire and watching the flashing of a light.

Flat rate Pay based on the amount of time published in a labor guide rather than using the actual amount of time spent on the repair.

Flat-tip screwdrivers A screwdriver used to remove and insert screws that have a single slot. Also called a straight blade screwdriver.

Flex handle See breaker bar.

Flexible brake hoses Brake hoses between the body or frame of a vehicle and the caliper or axle.

Flexible coupling A part of the steering mechanism between the steering column and the steering gear or rack and pinion assembly. Also called a rag joint or steering coupling disc. The purpose of the flexible coupling is to keep noise vibration and harshness from being transmitted from the road and steering to the steering wheel.

Floating caliper A type of caliper used with disc brakes which moves slightly to assure equal pad pressure on both sides of the rotor.

Floating ground An electrical system where neither the power nor ground circuits are connected to a chassis or body ground.

Flooded cell A battery cell with electrodes immersed in liquid electrolyte.

Floor jack A hydraulic jack mounted on casters or steel wheels and used to lift a vehicle.

Flow control valve A valve that regulates and controls the flow of power steering pump hydraulic fluids to the steering gear or rack and pinion assembly. The flow control valve is usually part of the power steering pump assembly.

Flux Magnetic lines of force.

Flux density The density of the magnetic lines of force around a magnet or other object.

FM Frequency modulation.

FMSI Friction Materials Standards Institute

FMVSS Federal Motor Vehicle Safety Standard.

Follower ball-joint A ball joint used in a suspension system to provide support and control without having the weight of the vehicle or the action of the springs transferred through the joint itself. Also called a friction ball-joint.

Foot-pound A measurement of torque. A one-pound pull, one foot from the center of an object.

Force The amount of effort measured in pounds or Newtons.

Force Energy applied to an object.

Forward bias Current flow in normal direction.

Forward steer See Front steer.

Foundation brakes See service brakes.

Four-stroke cycle An internal combustion engine design where four strokes of the piston (two crankshaft revolutions) are required to complete one cycle of events. The four strokes include intake, compression, power, and exhaust.

Four-wheel alignment A wheel alignment that checks and adjusts, if necessary, the angles of all four wheels.

Fractions A measurement in parts of an inch, such as 1/2, 1/4, and 1/8.

Free electrons The outer electrons in an atom that has fewer than four electrons in it outer orbit.

Free play The amount of movement that the steering wheel moves without moving the front wheels. The maximum allowable amount of free play is less than two inches for a parallelogram-type steering system and 3/8 inch for a rack and pinion steering system.

Frequency The number of times a waveform repeats in one second, measured in Hertz (Hz), frequency band.

Friction The resistance to sliding of two bodies in contact with each other.

Friction ball-joint Outer suspension pivot that does not support the weight of the vehicle. Also called a follower ball-joint.

Front steer A construction design of a vehicle that places the steering gear and steering linkage in front of the center line of the front wheels. Also called forward steer.

FTD Fischer-Tropsch diesel process. See Fischer-Tropsch.

FTP Federal test procedure.

Fuel cell An electrochemical device that converts the energy stored in hydrogen gas into electricity, water, and heat.

Fuel-cell stack A collection of individual fuel cells, which are stacked end-to-end into one compact package.

Fuel compensation sensor A sensor used in flex-fuel vehicles that provides information to the PCM on the ethanol content and temperature of the fuel as it is flowing through the fuel delivery system.

Fuel trim A computer function that adjusts fuel delivery during closed-loop operation to bring the air-fuel mixture to as close to 14.7:1 as possible.

Fulcrum A pivot point of a lever.

Full fielding The method of supplying full battery voltage to the magnetic field of a generator as part of the troubleshooting procedure for the charging system.

Full-floating A type of axle assembly where the weight of the vehicle is supported by the axle housing and not on the axle itself.

Full frame A frame of a vehicle that extends the entire length and width of the vehicle.

Full hybrid A hybrid electric vehicle that utilizes high voltages (200 volts and above) and is capable of propelling the vehicle using "all-electric" mode at low speeds. Also known as a "strong" hybrid.

Fuse An electrical safety unit constructed of a fine tin conductor that will melt and open the electrical circuit if excessive current flows through the fuse.

Fuse link A safety device used on a solvent washer which would melt and cause the lid to close in the event of a fire. A type of fuse used to control the maximum current in a circuit.

Fusible link A type of fuse that will melt and open the protected circuit in the event of a short circuit, which could cause excessive

current flow through the fusible link. Most fusible links are actually wires that are four gauge sizes smaller than the wire of the circuits being protected.

FWD Front wheel drive.

G force The amount of force applied to an object by gravity.

Galvanized steel Steel with a zinc coating to help protect the steel from rust and corrosion.

Garter spring A spring used in a seal to help keep the lip of the seal in contact with the moving part.

Gas fade A type of brake fade where the lining materials are heated enough to emit gas. The gas between the pads and the rotor result in a loss of braking force.

Gasoline Refined petroleum product that is used primarily as a gasoline engine.

Gassing The release of hydrogen and oxygen gas from the plates of a battery during charging or discharging.

Gauge Wire sizes as assigned by the American wire gauge system; the smaller the gauge number, the larger the wire.

Gauss A unit of magnetic induction or magnetic intensity named for Karl Friedrich Gauss (1777–1855), a German mathematician.

GAWR Gross axle weight rating. A rating of the load capacity of a vehicle and included on placards on the vehicle and in the owner's manual.

GC-LB A grease rating for GC is the highest rating for wheel bearing grease and LB is the highest rating for chassis grease. A GC-LB grease, therefore, can be used.

GDI Gasoline direct injection. A fuel injection system design in which gasoline is injected directly into the combustion chamber.

Gear lash Clearance between gears.

Gear ratio For a transmission or drive axle, the number of turns of the input shaft required to produce one turn of the output shaft.

Gel battery A lead-acid battery with silica added to the electrolyte to make it leakproof and spill proof.

Generation mode A mode of operation in hybrid electric vehicles that uses engine power to generate electricity for charging the high-voltage battery.

Generator A device that converts mechanical energy into electrical energy.

Geometric centerline A type of wheel alignment where all four wheels are aligned parallel to the centerline of the vehicle.

Germanium A semiconductor material.

GFD Ground-Fault Detection. A diagnostic function used to monitor the auxiliary power outlets in a GM parallel hybrid truck.

GHG An abbreviation for greenhouse gas.

GKN A company named after its founders, Guest, Keene, and Nettelfolds.

Global warning An overall increase in the temperature of the earth thought to be caused by increased greenhouse gases such as carbon dioxide and methane.

Gland nut The name commonly used to describe the large nut at the top of a MacPherson strut housing. This gland nut must be removed to replace a strut cartridge.

Glazed drum A drum surface hardened excessively by intense heat.

Glitch A momentary spike in a waveform. This can be caused by a momentary disruption in the tested circuit.

GMLAN GM local area network. A type of serial data transmission by General Motors.

GMM Graphing Multimeter.

GPS Global Positioning System. A government program of 24 satellites which transmit signals and used by receivers to determine their location.

Grab Seizure of the drum on linings when brakes are applied.

Grade The strength rating of a bolt.

Grain alcohol See Ethanol.

Gram A metric unit of weight measurement equal to 1/1000 kilogram (1 oz. × 28 = 1 gram). An American dollar bill or paper clip weighs about 1 gram.

Graticule The series of squares on the face of a scope. Usually 8 by 10 on a screen.

Gravity bleeding Removing air from a hydraulic brake system by opening the bleeder valve and allowing the brake fluid to flow downward and out the bleeder taking any trapped air with it.

Grease Oil with thickener.

Grease cap A functional metal cap that keeps grease in and dirt out of wheel bearings. Also called a dust cap.

Grease fitting A metal replaceable fitting shaped to hold the end of a grease gun in place and equipped with a spring-loaded valve.

Grease retainer See grease seal.

Grease seal A seal used to prevent grease from escaping and to prevent dirt and moisture from entering.

Green tire An uncured assembled tire. After the green tire is placed in a mold under heat and pressure, the rubber changes chemically and comes out of the mold formed and cured.

Greenhouse gas See GHG.

Grid The lead-alloy framework (support) for the active materials of an automotive battery.

Grommet An eyelet usually made from rubber used to protect, strengthen, or insulate around a hole or passage.

Gross pay Total amount of income earned before deductions.

Ground The lowest possible voltage potential in a circuit. In electrical terms, a ground is the desirable return circuit path. Ground can also be undesirable and provide a shortcut path for a defective electrical circuit.

Ground brushes The brushes in a starter motor that carry current to the housing of the starter or ground.

Ground-controlled circuit A circuit that energizes by applying ground; voltage is already being applied.

Ground plane A part of antenna that is metal and usually the body of the vehicle.

Ground (return) path The electrical return path that the current flows though in a complete circuit.

Growler Electrical tester designed to test starter and DC generator armatures.

GTL Gas-to-liquid. A refining process in which natural gas is converted into liquid fuel.

GVW Abbreviation for gross vehicle weight. GVW is the weight of the vehicle plus the weight of all passengers and cargo up to the limit specified by the manufacturer.

GVWR Gross vehicle weight rating. The total weight of the vehicle including the maximum cargo.

Hacksaw A saw that uses a replaceable blade and is used to cut a variety of materials depending on the type of blade used.

Half shaft Drive axles on a front-wheel drive vehicle or from a stationary differential to the drive wheels.

Hall-effect sensor A type of electromagnetic sensor used in electronic ignition and other systems. Named for Edwin H. Hall, who discovered the Hall effect in 1879.

Hall-effect switch A semiconductor moving relative to a magnetic field, creating a variable voltage output. Used to determine position. A type of electromagnetic sensor used in electronic ignition and other systems. Named for Edwin H. Hall, who discovered the Hall effect in 1879.

Halogenated Compounds Chemicals containing chlorine, fluorine, bromine, or iodine. These chemicals are generally considered to be hazardous and any product containing these chemicals should be disposed of using approved procedures.

Haltenberger linkage A type of steering linkage commonly used on light trucks.

Hammer A hand tool used to deliver a force to a concentrated place.

Hanger bearing See center support bearing.

Hand brake See parking brake.

Handwheel position sensor A sensor that detects the direction and speed of rotation of the steering wheel.

Hard spots Formed in brake drums or rotors due to high heat.

Hash An unclear or a messy section of a scope pattern.

Hazard flasher Emergency warning flashers; lights at all four corners of the vehicle and flashes on and off.

Hazard warning A sticker or decal warning that a hazard is close.

HC Hydrocarbons (unburned fuel); when combined with NO_x and sunlight, they form smog.

HCCI See Homogeneous-charge compression ignition.

HCU Hydraulic control unit.

HD Heavy duty.

Heat checked Cracks in the braking surface of a drum caused by excessive heat.

Heat sink Usually, a metallic-finned unit used to keep electronic components cool.

Heater core A cooling system component that is responsible for transferring heat from the engine coolant to the passenger compartment.

Heat shrink tubing A type of rubber tubing that shrinks to about half of its original diameter when heated. Used over a splice during a wire repair.

HEI General Motors' name for their high energy ignition.

Height-sensing proportioning valve A valve connected to the rear suspension that limits the brake pressure sent to the rear brakes if the rear of the vehicle is high (unloaded).

Height sensor A height sensor determines the vertical relationship between the suspension component and the body of a vehicle.

Helical insert A steel insert used to repair damaged threads.

Helicoil A brand name for a helical insert.

Helper springs Auxiliary or extra springs used in addition to the vehicle's original springs to restore proper ride height or to increase the load carrying capacity of the vehicle.

HEPA High Efficiency Particulate Air filter.

HEPA vacuum High efficiency particulate air filter vacuum used to clean brake dust.

Hertz A unit of measurement of frequency. One Hertz is one cycle per second, abbreviated Hz. Named for Heinrich R. Hertz, a 19th century German physicist.

HEV Hybrid electric vehicle. Describes any vehicle that uses more than one source of propulsion, such as internal combustion engine (ICE) and electric motor(s).

HID High Intensity Discharge. A type of headlight that uses high voltage to create an arc inside the arc tube assembly which then produces a blue-white light.

High energy ignition (HEI) The brand name for the electronic ignition used in General Motors vehicles.

High flotation tires A type of tire that is large in size and holds a large volume of air.

High impedance meter A digital meter that has at least 10 million ohms of internal resistance as measure between the test leads with the meter set to read volts.

High-pass filter A filter in an audio system that blocks low frequencies and only allows high frequencies to pass through to the speakers.

HOAT Hybrid Organic Acid Technology. A corrosion inhibitor additive with reduced silicate content.

Hold-in winding One of two electromagnetic windings inside a solenoid; used to hold the movable core into the solenoid.

Hole theory A theory which states that as an electron flows from negative (−) to positive (+), it leaves behind a hole. According to the hole theory, the hole would move from positive (+) to negative (−).

HomeLink A brand name of a system used and included in many new vehicles to operate the automatic garage door opener.

Homogeneous-charge compression ignition A low-temperature combustion process that involves air-fuel mixtures being burned without the use of spark ignition.

Hooke's Law The force characteristics of a spring discovered by Robert Hooke (1635–1703). An English physicist. Hooke's Law states "the deflection (movement or deformation) of a spring is directly proportional to the applied force."

Horn An electro-mechanical device that creates a loud sound when activated.

Horsepower A unit of power; 33,000 foot-pounds per minute. One horsepower equals 746 W.

Hotchkiss drive A type of power transmission for a front engine, rear-drive vehicle where the engine torque reaction is controlled by the suspension as compared to the use of torque arm or frame-mounted differential.

Housing expense Includes rent or mortgage payment, plus heat, light, and other utility expenses.

HOV lane High-occupancy vehicle lane. Sometimes known as the carpool or diamond lane.

hp Horsepower.

HPA High pressure accumulator.

HSD High side driver.

HSMO Hydraulic system mineral oil.

HSS High strength steel—a low carbon alloy steel that uses various amounts of silicon, phosphorus and manganese.

Hub cap A functional and decorative cover over the lug nut portion of the wheel. Also see wheel cover.

HUD Head up display.

HV High voltage. Applies to any voltage above 50 volts.

HV battery High-voltage battery. Hybrid electric vehicles use NiMH battery packs that are rated up to 330 volts DC.

HV cables Vehicle cables that carry high voltage.

HVTB High voltage traction battery. The high-voltage battery in a Ford Escape Hybrid.

Hybrid Abbreviated version of hybrid electric vehicle (HEV); a type of vehicle that uses two types of propulsion.

Hybrid flasher A type of flasher unit that can operate two or more bulbs at a constant rate.

Hydraulic The force exerted by pressurized liquid in a closed system.

Hydraulic control unit A mechanical assembly that controls hydraulic pressure to wheel brakes. Used in ABS and traction control systems.

Hydraulic lifter A valve lifter that, using simple valving and the engine's oil pressure, can adjust its length slightly, thereby maintaining zero clearance in the valve train. Hydraulic lifters reduce valve train noise and are maintenance-free.

Hydraulic press A piece of shop equipment usually mounted on the floor, which uses a hydraulic cylinder to remove and install pressed-on components, such as bearings.

Hydraulic system The base brake system containing the master cylinder, wheel cylinders, calipers, and brake fluid lines.

Hydrocarbons (HC) Any of a number of compounds of carbon and hydrogen used as fuel, such as gasoline. High levels of hydrocarbons in tailpipe emissions are a result of unburned fuel. When combined with NO_x and sunlight, they form smog.

Hydrocracking A refinery process that converts hydrocarbons with a high boiling point into ones with low boiling points.

Hydrometer An instrument used to measure the specific gravity of a liquid. A battery hydrometer is calibrated to read the expected specific gravity of battery electrolyte.

Hydrophilic A term used to describe a type of rubber used in many all-season tires where the rubber has an affinity for water (rather than repels).

Hydrophobic A term used to describe the repelling of water.

Hydroplaning Condition that occurs when driving too fast on wet roads where the water on the road gets trapped between the tire and the road forcing the tire onto a layer of water and off the road surface. All traction between the tire and the road is lost.

Hygroscopic Ability of brake fluid to absorb moisture from the air.

Hypoid gear set A ring gear and pinion gear set that meshes together below the center line of the ring gear. This type of gear set allows the drive shaft to be lower in the vehicle, yet requires special hypoid gear lubricant.

Hz An abbreviation for Hertz, cycles per second.

IAC Idle air control.

IAT Inorganic Additive Technology. The corrosion inhibitor used in most green-colored coolants.

ICE Internal combustion engine.

Icing Formation of ice on or around the throttle plate due to atmospheric conditions and the lowering of temperatures as the air-fuel mixture passes through the throttle opening.

ICU Integrated control unit.

Idle stop mode A phase in hybrid electric vehicle operation in which the internal combustion engine shuts off during idle operation.

Idler arm The pivot point and support arm of a parallelogram-type steering linkage located on the passenger side of the vehicle.

IEC International Electrotechnical Commission.

IGBT Insulated gate bipolar transistors. IGBTs are the primary switching devices for the inverter in a hybrid electric vehicle.

Ignition circuit Electrical components and connections that produce and distribute high-voltage electricity to ignite the air-fuel mixture inside the engine.

Ignition coil An electrical device consists of two separate coils of wire: a primary and a secondary winding. The purpose of an ignition is to produce a high-voltage (20,000 to 40,000 V), low-amperage (about 80 mA) current necessary for spark ignition.

Ignition timing The exact point of ignition in relation to piston position.

ILC Idle load control.

ILEV Inherently low-emission vehicle. One category of emission standards set by the state of California.

ILSAC International Lubricant Standardization and Approval Committee. Responsible for development of the ILSAC standard for motor oil performance.

IMA Integrated Motor Assist. Describes the motor-generator located between the internal combustion engine and the transmission on Honda hybrid electric vehicles.

Impact wrench An air-operated hand tool used to install and remove threaded fasteners.

Impedance The resistance of a coil of wire, measured in ohms.

Impeller The mechanism in a water pump that rotates to produce coolant flow.

Impurities Doping elements.

Incandescent light A type of light that uses an incandescent rather than a fluorescent or LED light source.

Incentive pay See commission pay.

Included angle SAI angle added to the camber angle of the same wheel. Includes starter motor, starter solenoid/relay, battery, neutral safety switch, ignition including co-solvents, in unleaded gasoline is limited by law to 5 percent.

Independent suspension A suspension system that allows a wheel to move up and down without undue effect on the opposite side.

Independent switches Switch located at each door and used to raise or lower the power window for that door only.

Inductance The signal caused by the sudden change of a magnetic field. For example, when you turn off the current through a solenoid, a voltage spike is generated across the solenoid.

Induction motor An AC motor in which electromagnetic induction is used to generate a magnetic field in the rotor without the need for brushes.

Inductive ammeter A type of ammeter that is used a Hall Effect sensor in a clamp that is used around a conductor carrying a current.

Inductive reactance An opposing current created in a conductor whenever there is a charging current flow in a conductor.

In. Hg Abbreviation for inches of Mercury—a unit of measure for vacuum.

Inches of Mercury A measurement of vacuum; pressure below atmospheric pressure.

Inclinometer An instrument used to measure angles. Normally used to measure driveshaft angles.

Included angle SAI angle added to the camber angle of the same wheel.

Independent suspension A suspension system that allows a wheel to move up and down without undue effect on the opposite side.

Indicator ball joints A type of ball joint that shows when the joint is worn enough to require replacement.

Inertia Energy in a moving object.

Inflator module The part of an airbag that contains the airbag itself, plus the unit that is used to inflate the airbag.

Inlet port See replenishing port.

Inner liner The inner layer of rubber inside a tire.

Input Information on data from sensors to an electronic controller is called input. Sensors and switches provide the input signals.

Input conditioning What the computer does to the input signals to make them useful; usually includes an analog to digital converter and other electronic circuits that eliminate electrical noise.

Insulated brushes Brushes used in a starter motor that connect to battery power through the solenoid.

Insulated path The power side of an electrical circuit.

Insulator A material that does not readily conduct electricity and heat. A nonmetal material that contains more than four electrons in its atom's outer shell.

Insulators Thin strips of plastic or hard rubber used to separate the leaves of a leaf spring.

Intake air temperature (IAT) sensor Measures the air temperature of the air entering the engine.

Integral ABS An antilock braking system that includes the master cylinder, booster, ABS solenoids, and accumulator(s) all in one unit.

Integral reservoir A type of power steering pump that includes the pump inside the fluid reservoir.

Integral sensor A term used to describe a crash sensor that is built into the airbag control module.

Integrally molded Disc brake pads where the friction material is molded and locked into holes in the steel backing plate.

Integrated circuit (IC) An electronic circuit that contains many circuits all in one chip.

Intermediate lever A lever used as part of the parking brake cable system.

Intermittent Irregular; a condition that happens with no apparent or predictable pattern.

Invert To change to the opposite polarity. Puts the waveform display upside down.

Inverter An electronic device used to convert DC (direct current) into AC (alternating current).

IOD Ignition off draw. A Chrysler term used to describe battery electrical drain or parasitic draw.

Ion An atom with an excess or deficiency of electrons forming either a negative or a positive charged particle.

Ion-sensing ignition An electronic ignition system that uses the spark plug as a sensor to determine camshaft position, misfire, and knock.

IP Abbreviation for instrument panel.

IP certification Interprovincial certification in Canada.

IPCC Intergovernmental Panel on Climate Change.

IPM Interior permanent magnet. Describes the arrangement of the permanent magnets on the inside of the rotor shell in an AC synchronous electric motor.

Iron Refined metal from iron ore (ferrous oxide) in a furnace. (Also see steel.)

IRS Independent rear suspension.

ISC Idle speed control.

ISO International Standards Organization.

Isolation solenoid A solenoid used in an antilock braking system to isolate the master cylinder from the wheel brakes.

Isolator bushing Rubber bushing used between the frame and the stabilizer bar. Also known as a stabilizer bar bushing.

IVR Instrument voltage regulator.

i-VTEC Intelligent Variable Valve Timing and Lift Electronic Control. A system used to control the valve train on some Honda vehicles.

Jack stand See safety stand.

Jam nut A second nut used to prevent the first nut from loosening.

Joule A unit of electrical energy. One joule equals 1 watt × 1 second (1 V × 1 A × 1 s).

Jounce A term used to describe up and down movement or to cause up and down motion.

Jounce bumper A rubber or urethane stop to limit upward suspension travel. Also called a bump stop, a strike-out bumper suspension bumper or compression bumper.

Julian date The day of the year. Named for Julius Caesar.

Jumper cables Heavy-gauge (4 to 00) electrical cables with large clamps, used to connect a vehicle that has a discharged battery to a vehicle that has a good battery.

Junction The point where two types of materials join.

JWL Japan Wheel Light Metal Standard Mark.

KAM Keep alive memory.

Kelvin (K) A temperature scale where absolute zero is zero degrees. Nothing is colder than absolute zero.

Kerf Large water grooves in the tread of a tire.

Kevlar Dupont brand name of aramid fibers.

Key fob A decorative unit attached to keys. Often includes a remote control to unlock/lock vehicles.

Keyword A type of network communications used in many General Motors vehicles

Kickback The movement of the steering wheel when the front wheels strike a curb or bump.

Kicker A throttle kicker is used on some computer engine control systems to increase engine speed (RPM) during certain operating conditions, such as when the air conditioning system is on.

Kilo Means 1000; abbreviated k or K.

Kinetic energy The energy in any moving object. The amount of energy depends on the weight (mass) of the object and the speed of the object.

Kinetic friction Friction between two surfaces which are moving against each other.

King pin A pivot pin commonly used on solid axles or early model twin I-beam axles that rotate in bushings and allow the front wheels to rotate. The knuckle pivots about the ping pin.

King pin inclination Inclining the tops of the king pins toward each other creates a stabilizing force to the vehicle.

Kirchhoff's current law A law that states "The current flowing into any junction of an electrical circuit is equal to the current flowing out of that junction."

Kirchhoff's voltage law A law about electrical circuits that states: "The voltage around any closed circuit is equal to the sum (total) of the resistances."

Knock sensor A sensor that can detect engine spark knock.

KPI King pin inclination (also known as steering axis inclination, SAI). The angle formed between true vertical and a line drawn between the upper and lower pivot points of the spindle.

Kyoto Protocol An agreement reached among most of the world's industrialized nations for limiting the production of carbon dioxide and other greenhouse gases.

kW Abbreviation for kilowatt, a measure of power. One kilowatt is 1,000 watts, and 746 watts is equivalent to 1 horsepower.

Labor guides A book or service information that provides the time that is needed to perform a service or repair operation.

Labyrinth seal A water seal formed by the curved area at the lip of the backing plate and the notch in the brake drum.

Ladder frame A steel frame for a vehicle that uses cross braces along the length, similar to the rungs of a ladder.

Lambda sensor Oxygen sensor or O_2 sensor. Lambda is the Greek letter that represents ratio, as in air-fuel ratio.

Lateral accelerometer sensor A sensor used in many vehicles equipped with electronic suspension and/or traction control systems used to detect sideways movement of the vehicle.

Lateral links Suspension arms that control the side-to-side movement of the wheels and vehicle. Also called transverse links.

LCD Liquid-crystal display.

LDWS Lane departure warning system.

Lead peroxide The positive plate of an automotive-style battery, the chemical symbol is $PbSO_4$.

Lead sulfate Both battery plates become lead sulfate when the battery is discharged. The chemical symbol for lead sulfate is $PbSO_4$.

Leading shoe The forward facing brake shoe on a leading/trailing type of drum brake.

Leading-trailing brakes A type of drum brake design which anchors the bottom of both shoes to the backing plate.

Leaf spring A spring made of several pieces of flat spring steel.

Least likely questions A type of question asked on the ASE certification tests.

LED Light-emitting diode. A high-efficiency light source that uses very little electricity and produces very little heat.

Ledges Also called shoe pads, where the brake lining controls the backing plate.

Left hand rule A method of determining the direction of magnetic lines of force around a conductor. The left-hand rule is used with the electron flow theory (− flowing to +).

Legs Another name for the branches of a parallel circuit.

Lenz's law The relative motion between a conductor and a magnetic field is opposed by the magnetic field of the current it has induced.

LEV Low emission vehicle.

Leverage The ability of a lever or other mechanical device used to increase force.

Leyden jar A device first used to store an electrical charge. The first type of capacitor.

Li-ion Lithium-ion battery design.

Linesman's gloves Type of gloves worn by technicians when working around high-voltage circuits. Usually includes a rubber inner glove rated at 1,000 volts and a protective leather outer glove when used for hybrid electric vehicle service.

Lining edge codes Letters and numbers that indicate the friction code cold and hot, as well as the manufacturer and details about the lining.

Lining fade A condition where the brake lining overheats, reducing the coefficient of friction.

Lining table The part of a drum brake shoe where the lining is attached.

Li-poly Lithium-polymer battery design.

Liquid crystal display (LCD) A display that uses liquid crystals to display waveforms and text on its screen.

LLR Low roll resistance.

LLVW Lightly loaded vehicle weight.

Load A term used to describe a device when an electrical current is flowing through it.

Load-carrying ball-joint A ball-joint used in a suspension system to provide support and control and through which the weight (load) of the vehicle is transferred to the frame.

Load Index An abbreviated method that uses a number to indicate the load carrying capabilities of a tire.

Load test A type of battery test where an electrical load is applied to the battery and the voltage is monitored to determine the condition of a battery.

Load tester A device for applying a heavy current load to a battery, which is usually half of the CCA rating for 15 seconds.

Lock plate A plate located in the steering column that is used to lock the steering wheel when the key is removed from the ignition.

Lock tang A mechanical tab that is used to secure a terminal into a connector. This lock tang must be depressed to be able to remove the terminal from the connector.

Locking pliers Pliers that can be used to grasp an object and then be locked into position. Often called by a popular brand name VISE-GRIPS®.

Lockout switch A lock placed on the circuit breaker box to insure that no one turns on the electrical circuit while repairs are being made.

Lodestone A type of iron ore that exists as a magnet in its natural state.

Logic probe A type of tester that can detect either power or ground. Most testers can detect voltage but most of the others can not detect if a ground is present without further testing.

Loose A term used to describe an over steering condition.

Low-drag caliper A type of disc brake caliper where the piston retracts more than usual, reducing the brake drag between the pad and the rotor.

Low-pass filter A device used in an audio system that blocks high frequencies and only allows low frequencies to pass to the speakers.

Low-water loss battery A type of battery that uses little water in normal service. Most batteries used in cars and light trucks use this type of battery.

LPA Low pressure accumulator.

LPG Liquefied petroleum gas. Another term for propane.

LRO An abbreviation for lateral runout.

LSD Low side driver.

LSD An abbreviation commonly used for limited slip differentials.

LT Light truck.

Lug nuts Nuts used on wheel studs to attach wheels to hubs.

Lumbar The lower section of the back.

M85 Internal combustion engine fuel containing 85% methanol and 15% gasoline.

M & S Mud and snow.

M/C solenoid Mixture control solenoid.

MacPherson strut A type of front suspension with the shock absorber and coil spring in one unit which rotates when the wheels are turned. Assembly mounts to the vehicle body at top and to one ball-joint and control arm at the lower end. Named for its inventor, Earle S. MacPherson.

Magnasteer A type of electronically controlled hydraulic power steering.

Magnequench A magnetic alloy made from neodymium, iron, and boron.

Magnetic flux The lines of force produced in a magnetic field.

Magnetic induction The transfer of the magnetic lines of force to another nearby metal object or coil of wire.

Magnetic timing A method of measuring ignition that uses a magnetic pickup tool to sense the location of a magnet on the harmonic balancer.

Magnetism A form of energy that is recognized by the attraction it exerts on other materials.

Magneto-rheological suspension A type of electronic suspension that uses magneto-rheological fluid shocks.

Maintenance-free battery A type of battery that does not require routine adding of water to the cells. Most batteries used in cars and light truck are maintenance free design.

Major splice A place in a tire where the tread rubber and one or more body plies are spliced during tire construction.

Major thrust surface The side of an engine cylinder that receives the greatest thrust or force from the piston during the power stroke.

Malfunction indicator lamp (MIL) This amber dash board warning light may be labeled check engine or service engine soon.

Manifold absolute pressure (MAP) Sensor used to measure the pressure inside the intake manifold compared to a perfect vacuum.

Manifold vacuum Low pressure (vacuum) measured at the intake manifold of a running engine (normally between 17 and 21 inches Hg at idle).

MAP Manifold absolute pressure.

Mass The weight of an object. A measure of the amount of material contained in an object. Gravity acts on a mass to give it weight.

Mass air flow (MAF) The volume of air passing into the engine. Varies with temperature and humidity. Used in calculating injector operation and spark timing.

Master certified technician A technician who has successfully passed all eight ASE certification tests and has completed at least two years of experience.

Master control switch The control switch for the power windows located near the driver who can operate all of the windows.

Master cylinder The part of the brake hydraulic system where the pressure is generated.

Match mount The process of mounting a tire on a wheel and aligning the valve stem with a mark on the tire. The mark on the tire represents the high point of the tire and the valve stem location represents the smallest diameter of the wheel.

MCA Marine cranking amps. A battery specification.

MEA See Membrane electrode assembly.

Mechanical advantage The use of levers, such as a brake pedal to increase the force applied by the driver.

Mechanical brakes Brakes that are operated by a mechanical linkage or cable connecting the brakes to the brake pedal.

Mechanical fade Braking reduction caused by the heat expansion of the brake drum away from the brake lining.

Medium hybrid A hybrid electric vehicle design that utilizes "medium" voltage levels (between 50 and 200 volts). Medium hybrids use regenerative braking and idle stop but are not capable of starting the vehicle from a stop using electric mode.

Mega (M) Million. Used when writing larger numbers or measuring large amount of resistance.

Membrane electrode assembly (MEA) The part of the PEM fuel cell that contains the membrane, catalyst coatings, and electrodes.

Memory steer Memory steer is a lead or pull of a vehicle caused by faults in the steering or suspension system. If after making a turn, the vehicle tends to pull in the same direction as the last turn, then the vehicle has memory steer.

Meniscus The puckering or curvature of a liquid in a tube. A battery is properly filled with water when the electrolyte first becomes puckered.

Mentor An experienced technician who offers to help a beginning technician learn all aspects of the trade.

Menu A list of choices for selecting a test, function, or setting.

Mercury A heavy metal.

Mesh spring A spring used behind the starter pinion on a starter drive to force the drive pinion into mesh with the ring gear on the engine.

Mesothelioma A fatal type of cancer of the lining of the chest or abdominal cavity, which can be caused by asbestos inhalation.

Metal hydride A hydrogen storage alloy used in the negative electrode of a NiMH cell.

Meter accuracy The accuracy of a meter measured in percent.

Meter resolution The specification of meter that indicates how small or fine a measurement the meter can detect and display.

Metering valve (Hold-off valve)—A valve installed between the master cylinder and front disc brakes which prevents operation of front disc brakes until 75–125 PSI is applied to overcome rear drum brake return spring pressure.

Methanol (wood alcohol) Typically manufactured from natural gas. Methanol content, including co-solvents, in unleaded gasoline is limited by law to 5 percent.

Methyl alcohol See Methanol.

Methyl tertiary butyl ether (MTBE) A fuel oxygenate which is permitted in unleaded gasoline up to a level of 15 percent.

Metric bolts Bolts manufactured and sized in the metric system of measurement.

Metric wire gauge The metric method for measuring wire size in the square millimeters. This is the measure of the core of the wire and does not include the insulation.

Micro (μ) One-millionth of a volt or ampere.

Micro-hybrid drive A term used to describe Belt Alternator Starter (BAS) and other mild hybrid systems.

Micro inches One-millionth of an inch; a unit of measure of surface finish. The lower the number, the smoother the surface.

Microbe A microorganism that is too small to be seen by the human eye.

MIL See malfunction indicator lamp.

Mild hybrid A hybrid electric vehicle design that utilizes regenerative braking and idle stop but cannot propel the vehicle in electric-only mode. Also called an assist hybrid and typically operates below 50 volts.

Miller cycle A four-stroke cycle engine design that utilizes the Atkinson cycle along with a forced induction system such as a supercharger.

Milli (m) One thousandth of a volt or ampere.

Millisecond One thousandths of one second (1/1,000).

Minutes A unit of measure of an angle. Sixty minutes equal one degree.

Misfire When complete combustion does not occur in one or more cylinders due to fuel, ignition, or cylinder compression.

Mm Hg Abbreviation for millimeters of Mercury. A metric measure of vacuum.

Mode select switch A switch used to select ride comfort settings on a vehicle equipped with electronic suspension.

Model year (MY)—The year of a vehicle, which may be different from the calendar year when it is sold.

Modified X A method of tire rotation.

Modulation A combination of a carrier wave frequency with an audio frequency.

Module A group of electronic components functioning as a component of a larger system.

Mold bonded lining A design of disc brake pads where the lining material is molded into holes in the steel backing plate.

Moly grease Grease containing molybdenum disulfide.

Momentary switch A type of switch that toggles between on and off.

Mono leaf A leaf spring that uses only one leaf.

Morning sickness A slang term used to describe temporary loss of power steering assist when cold caused by wear in the control valve area of a power rack and pinion unit.

MOS Metal oxide semiconductor.

MOSFET Metal oxide semiconductor field-effect transistor. A type of transistor.

Most likely A type of test question used on ASE certification tests.

Motor An electromechanical device that converts electrical energy into mechanical movement.

Motoring mode A phase of BAS hybrid vehicle operation where the motor-generator cranks the ICE to start it.

MOV Metal oxide varistor. An electronic device that operates like two back-to-back zener diodes.

MR Magneto-Rheological.

MRFS Mechanical returnless fuel system. A returnless fuel delivery system design that uses a mechanical pressure regulator located in the fuel tank.

MRRTD Magneto-rheological real time dampening.

MSDS Material safety data sheets.

MSI MacPherson Strut Inclination.

MTBE Methyl tertiary butyl ether. MTBE is an oxygenated fuel that is used as a gasoline additive to enhance its burning characteristics being phased out due to ground water contamination concerns.

MTG Methanol-to-gasoline. A refining process in which methanol is converted into liquid gasoline.

MTHF Methyltetrahydrofuron. A component of P-series nonpetroleum-based fuels.

Mμ The Greek letter that represents the coefficient of friction.

Multi-groove adjustable pliers Pliers that are capable of grasping a wide range of object sizes; also called water pump pliers or by a popular brand name of Channel Locks®.

Multiple choice The type of questions used on the ASE certification tests.

Multiplexing A process of sending multiple signals of information at the same time over a signal wire.

Mutual induction The generation of an electric current due to a changing magnetic field of an adjacent coil.

MY Model year.

NAO Non-asbestos organic.

NAS Non-asbestos synthetic.

Natural frequency The frequency where the brake pads tend to vibrate.

N.C. Normally closed.

NEDRA National Electric Drag Racing Association.

Needle-nose pliers Pliers that are equipped with pointed jaws, which allow use in restricted areas or for small parts.

Negative temperature coefficient (NTC) Usually used in reference to a temperature sensor (coolant or air temperature). As the temperature increases, the resistance of the sensor decreases.

Net pay Amount earned minus deductions. Also called take home pay.

Network A communications system used to link multiple computers or modules.

Neutral charge An atom that has the same number electrons as protons.

Neutral run-up test A test used to help determine the source of a vibration. Engine speed is increased and vibration is measured with the transmission in neutral.

Neutral safety switch A switch connected in series in the starter control circuit that allows operation of the starter motor to occur only when the gear selection is in neutral (N) or park (P).

Neutrons A neutral-charged particle; one of the basic particles of the nucleus of an atom.

Newton A unit of force in the metric system.

NGV Natural gas vehicle.

NHTSA Abbreviation for the National Highway Traffic Safety Administration.

Nibs Small V-shaped notches on the side of brake shoes where they rest against the backing plate.

NiCD Nickel-cadmium battery design; also called an alkaline battery.

NiMH Nickel-metal hydride. A battery design used for the high-voltage batteries in most hybrid electric vehicles.

Nitrile A type of rubber that is okay for use with petroleum.

Nitrogen An inert gas that comprises approximately 78% of the earth's atmosphere.

NLEV National Low-Emission Vehicle.

NLGI National Lubricating Grease Institute. Usually associated with grease. The higher the NLGI number, the firmer the grease. #000 is very fluid whereas #5 is very firm. The consistency most recommended is NLGI #2 (soft).

N.O. Normally open.

Node A module and computer that is part of a communications network.

Noise Noise is the vibration of air caused by a body in motion.

Nominal voltage The approximate voltage of a fully charged battery cell.

Nonasbestos Brake linings or pads that do not contain asbestos.

Nonhygroscopic Brake fluid, such as DOT 5 that does not absorb moisture from the air.

Nonintegral ABS A antilock braking system (ABS) that uses a conventional master cylinder and power brake booster.

Non-servo brakes A drum brake design where the primary lining (forward facing) does not control or transmit a force to the secondary (rearward facing) brake shoe.

Nonvolatile memory Computer memory capability that is not lost when power is removed. See also read-only memory (ROM).

NO_x Oxides of nitrogen; when combined with HC and sunlight, form smog.

NPN transistor A type of transistor that has the P-type material in the base and the N-type material is used for the emitter and collector.

NTC Negative temperature coefficient. Usually used in reference to a temperature sensor (coolant or air temperature). As the temperature increases, the resistance of the sensor decreases.

N-type material Silicon or germanium doped with phosphorus, arsenic, or antimony.

Nucleus The central part of an atom which has a positive charge and contains almost all the mass of the atom.

Nut splitter A hand tool designed to break a nut that is rusted onto a bolt or stud.

Nuts A female threaded fastener to be used with a bolt or stud.

NVH Abbreviation for noise, vibration and harshness.

NVRAM Nonvolatile random access memory.

O_2 sensor Oxygen sensor; also called O2S.

OAD Override alternator dampener.

OAP Override alternator pulley

OAT Organic Acid Technology. A corrosion inhibitor additive containing no silicates or phosphates. Used in DEX-COOL and some other extended-life coolants.

Occupant detection systems An airbag system that includes a sensor in the passenger seat used to detect whether or not a passenger is seated in the passenger side and the weight range of that passenger.

Octane rating The measurement of a gasoline's ability to resist engine knock. The higher the octane rating, the less prone the gasoline is to cause engine knock (detonation).

OE Original equipment.

OEM Original equipment manufacturer.

Offset The distance the center section (mounting pad) is offset from the centerline of the wheel.

Offset aviation snip A tin snip that has curved jaws allowing it to make curved cuts either left or right.

Offset crankshaft The internal combustion engine crankshaft is offset from the centerline of the cylinders to reduce internal friction.

Off-time The part of an electrical signal during which an electrical device is deenergized.

Ohm The unit of electrical resistance. Named for Georg Simon Ohm (1787–1854).

Ohmmeter An electrical test instrument used to measure ohms (unit of electrical resistance).

Ohm's Law An electrical law that requires 1 volt to push 1 ampere through 1 ohm of resistance.

OL Overload or over limit.

Omega The last letter of the Greek alphabet; a symbol for ohm, (Ω) the unit for electrical resistance.

Op-amps Used in circuits to control and simplify digital signals.

Open circuit Any circuit that is not complete and in which no current flows.

Open circuit voltage Voltage measured without the circuit in operation.

Open end The end of a wrench that is open to allow the wrench to be inserted onto a fastener from the side.

Open-loop operation A phase of computer-controlled engine operation where air/fuel mixture is calculated in the absence of oxygen sensor signals. During open loop, calculations are based primarily on throttle position, engine RPM, and engine coolant temperature.

Opposite phase steering Used on a 4-wheel steer vehicle at low speeds where the rear wheels steer in the opposite direction of the front wheels.

Orbital steer See bump steer.

Organic A term used to describe anything that was alive at one time.

Oscilloscope A visual display of electrical waves on a fluorescent screen or cathode ray tube.

OSHA Occupational Safety and Health Administration. OSHA is the main federal agency responsible for enforcement of workplace safety and health legislation.

OT Orifice tube. Refers to an A/C system design that uses an orifice tube as a refrigerant expansion device.

Out-of-round A fault with a brake drum, which is not perfectly round.

Output The command from an electronic control module.

Over center adjustment An adjustment made to a steering gear while the steering is turned through its center straight-ahead position. Also known as a sector lash adjustment.

Overdrive In a transmission or drive axle, when the input shaft turns slower than the output shaft. A gear ratio of 0.87:1 is considered to be an overdrive gear ratio because only 0.87 turns of the input shaft will result in 1 full turn of the output shaft.

Over inflation Used to describe a tire with too much tire pressure (greater than maximum allowable pressure).

Overrunning alternator dampener An alternator (generator) drive pulley that has a one-way clutch and a dampener spring used to smooth the operation of the alternator and reduce the stress on the drive belt.

Overrunning alternator pulley An alternator (generator) drive pulley that has a one-way clutch used to smooth the operation of the alternator and reduce the stress on the drive belt.

Overrunning clutch A mechanical coupling device that allows torque to be transmitted in one direction of rotation, but freewheels when turned in the opposite direction. Also known as a one-way clutch.

Oversteer A term used to describe the handling of a vehicle where the driver must move the steering wheel in the opposite direction from normal while turning a corner. Oversteer handling is very dangerous. Most vehicle manufacturers design their vehicles to understeer rather than oversteer.

Over-travel spring A spring used as part of the self-adjusting components that allow normal operation even if the star wheel adjuster does not move.

Oxidation catalysts Platinum and palladium used in the catalytic converter to combine oxygen (O_2) with hydrocarbons (HC) and carbon monoxide (CO) to form nonharmful tailpipe emissions of water (H_2O) and carbon dioxide (CO_2).

Oxides of nitrogen (NO_x) A primary emission produced in the combustion chamber under high temperatures when nitrogen combines with oxygen. Oxides of nitrogen contribute to the formation of smog (ground level ozone [O_3]) when combined with HC and sunlight.

Oxygen A colorless, odorless gas that is a direct supporter of combustion. Earth's atmosphere contains approximately 21% oxygen.

Oxygenate An octane component containing hydrogen, carbon, and oxygen in its molecular structure. Types of oxygenates include ethers such as MTBE and alcohols such as ethanol and methanol.

Oxygenated fuels Fuels such as ETBE or MTBE that contain extra oxygen molecules to promote cleaner burning. Oxygenated fuels are used as gasoline additives to reduce CO emissions.

Oz-in. Measurement of imbalance. 3 oz-in. means that an object is out of balance; it would require a 1 oz weight placed 3 inches from the center of the rotating object or a 3 oz weight placed 1 in. from the center or any other combination that when multiplied equals 3 oz-in.

Ozone Oxygen rich (O_3) gas created by sunlight reaction with unburned hydrocarbons (HC) and oxides of nitrogen (NO_x); also called smog.

Pacific fuse element A type of automotive fuse.

Pad wear indicators A metal strap or notch in the disc brake pad to indicate that the pads are worn to the point of needing replacement.

PAG Polyalkylene glycol. A type of refrigerant oil used in most R-134a A/C systems.

Pal nut See jam nut.

Pancake engine See boxer.

Panhard rod A horizontal steel rod or bar attached to the rear axle housing at one end and the frame at the other to keep the center of the body directly above the center of the rear axle during cornering and suspension motions. Also called a track rod.

Parallel circuit An electrical circuit with more than one path from the power side to the ground side. Has more than one branch or leg.

Parallel hybrid A hybrid vehicle design where the electric machine (or other source of energy) assists the ICE to propel the vehicle.

Parallelism A measurement of a brake rotor to determine that both sides of the rotors are perfectly parallel.

Parallelogram A geometric box shape where opposite sides are parallel (equal distance apart).

Parallelogram linkage A geometric box shape where opposite sides are parallel (equal distance apart). A type of steering linkage used with a conventional steering gear that uses a pitman arm, center link, idler arm and tie rods.

Parasitic load test An electrical test that measures how much current (amperes) is draining from the battery with the ignition off and all electrical loads off.

Parking brake Components used to hold a vehicle on a 30° incline. Formerly called an emergency brake before 1967 when dual master cylinders and split braking systems became law. The parking brake is also called the hand brake.

Partitions Separations between the cells of a battery. Partitions are made of the same material as that of the outside case of the battery.

Pascal's law A law of hydraulics named for the person who developed it, Blaise Pascal (1632–1662).

PASS A word used to help remember how to use a fire extinguisher: pull pin, aim, squeeze the lever, and sweep the nozzle from side to side.

Passenger presence system (PPS) An airbag system that includes a sensor in the passenger seat used to detect whether or not a passenger is seated in the passenger side and the weight range of that passenger.

Passkey I and II A type of anti-theft system used in General Motors vehicles.

Pasting The process of applying active battery materials onto the grid framework of each plate.

PATS Passive Anti-Theft System. A type of anti-theft system used in Ford, Lincoln, and Mercury vehicles.

Pawl A lever for engaging in a notch. Used to rotate the notched star wheel on self-adjusting brakes.

PCI Programmable Communication Interface, a type of serial data transmission used by Chrysler.

PCM Powertrain control module.

PCV Positive crankcase ventilation.

Peak value The highest and lowest value of a waveform.

Peak-and-hold A method for regulating the current flow through electronic fuel injectors. Supplies higher current necessary to energize the injector, then drops to a lower level just enough to keep the injector energized.

Peak inverse voltage (PIV) The rating of resistance to reverse-bias voltage. Also called peak reverse voltage (PRV).

Peak oil A term used to describe the peak of worldwide oil production.

Pedal free play The amount of brake pedal movement where no pressure is built up in the master cylinder.

Pedal height perform ride mode A mode of operation for a General Motors vehicle equipped with electronic suspension. In this mode, the suspension is set to a firm setting.

Pedal ratio The mechanical advantage of the brake pedal due to the location of the fulcrum and the length of the pedal arm.

Pedal reserve distance A measurement from the floor to the top of the brake pedal when the brakes are applied.

PEFC Polymer Electrolyte Fuel Cell. Another term for PEM fuel cell.

Peltier effect A French scientist Peltier found that electrons moving through a solid can carry heat from one side of the material to the other side. This effect is called the **Peltier effect.**

PEM Proton Exchange Membrane fuel cell. A low-temperature fuel cell known for fast starts and relatively simple construction.

Penetrating oil A thin oil that is designed to penetrate through rust and provide lubrication for the threads of a fastener.

Penetration A test for grease where the depth of a standard cone is dropped into a grease sample and its depth is measured.

Perimeter frame A steel structure for a vehicle that supports the body of the vehicle under the sides, as well as the front and rear.

Perimeter frame penetration A test for grease where the depth of a standard cone is dropped into a grease sample and its depth is measured.

Permalloy A permanent-magnet alloy of nickel and iron.

Permanent magnet electric motors Electric motors that use permanent magnets for the field instead of electro-magnets.

Permeability The measure of how well a material conducts magnetic lines of force.

Petrodiesel Another term for petroleum diesel, which is ordinary diesel fuel refined from crude oil.

Petroleum Another term for crude oil. The literal meaning of petroleum is "rock oil."

pH A measure of the acidity or alkalinity of a material. A pH of 7 is neutral, higher than 7 is alkaline, and lower than 7 is acidic.

Phase-change liquid A fluid used to transfer heat efficiently from electronic components. The components are immersed in the fluid, which changes from a liquid to a vapor as it absorbs heat.

Phenolic brake pistons Hard type of plastic disc brake caliper pistons which do not rust or corrode.

PHEV Plug-in hybrid electric vehicle.

Phosphor A chemical-coated light-emitting element called a phosphor is hit with high-speed electrons which cause it to glow and creates light.

Photocell A type of sensor that uses light-emitting diodes and a photo transistor to detect location.

Photodiodes A type of diode used as a sun-load sensor. Connected in reverse bias, the current flow is proportional to the sun load.

Photoelectricity When certain metals are exposed to light, some of the light energy is transferred to the free electrons of the metal. This excess energy breaks the electrons loose from the surface of the metal. They can then be collected and made to flow in a conductor which is called photoelectricity.

Photoelectric principle The production of electricity created by light striking certain sensitive materials, such as selenium or cesium.

Photons Light is emitted form an LED by the release of energy in the form of photons.

Photoresistor A semiconductor that changes in resistance with the presence or absence of light. Dark is high resistance and light is low resistance.

Phototransistor An electronic device that can detect light and turn on or off. Used in some suspension height sensors.

PHT Parallel hybrid truck. A term used to describe the Chevrolet Silverado/GMC Sierra hybrid pickup truck.

Pickle fork A tapered fork used to separate chassis parts that are held together by a nut and a taper. Hitting the end of the pickle fork forces the wedge portion of the tool between the parts to be separated and "breaks the taper." A pickle fork tool is generally not recommended because the tool can tear or rip the grease boot of the part being separated.

PID Parameter identification. The information found in the vehicle datastream as viewed on a scan tool.

Piezoelectric principle The principle by which certain crystals become electrically charged when pressure is applied.

Pin bushings The small roller bearings used in a universal joint.

Pinch bolt A bolt used to retain a ball joint in some designs of suspensions.

Pinch weld seam A strong section under a vehicle where two body panels are welded together.

Ping Secondary rapid burning of the last 3 to 5% of the air-fuel mixture in the combustion chamber causes a second flame front that collides with the first flame front causing a knock noise. Also called detonation or spark knock.

Pinion gear A small gear on the end of the starter drive which rotates the engine flywheel ring gear for starting.

Pin-slider caliper A disk brake caliper design that uses guide pins and is able to move slightly during a brake application.

Pinion torque The torque required to rotate the pinion shaft on a rack and pinion steering gear.

Piston assemblies A part of a master cylinder where the sealing cups and the piston are replaceable as an assembly.

Piston stops Metal tangs next to drum brake wheel cylinders used to prevent cylinder pistons from coming out of their bores when the brake lining is removed.

Pitch The pitch of a threaded fastener refers to the number of threads per inch.

Pitman arm A short lever arm that is splined to the steering gear cross shaft. It transmits the steering force from the cross shaft to the steering linkage.

Pitman shaft See sector shaft.

PIV Peak Inverse Voltage. A rating for a diode.

Pixel The smallest graphic detail possible for the liquid crystal display (LCD).

Planet carrier The part of a planetary gearset that houses the planet pinions.

Planetary gearset A simple mechanism made up of a ring gear, a planet carrier, and a sun gear. A single planetary gearset can be used to achieve a reduction, a direct drive, an overdrive, or a reverse.

Platform The platform of a vehicle includes the basic structure (frame and/or major body panels), as well as, the basic steering and suspension components. One platform may be the basis for several different brand vehicles.

Plenum A chamber, located between the throttle body and the runners of the intake manifold, used to distribute the intake charge more evenly and efficiently.

Pliers A hand tool with two moveable jaws.

Plowing A term used to describe an understeering condition.

Plug-in hybrid vehicle (PHEV) A hybrid electric vehicle utilizing batteries that can be recharged by plugging into a household electrical outlet.

Plunge joint An inner constant velocity joint that is able to move in and out and transmit torque while the vehicle suspension moves up and down over bumps.

Ply steer A term used to describe why a tire can cause a pulling condition based on the angle of the cords of the belt layers.

PM Particulate matter. PM can be made up of any airborne liquid or solid, and its concentration is regulated by both the CARB and the EPA.

PM generator A sensor that has a permanent magnet and a coil of wire and produces an analog voltage signal if a metal wheel with notches passes close to the sensor.

PM motor A permanent-magnet electric motor.

PNP transistor A type of transistor that used N-type material for the base and P-type material for the emitter and collector.

Polarity The condition of being positive or negative in relation to a magnetic pole.

Pole The point where magnetic lines of force enter or leave a magnet.

Pole shoes The metal part of the field coils in a starter motor.

Polyglycol A term used to describe brake fluid.

Polymer electrolyte fuel cell (PEFC) Another term for Proton Exchange Membrane fuel cell. See PEM.

Pop rivet A type of fastener that uses a rivet gun to pull out the rivet until the end deforms and thereby creating a light clamping form.

Poppet valve steering gear A type of power steering gear used on medium trucks that uses a poppet valve to control the direction and amount of assist.

Porous lead Lead with many small holes to make a surface porous for use in battery negative plates; the chemical symbol for lead is Pb.

Portable crane A piece of shop equipment that is used to lift and move heavy pieces of equipment, such as an engine.

Ported vacuum Low pressure (vacuum) measured above the throttle plates. As the throttle plates open, the vacuum increases and becomes of the same value as the manifold vacuum.

Positive crankcase ventilation (PCV) System used to prevent corrosive blow-by gases (by- products of combustion) in the crankcase from entering the atmosphere.

Positive temperature coefficient (PTC) Usually used in reference to a conductor or electronic circuit breaker. As the temperature increases, the electrical resistance also increases.

Post-ignition When the air-fuel mix self-ignited during combustion, resulting in a second flame front that collides with the first, causing a knock noise. See also detonation, ping, or spark knock.

Potentiometer A 3-terminal variable resistor that varies the voltage drop in a circuit.

Pound foot A measurement of torque. A 1-pound pull, 1 foot from the center of an object.

Power The rate of doing work, measured in horsepower as kilowatts. In electrical terms, is amperes × volts (Power = I × E).

Power assist mode A phase of hybrid vehicle operation in which the ICE is assisted by the electric motor(s) to propel the vehicle.

Power bleeding Also called pressure bleeding.

Power chamber The enclosure of a vacuum brake booster assembly which is separated into the vacuum side and the atmospheric air pressure side by a flexible diaphragm.

Power line capacitor A capacitor used to boost the output of a sound system to move the speakers especially when reproducing low frequencies.

Power side The wires leading from the power source (battery) to the resistance (load) of a circuit.

Power source In electrical terms the battery or generator (alternator).

Power train An engine and transmission in combination.

Power train control module (PCM) The on-board computer that controls both the engine management and transmission functions of the vehicle.

PPE Personal protective equipment, which can include gloves, safety glasses, and other items.

PPM Parts per million.

Pre-alignment checks The checks that should be performed before checking or changing the wheel alignment of a vehicle.

Preignition Ignition of the air-fuel mix before the timed ignition spark occurs.

Preload A term used to describe a tightening of a nut or bolt to provide a force.

Pressure A force applied to a surface divided by its area.

Pressure bleeder A device that forces pressure into the master cylinder, so that when the bleeder screws are opened at the wheel cylinder, air will be forced from the system.

Pressure bleeding A method used to bleed air out of a brake hydraulic system using compressed air above the master cylinder reservoir.

Pressure cap A device used to maintain and limit pressure in the cooling system.

Pressure decay stage A stage during ABS operation where the pressure of the brake fluid at a wheel brake is reduced.

Pressure differential A difference in pressure from one brake circuit to another.

Pressure-differential switch Switch installed between the two separate braking circuits of a dual master to light the dash board "brake" light in the event of a brake system failure, causing a difference in brake pressure.

Pressure dump stage See pressure decay stage.

Pressure holding stage A stage during ABS operation where the pressure of the brake fluid at a wheel brake is held at the correct level.

Pressure increase stage A stage during ABS operation where the pressure of the brake fluid at a wheel brake is increasing due to a driver brake application.

Pressure reduction stage See pressure decay stage.

Pressure regulator A regulating device that maintains a specified pressure in a system.

Pressure relief valve A valve located in a power steering pump that uses a check ball, which unseats allowing fluid to return to the reservoir if pressure exceeds a certain volume.

Pretensioners An explosive devices used to remove the slack from a safety belt when an airbag is deployed.

Prevailing torque nut A special design of nut fastener that is deformed slightly or has other properties that permit the nut to remain attached to the fastener without loosening.

Primary battery Nonrechargeable battery.

Primary shoe A brake shoe installed facing the front of the vehicle.

Primary wire Wire used for low voltage automotive circuits, typically 12 volts.

Principal end The end of the engine that the flywheel is attached to.

Prismatic cell A battery cell made with flat plates.

Processing The act of a computer when input data is run through computer programs to determine what output is needed to be performed.

Programmable Controller Interface (PCI) A type of network communications protocol used in Chrysler brand vehicles.

PROM Programmable read-only memory.

Prop shaft An abbreviation for propeller shaft.

Propane See LPG.

Propeller shaft A term used by many manufacturers for a drive shaft.

Proportioning valve Valve installed between the master cylinder and rear brakes which limits the amount of pressure to the rear wheels to prevent rear wheel lock-up.

Proton A positive-charged particle; one of the basic particles of the nucleus of an atom.

Proton exchange membrane (PEM) See PEM.

PRV See peak inverse voltage.

PSCM Power steering control module.

PSI Pounds per square inch.

PSP Power steering pressure

PTC Positive temperature coefficient. Normally used in reference to a conductor or electronic circuit breaker. As the temperature increases, the electrical resistance also increases.

PTC heater An electric heater used to supplement a coolant heater that operates on the principle of positive-temperature coefficient, where electrical resistance of the heater increases as temperature increases.

P-type material Silicon or germanium doped with boron or indium.

Pull Vehicle tends to go left or right while traveling on a straight, level road.

Pull-in windings One of two electromagnetic windings inside a solenoid used to move a movable core.

Pulse A voltage signal that increases or decreases from a constant value, then returns to the original value.

Pulse generators An electromagnetic unit that generates a voltage signal used to trigger the ignition control module that controls (turns on and off) the primary ignition current of an electronic ignition system.

Pulse modulated A circuit that maintains average voltage levels by pulsing the voltage on and off.

Pulse train A DC voltage that turns on and off in a series of pulses.

Pulse width The amount of "on" time of an electronic fuel injector.

Pulse width modulation (PWM) Operation of a device by an on/off digital signal that is controlled by the time duration the device is turned on and off.

Pulse wipers Windshield wipers that operate intermittingly. Also called delay wipers.

Pumping losses The energy lost due to restrictions in the air intake system, such as caused by a closed throttle plate.

Punch A hand tool designed to be used with a hammer to drive out pins.

Push rod The link rod connecting the brake pedal to the master cylinder piston.

PVV Pressure vent valve. A valve located in the fuel tank to prevent overpressure due to the thermal expansion of the fuel.

PWM Pulse-width modulation. The control of a device by varying the on-time of the current flowing through the device.

Quad driver Integrated circuit that is capable of four separate outputs. Some have digital and some have pulse width modulated outputs.

Quick take-up master cylinder A type of master cylinder that uses a large and small diameter bore for use with a low-drag caliper.

R-134a A refrigerant used in the A/C systems of most domestic vehicles built since 1994.

Ra Roughness average; a measurement of surface finish. The lower the number, the smoother the surface.

RABS Rear antilock braking system.

Race Inner and outer machined surface of a ball or roller bearing.

Rack and pinion A type of lightweight steering unit that connects the front wheels through tie rods to the end of a long shaft called a rack. When the driver moves the steering wheel, the force is transferred to the rack and pinion assembly. Inside the rack housing is a small pinion gear that meshes with gear teeth, which are cut into the rack.

Rack support A spring-loaded unit that is used to hold the rack part of a rack and pinion steering gear assembly in proper position.

Radial force variation The variation in force a tire exerts as it rotates and contacts the road surface.

Radial grid A lead-alloy framework for the active materials of a battery that has radial support spokes to add strength and to improve battery efficiency.

Radial load The load applied to a bearing 90 degrees from the axis. The weight of the vehicle applies a radial load to the wheel bearing.

Radial runout A measure of the amount a tire or wheel is out of round. Excessive radial runout can cause a tramp-type vibration.

Radial tire A tire whose carcass plies run straight across (or almost straight across) from bead to bead.

Radiator A cooling system component used to dissipate heat from the coolant to the surrounding air.

Radiator hose A flexible hose used to transfer coolant between the various cooling system components.

Radio choke A small coil of wire installed in the power lead, leading to a pulsing unit such as an IVR to prevent radio interference.

Radio frequency interference (RFI) A high-frequency type of EMI that is in the radio frequency band.

Radius rod A suspension component to control longitudinal (front-to-back) support and is usually attached with rubber bushings to the frame at one end and the axle or control arm at the other end. Also see strut rod.

Rag joint See Flexible coupling.

Rain-sense wipers Windshield wiper that use an electronic sensor to detect the presence of rain on the windshield and start operating automatically if the wiper switch is in the Auto position.

RAM Random access memory.

Random access memory (RAM) A nonpermanent type of computer memory used to store and retrieve information.

Range The distance a vehicle can travel on a full charge or full-fuel tank without recharging or refueling. Range is measured in miles or kilometers.

Ratchet A handle used to rotate a socket, which is reversible and allows the socket to be rotated in one direction and then free movement in the opposite direction of rotation.

Ratio The expression for proportion. For example, in a typical rear axle assembly, the drive shaft rotates 3 times faster than the rear axles. Expressed as a ratio of 3:1 and rear as "three to one." Power train ratios are always expressed as driving divided by driven gears.

RBS Rubber bonded socket.

RBS Regenerative braking system. A hybrid electric vehicle system that allows vehicle kinetic energy to be converted into electrical energy for charging the high-voltage battery.

RBWL Red brake warning lamp.

RCRA Resource Conservation and Recovery Act.

Reaction disc A feature built into a power brake unit to provide the driver with a "feel" of the pedal.

Read-only memory (ROM) A permanent type of computer memory programmed by the computer manufacturer to store the operating instructions and parameters of the computer.

Real time dampening A General Motors term for an electronically controlled suspension system that uses solenoid-operated shock absorbers.

Rear spacing See back spacing.

Rear steer A construction design of a vehicle that places the steering gear and steering linkage behind the centerline of the front wheels.

Rebound clips Clips used around the leaves of a leaf spring.

Rebuilt See Remanufactured.

Recall A notification to the owner of a vehicle that a safety issue needs to be corrected.

Receiver-drier An A/C system component used to filter and remove moisture from liquid refrigerant on the high side of the system.

Recirculating ball-steering gear A steering gear that uses a series of ball bearings that feed through and around the grooves in the worm and nut.

Recombinant battery A battery design that does not release gasses during normal operation. AGM batteries are known as recombinant batteries.

Rectifier An electronic device that converts alternating current into direct current.

Rectifier bridge A group of six diodes, three positive (+) and three negative (−) commonly used in alternators.

Red brake warning lamp The dash-mounted warning lamp that lights if a hydraulic system fault is detected.

Reduction A drive train mechanism designed to decrease speed and increase torque. A gear ratio of 3.56:1 would be considered to be a reduction because the input shaft must turn 3.56 times in order to achieve 1 turn of the output shaft.

Reference voltage A voltage applied to a circuit. Battery plus and ground are examples of reference voltages.

Refractometer A device used to measure battery state of charge by allowing light to pass through an electrolyte sample.

Refrigerant A fluid used in A/C systems to absorb, transfer, and release heat energy.

Regen An abbreviation for regenerative braking.

Regeneration A process of taking the kinetic energy of a moving vehicle and converting it to electrical energy and storing it in a battery.

Regenerative braking A hybrid vehicle function that recovers kinetic energy while the vehicle is decelerating and stores it for later use.

Reid vapor pressure (RVP) A method of determining vapor pressure of gasoline and other petroleum products. Widely used in the petroleum industry as an indicator of the volatility of gasoline.

Relay An electromagnetic switch that uses a movable arm.

Release solenoid A solenoid used to open a vent port to release pressure from a brake circuit.

Reluctance The resistance to the movement of magnetic lines of force.

Remanufactured A term used to describe a process where a component is disassembled, cleaned, inspected and re-assembled using new or reconditioned parts. According to the Automotive Parts Rebuilders Association (APRA), this same procedure is also called rebuilt.

Remote reservoir A type of power steering pump where the fluid is in a reservoir separate from the pump.

Removers This term is used to describe hand tools, which are designed to remove broken studs, bolts, and other fasteners.

Renewal A part built to be used as a replacement for the original equipment (OE) part.

Repair order Also called an R.O. or work order. Contains all vehicle and customer information and the list of service work that is to be completed.

Replenishing port The Society of Automotive Engineers (SAE) term for the rearward low pressure master cylinder port. Also called inlet port, bypass port, filler port or breather port.

Reserve capacity The number of minutes a battery can produce 25 A and still maintain a battery voltage of 1.75 V per cell (10.5 V for a 12 V battery).

Residual check valve A valve in the outlet end of the master cylinder to keep the hydraulic system under a light pressure on drum brakes only.

Residual magnetism Magnetism remaining after the magnetizing force is removed.

Resistance The opposition to current flow measured in ohms.

Resolver A speed sensor that utilizes three coils to determine rotor position.

Resume A statement of your background and experience submitted to a potential employer.

Retainer-type axles A type of rear axle that uses a retainer plate instead of a C-clips to keep the axle retained to the axle housing.

Returnability The ability of the steering wheel to return to the straight ahead position after making a turn.

Reverse bias Current flow in the opposite direction from normal.

Reverse fluid injection A hand-operated device used to inject brake fluid into the bleeder valves at the wheel brake.

Revolutions per minute (RPM) A measure of how fast an object is rotating around an axis.

RF Radio frequency.

RFG Reformulated gasoline. RFG has oxygenated additives and is refined to reduce both the lightest and heaviest hydrocarbon content from gasoline in order to promote cleaner burning.

RGB Regenerative braking.

Rheostat A two-terminal variable resistor.

Ride height The height of the vehicle. Also called the trim height.

Right-hand rule A method of determining the direction of the magnetic lines of force in a current-carrying conductor. The right-hand rule is used with conventional current flow theory (+ flowing to −)

Right-to-know laws Laws that state that employees have a right to know when the materials they use at work are hazardous.

RIM Reaction injection molded.

Rim width The width of a wheel measured between bead sections.

Ring gear The large gear inside a differential assembly, which meshes with the drive pinion gear.

Ripple voltage Excessive AC voltage produced by a generator (alternator, usually caused by a defective diode.

Rise time The time, measured in microseconds, for the output of a coil to rise from 10% to 90% of its maximum output.

Riveted linings Brake lining that is held to the brake shoe using rivets.

RMP Reaction moldable polymer.

RMS Root mean square.

R.O. An abbreviation for repair order.

Road crown A roadway where the center is higher than the outside edges. Road crown is designed into many roads to drain water off the road surface.

Role model A role played by a mentor.

Roll bar See Stabilizer bar.

Roll steer See Bump steer.

Roller bearings Antifriction bearings that use hardened steel rollers between the inner and outer races.

Rolling circumference The distance a tire travels when rotated one revolution.

ROM Read-only memory.

Root mean square (RMS) Conversion of AC voltages to the effective DC value.

Rosin-core solder A type of solder for use in electrical repairs. Inside the center of the solder is a rosin that acts as a flux to clean and help the solder flow.

Rotary control valve A power steering valve that operates by rotating an inner valve inside an outer valve to control the amount of steering assist.

Rotor The rotating part of a generator where the magnetic field is created.

RPA Rear Park Assist. The General Motors term to describe the system used to detect objects and warn the drive when backing.

RPM Engine speed expressed in revolutions per minute of the crankshaft.

RPO Regular Production Order

RSS Road sensing suspension.

RTD Real time dampening.

RTV Room-temperature vulcanization.

Rubber coupling A flexible connection between the power seat motor and the drive cable.

Run-flat tires Tires specially designed to operate for reasonable distances and speeds without air inside to support the weight of the vehicle. Run-flat tires usually require the use of special rims designed to prevent the flat tire from coming off the wheel.

RVP Reid vapor pressure. A measure of the volatility at exactly 100 degrees F.

RVS Remote Vehicle Start. A general Motor's term for the system that allows the driver to start the engine using a remote control.

RWAL Rear wheel antilock.

RWD Rear wheel drive

Rzeppa A type of constant velocity (CV) joint named after its inventor, Alfred H. Rzeppa.

SAE Society of Automotive Engineers.

Safety stand A metal device with an adjustable vertical support that is designed to support a vehicle after it has been raised off the ground. Also called a jack stand.

Saginaw Brand name of steering components manufactured in Saginaw, Michigan, USA.

SAI Steering axis inclination (same as KPI).

Same phase steering A vehicle equipped with four-wheel steering where the front and the rear wheels move in the same direction.

Sample A reading taken from an electrical signal. A waveform is created from a successive number of samples.

Sampling rate The number of readings taken from an electrical signal every second.

SAR Supplemental Air Restraints. Another term used to describe an airbag system.

Saturated driver Fuel-injection circuit that maintains the same voltage level throughout its on-time.

Saturation The point of maximum magnetic field strength of a coil.

SBR Styrene butadiene rubber.

Scavenging The process of drawing air-fuel into the cylinder of the engine, due to the relative movement of exhaust gases out of the cylinder.

Schrader valve A type of valve used in tires, air-conditioning, and fuel injection systems. Invented in 1844 by August Schrader.

(SCI) Serial Communication Interface A type of serial data transmission used by Chrysler.

Scoring Grooves worn into the drum or disc braking surface.

SCP Standard Corporate Protocol. A type of serial data transmission used by Ford.

SCR Silicon Controller Rectifier.

Screwdriver A hand tool used to install or remove screws.

Screw jack assembly A screw jack that is used to raise or lower a power seat.

Scroll compressor An A/C compressor design known for its efficiency and excellent NVH characteristics.

Scrub radius Refers to where an imaginary line drawn through the steering axis intersects the ground compared to the centerline of the tire. Zero scrub radius means the line intersects at the center line of the tire. Positive scrub radius means that the line intersects below the road surface. Negative scrub radius means the line intersects above the road surface. It is also called steering offset by some vehicle manufacturers.

SDARS Satellite Digital Audio Radio Services. Another term used to describe satellite radio.

Seal driver A hand tool used with a mallet or hammer to seat seals into a seal groove.

Seal puller A hand tool designed to remove seals.

Second class lever A type of lever where the fulcrum is at one end of the lever and the applied force is at the other end of the lever with the load in the center.

Secondary battery Rechargeable battery.

Secondary pickup An accessory that can be clamped on the high voltage coil wire used to measure secondary ignition patterns.

Secondary shoe The brake shoe installed facing the rear of the vehicle.

Sector gear A section of a gear inside a steering gear that is attached to the sector shaft. Also called the pitman shaft.

Sector lash Refers to clearance (lash) between a section of gear (sector) on the pitman shaft in a steering gear. Also see Overcenter adjustment.

Sector shaft The output shaft of a conventional steering gear. It is a part of the sector shaft in a section of a gear that meshes with the worm gear and is rotated by the driver when the steering wheel is turned. It is also called a pitman shaft.

Sediment chamber A space below the cell plates of some batteries to permit the accumulation of sediment deposits flaking from the battery plates. A sediment chamber keeps the sediment from shorting the battery plates.

Select low The principle where during an ABS stop, the wheel on the same axle that is slowing the fastest is the one which determines when to increase, hold, or decrease pressure to both wheel brakes.

Select low principle See select low.

Selectable ride A brand name for a type of electronic suspension system.

Self-adjusting brakes Brakes that maintain the proper lining-to-drum clearance by automatic adjusting mechanism.

Self aligning spacer A double cone used to spread the force of the retaining nut on the spindle of a brake lathe.

Self apply A condition where the brakes apply without the driver depressing the brake pedal.

Self-energizing A brake shoe, that when applied, develops a wedging action that assists the braking force applied by the wheel cylinder.

Self-energizing action A brake shoe, that when applied, develops a wedging action that assists the braking force applied by the wheel cylinder.

Self-induction The generation of an electric current in the wires of a coil created when the current is first connected or disconnected.

Self-tapping screw A screw that has a tapered tip which allows the screw to form threads in the metal.

SEMA Specialty Equipment Manufacturers Association.

Semi-closed loop A phase of computer-controlled engine operation in which lean air-fuel mixtures are used to maximize fuel economy.

Semiconductor A material that is neither a conductor nor an insulator; has exactly four electrons in the atom's outer shell.

Semi-floating A type of line axle where the inner end of the axle floats and the outer end is supported by a bearing.

Semi-independent suspension A type of rear suspension that allows some transfer of motion to the opposite side.

Semi-mets Semi-metallic brake linings.

Semi-trailing arm A type of rear suspension that controls both side-to-side and front-to-rear motion.

Senseless DC motor An AC synchronous electric motor that does not require a rotor position sensor for operation.

Separators In a battery, nonconducting porous, thin materials used to separate positive and negative plates.

Serial Communication Interface (SCI) Serial Communication Interface, a type of serial data transmission used by Chrysler.

Serial data Data that is transmitted by a series of rapidly changing voltage signals.

Series circuit An electrical circuit that provides only one path for current to flow.

Series circuit laws Laws that were developed by Kirchhoff which pertain to series circuits.

Series hybrid A hybrid vehicle design in which there is no mechanical connection between the ICE and the drive wheels. Instead, the ICE drives a generator that is used to produce electricity for recharging the high-voltage battery and for propelling the vehicle through an electric motor.

Series-parallel circuit Any type of circuit containing resistances in both series and parallel in one circuit.

Series-parallel hybrid A hybrid vehicle design that can operate as a series hybrid, a parallel hybrid, or both series and parallel at the same time.

Series-wound field A typical starter motor circuit where the current through the field windings is connected in series with the armature before going to ground. Also called a series-wound starter.

Service advisor A person who talks to the customer about a vehicle service and completes the work order.

Service bay A work area for a vehicle, with or without a lift. Also called a stall.

Service manager The person in charge of a shop or dealer service department.

Service plug A high-voltage electrical disconnect device on hybrid electric vehicles. The service plug should always be disconnected whenever working on a hybrid electric vehicle's high-voltage circuits.

Series wound In a starter motor, the field coils and the armature are wired in series. All the current flows through the field coils, through the hot brushes, through the armature, then to the ground through the ground brushes.

Service brake The main driver-operated vehicle brakes.

Service information Includes service manuals, owner's manuals, CD ROM discs, Internet sites, or other sources where vehicle information is found.

Servo action Brake construction having the end of the primary shoe bear against the secondary shoe. When the brakes are applied, the primary shoe applies force to the secondary shoe.

Servo brake A type of drum brake that uses the primary (forward facing) brake shoe to increase the application force to the rear facing brake shoe.

Servomotor The actuator in an electronic throttle control (ETC) system.

Servo unit A vacuum-operated unit that attaches to the throttle linkage to move the throttle on a cruise control system.

Setback The amount the front wheels are set back from true parallel with the rear wheels. Positive setback means the right front wheel is set back farther than the left. Setback can be measured as an angle formed by a line perpendicular (90°) to the front axles.

SFI Sequential fuel injection. A fuel injection system in which injectors are pulsed individually in sequence with the firing order.

SGCM Starter Generator Control Module. The module in a GM parallel hybrid truck that controls the current to and from the integrated starter generator.

Shackle A mounting that allows the end of a leaf spring to move forward and backward as the spring moves up and down during normal operation of the suspension.

Shelf life The length of time that something can remain on a storage shelf and not be reduced in performance level from that of a newly manufactured product.

Shielded test lead A test lead that is surrounded by a conductive screen to protect the measurement signal against environmental influences such as electrical noise or radiation.

Shim A thin metal spacer.

Shim chart A chart used to help align a vehicle that uses shims for camber and caster adjustment.

Shimmy A vibration that results in a rapid back and forth motion of the steering wheel. A bent wheel or a wheel assembly that is not correctly dynamically balanced are common causes of shimmy.

Shock absorbers A suspension component that links and controls the action and reaction of the springs.

Shoe anchors A round part at the top of most backing plates used to prevent the brake shoes from rotating with the drum during a brake application.

Shoe contact area Raised areas on the backing plate of a drum brake where the brake shoes contact.

Shoe pad A raised support on the backing plate against which the shoe edge rests; also called a shoe ledge.

Shoe rim Another name for the lining table where the brake lining is attached to the brake shoe.

Shoe support pads Six areas on the backing plate of a drum brake where the lining makes contact.

Shoe web The support under the shoe table on a drum brake shoe.

Shop foreman A journeyman service technician who helps solve technical problems and helps service technicians.

Short circuit A circuit in which current flows, but bypasses some or all the resistance in the circuit. A connection that results in a "copper-to-copper" connection.

Shorted A condition of being shorted such as a short circuit.

Short/long arm suspension Abbreviated SLA. A suspension system with a short upper control arm and a long lower control arm. The wheel changes very little in camber with a vertical deflection. Also called double-wishbone-type suspension.

Short to ground A short circuit in which the current bypasses some or all the resistance of the circuit and flows to ground. Because ground is usually steel in automotive electricity, a short to ground (grounded) is a "copper-to-steel" connection.

Short-to-voltage A circuit in which current flows, but bypasses some or all the resistance in the circuit. A connection that results in a "copper-to-copper" connection.

Shunt A device used to divert or bypass part of the current from the main circuit.

Shunt field A field coil used in a starter motor that is not connected to the armature in series but is grounded to the starter case.

Side gears The gears inside a differential that attach to the axles.

Sidewall The side of a tire.

Silicon A semiconductor material.

Silicone brake fluid A type of brake fluid that is purple and does not absorb moisture.

Single cut file A file that has just one row of cutting teeth.

Single stroke bleeding method A method of manual brake bleeding where the brake pedal is depressed one time, held until the bleeder is closed and the released.

Sintered metal See sintering.

Sintering A process where metal particles are fused together without melting.

Sipes Small traction improving slits in the tread of a tire.

SIR Supplemental Inflatable restraints. Another term for air bags.

SKIS Sentry Key Immobilizer System. A type of antitheft system used in Chrysler vehicles.

SLA Abbreviation for short/long arm suspension.

SLI battery The battery that is responsible for starting, charging, and lighting in a vehicle's electrical system.

Sliding caliper A type of disc brake caliper that is free to move within a limited range.

Slip angle The angle between the true centerline of the tire and the actual path followed by the tire while turning.

Slip-joint pliers A hand tool which has two positions allowing the use of two different ranges of sizes.

Slip-ring end (SRE) The end of a generator (alternator) that has the brushes and the slip rings.

Slope The ratio of front to rear brake pressure by a proportioning valve.

Small-hole gauge A handheld measuring tool that is adjustable to fit inside small holes. A micrometer is then used to measure the gauge to determine the inside diameter of the hole. Also called a split-ball gauge.

SMC Sheet molding compound.

Smog The term used to describe a combination of smoke and fog. Formed by NO_x and HC with sunlight.

SMR System main relay. The high-voltage disconnect relays used in most hybrid electric vehicles.

Snap ring A spring steel clip that is used to retain an object in a bore by being inserted into a groove.

Snap ring pliers A hand tool, which is designed to install or remove snap rings.

Snips A hand tool designed to cut sheet metal.

Snub One brake application.

SOC State-of-charge. Expressed as a percentage, this refers to the charge level of a battery.

Society of Automotive Engineers (SAE) A professional organization made up of automotive engineers and designers that establishes standards and conducts testing for many automotive-related functions.

Socket A tool that fits over the head of a bolt or nut and is rotated by a ratchet or breaker bar.

Socket adapter An adapter that allows the use of one size of driver (ratchet or breaker bar) to rotate another drive size of socket.

Solar cells A device that creates electricity when sunlight hits a semiconductor material and electrons are released. About one kilowatt from a solar cell that is one square meter in size.

Solenoid An electromagnetic device that uses a moveable core which can be connected to linkage to move a valve or other device.

Solenoid controlled damper A shock absorber that is electronically controlled by a solenoid.

Solenoid valves Valves that are opened and closed using an electromagnetic solenoid.

Solid axle A solid supporting axle for both front or both rear wheels. Also referred to as a straight axle or nonindependent axle.

Solid state A term used to describe electronic components that have no moving parts.

Solvent Usually colorless liquids that are used to remove grease and oil.

Soot Particulate matter emitted by diesel engines.

Space frame A type of vehicle construction that uses the structure of the body to support the engine and drive train, as well as the steering and suspension. The outside body panels are nonstructure.

Spalling A term used to describe a type of mechanical failure caused by metal fatigue. Metal cracks then break out into small chips, slabs or scales of metal. This process of breaking up is called spalling.

Spark knock Secondary rapid burning of the last 3 to 5% of the air-fuel mixture in the combustion chamber. Causes a second flame front that collides with the first flame front causing a knock noise.

SPDT Single pole, double throw. A type of electrical switch.

Speakers A device consisting of a magnet, coil of wire and a cone which reproduces sounds from the electrical signals sent to the speakers from a radio or amplifier.

Specific gravity The ratio of the weight of a given volume of a liquid divided by the weight of an equal volume of water.

Speed nuts Also called Tinnerman nuts. Used to keep the brake drum on at the assembly plant. Can be removed and discarded when servicing drum brakes for the first time.

Speed rating A letter on most tires that indicates the maximum speed at which the tire is designed to perform.

Spider Center part of a wheel. Also known as the center section.

Spider gears Another name for the pinion gear used in a differential.

Spike A (high) voltage pulse during a short period of time (sharp pulse).

Spike protection resistor A resistor usually between 300 and 500 ohms that is connected in a circuit in parallel with the load to help reduce a voltage spike caused when a current following through a coil is turned off.

Spindle The part of a micrometer that moves and contacts the object being measured.

Spindle nut Nut used to retain and adjust the bearing clearance of the hub to the spindle.

Splice pack A central point where many serial data lines jam together, often abbreviated SP.

Spline bind A condition where the splines on the yoke of a drive shaft bind and then release as a vehicle is first accelerated after a stop.

Split-ball gauge See small hole gauge.

Split μ A term used to describe two different friction (μ) surfaces under the wheels of a vehicle. Mu is the Greek letter for coefficient of friction.

Split point The pressure point where reduction of pressure to the rear brake begins in a proportioning valve.

Split system A divided hydraulic brake system.

SPM Surface permanent magnet. A type of rotor in an AC synchronous electric motor that places the magnets on its outside circumference.

Spoke angle The angle of the steering wheel.

Sponge lead Lead with many small holes used to make a surface porous or sponge-like for use in battery negative plates; the chemical symbol for lead is Pb.

Spongy pedal When there is air in the brake lines, the pedal will have a springy or spongy feeling when applied.

Spontaneous combustion A condition that can cause some materials, such as oily rags to catch fire without a source of ignition.

Spring pocket Also called a spring seat.

Spring rate The spring rate is the amount of weight it takes to compress a spring a certain distance, such as 200 pounds per inch.

Springs Used as a buffer between the suspension and the frame or body and used to absorb wheel movement plus support the weight of the vehicle.

Sprung weight The weight of a vehicle that is supported by the suspension.

SPS Suspension position sensor.

SPST Single pole, single throw. A type of electrical switch.

Squeal A high pitched noise caused by high-frequency vibrations when brakes are applied.

Squib The heating element of an inflator module which starts the chemical reaction to create the gas which inflates an air bag.

Squirrel-cage rotor A rotor design utilized in AC induction motors. The conductors in the rotor are made in the shape of a squirrel cage.

SR Selectable ride.

SRS Supplemental restraint system. Another term for an airbag system.

SSS Speed sensitive steering.

SST Special service tools.

Stabilitrack A brand name of the General Motors Corporation electronic stability control (ESC) system.

Stabilizer bar A hardened steel bar connected to the frame and both lower control arms to prevent excessive body roll. Also called an anti-sway or anti-roll bar.

Stabilizer links Usually consists of a bolt, spacer and nut to connect (link) the end of the stabilizer bar to the lower control arm.

Stall See service bay.

Standard Corporate Protocol (SCP) A network communications protocol used by Ford.

Starter drive A term used to describe the starter motor drive pinion gear with overrunning clutch.

Starter solenoid A type of starter motor that uses a solenoid to activate the starter drive.

Star wheel A notched wheel with a left-or right-hand threaded member for adjusting brake shoes.

State of charge The degree or the amount that a battery is charged. A fully charged battery would be 100% charged.

State-of-health (SOH) A signal sent by modules to all of the other modules in the network indicating that it is well and able to transmit.

State tax A typical payroll deduction.

Static balance When a tire has an even distribution of weight about its axis, it is in static balance.

Static electricity An electrical charge that builds up in insulators and then discharges to conductors.

Static friction The friction between two surfaces at rest (not moving).

Static balancer A type of wheel balancer that is in one plane.

Static seal A seal used between two surfaces that are not moving.

Stator A name for three interconnected windings inside an alternator. A rotating rotor provides a moving magnetic field and induces a current in the windings of the stator.

Steady bearing See Center support bearing.

Steel Refined iron metal with most of the carbon removed.

Steering arms Arms bolted to or forged as a part of the steering knuckles. They transmit the steering force from the tie rods to the knuckles, causing the wheels to pivot.

Steering coupling disc See Flexible coupling.

Steering damper A shock absorber installed on the steering linkage to reduce road shock from being transferred to the steering wheel.

Steering gear Gears on the end of the steering column that multiply the driver's force to turn the front wheels.

Steering knuckle The inner portion of the spindle that pivots on the king pin or ball joints.

Steering offset See Scrub radius.

Steering shaft The part of the steering that connects the steering wheel to the steering gear assembly.

Steering stop The location where the steering linkage stops at the extreme left and right end of travel.

Steering wheel position sensor A sensor that determines in which direction and how fast the steering wheel is being turned.

Step-bore cylinder A wheel cylinder having a different diameter at each end.

Stepper motor A motor that moves a specified amount of rotation.

Stiffening capacitor See powerline capacitor.

Stoichiometric An air-fuel ratio of exactly 14.7: 1. At this specific rate, all the gasoline is fully oxidized by all the available oxygen.

Stone wheel A grinding stone attached to a grinder used for cleaning, sharpening, or other similar operations.

Storage The process inside of a computer where data is stored before and after calculations have been made.

Straight axle See Solid axle.

Straight cut aviation snip A tin snip that is designed with curved jaws that allow a straight cut through sheet metal.

Straight time The amount of time actually spent performing a service operation.

Stratosphere The earth's upper atmosphere. Most of the earth's ozone is located in the stratosphere.

Stress riser A nick or rust area in a spring that could cause the spring to break.

Strikeout bumper See Jounce bumper.

Stroboscopic A very bright pulsing light triggered from the firing of one spark plug. Used to check and adjust ignition timing.

Strong hybrid Another term for "full hybrid." See Full hybrid.

Strut rod Suspension member used to control forward/backward support to the control arms. Also called tension or compression rod (TC rod) or drag rod.

Strut rod bushing A rubber component used to insulate the attachment of the strut rod to the frame on the body of the vehicle.

Strut suspension A type of suspension system that uses struts.

Struts A structural part of a suspension that includes the shock absorber.

Stub shaft A short shaft which is part of the steering gear and attaches to the steering shaft assembly.

Stub-type frame A type of vehicle frame that only supports the front suspension and engine.

Stud A short rod with threads on both ends.

Stud removal tool A hand tool used with a breaker bar or ratchet to remove what is left of a broken stud.

Subwoofer A type of speaker that is used to reproduce low frequency sounds.

SULEV Super-Ultra-Low-Emission Vehicle.

Sulfation Permanent damage in a lead-acid battery caused by the hardening of lead sulfate on the battery plates. Sulfation takes place when a lead-acid battery is discharged for an extended period of time.

Sun gear The center member of a planetary gearset. The other members (planet carrier and ring) rotate around the sun gear, thus the term "planetary."

Suppression diode A diode installed in the reverse bias direction and used to reduce the voltage spike that is created when a circuit that contains a coil is opened and the coil discharges.

Surface charge A "false" charge that exists on the battery plates when a vehicle is first turned off.

Surge tank A reservoir mounted at the highest point in the cooling system.

Suspension Parts or linkages by which the wheels are attached to the frame or body of a vehicle. These parts or linkages support the vehicle and keep the wheels in proper alignment.

Suspension bumper See Jounce bumper.

SUV Sport utility vehicle.

SVR Sealed valve regulated. A term used to describe a type of battery that is valve regulated lead acid or sealed lead acid.

Sway bar Shortened name for anti-sway bar. See Stabilizer bar.

SWCAN An abbreviation for single wire CAN (Controller Area Network).

Swept area The amount of brake drum or rotor friction surface that moves past the brake linings every time the drum or rotor completes a rotation.

Switchgrass A feedstock for ethanol production that requires very little energy or fertilizer to cultivate.

SWPS Steering wheel position sensor.

Syn-Gas Synthesis gas generated by a reaction between coal and steam. Syn-gas is made up of mostly hydrogen and carbon monoxide and is used to make methanol. Syn-gas is also known as town gas.

Synthetic fuel Fuels generated through synthetic processes such as Fischer-Tropsch.

Synthetic retainers A type of retention method for holding together parts of a universal joint.

Table The portion of the shoe to which the lining is attached.

Tach Tachometer, instrument, or gauge used to measure RPM (revolutions per minute).

Tachometer (tach) Instrument or gauge used to measure RPM (revolutions per minute).

TAME Tertiary amyl methyl ether. TAME is an oxygenating fuel and is used as a gasoline additive similar to ETBE or MTBE.

Tandem cylinder A master cylinder with two pistons arranged one ahead of the other. One cylinder operates rear brakes and the other front brakes.

Tandem diaphragm A type of vacuum brake booster that uses two diaphragms.

Tap A metal cutting tool used to create threads in metal after a hole of the proper size has been drilled.

Tapered roller bearings A type of antifriction bearing that uses tapered rollers between the inner and outer races.

TBI Throttle body injection.

TC Traction control.

TCC Torque converter clutch. Used to lock the turbine to the housing, thus producing a direct drive through the torque converter assembly.

TCM Transmission control module. The electronic control module that is responsible for the operation of the vehicle's transmission or transaxle.

TC rod See Strut rod.

TDC Top dead center.

Teacher A role played by a mentor.

Team leader An experienced technician who helps advise a small group of technicians who are paid according to the total amount of work completed by all members of the team.

Technical service bulletin When a problem has a correction, the vehicle manufacturer releases a technical service bulletin (TSB), which details the repair. Also called technical service bulletin information (TSBI).

Technician A person who performs diagnosis and service work to a vehicle.

Technician A and B questions A type of question used on ASE certification tests.

Telescoping steering column A steering column that can be adjusted toward and away from the driver.

Tell-tale light Dash warning light (sometimes called an idiot light).

Tensile strength The maximum stress used under tension (lengthwise force) without causing failure.

Tension rod See strut rod.

Terminal The metal end of a wire which fits into a plastic connector and is the electrical connection part of a junction.

Terminating resistor Resistors placed at the end of a high-speed serial data circuit to help reduce electromagnetic interference.

Test light A light used to test for voltage. Contains a light bulb with a ground wire at one end and a pointed tip at the other end.

TFE Two-flow electronic. A type of variable assist steering.

TFI Thick-film integration.

THD Total Harmonic Distortion. A rating for an amplifier used in sound system.

Thermistor A resistor that changes resistance with temperature. A positive-coefficient thermistor has increased resistance with an increase in temperature. A negative-coefficient thermistor has increased resistance with a decrease in temperature.

Thermocouple Two dissimilar metal when connected and heated creates a voltage. Used for measuring temperature.

Thermoelectric meters A type of dash instrument that uses heat created by current flow through the gauge to deflect the indicator needle.

Thermoelectric principle The production of current flow created by heating the connection of two dissimilar metals.

Thermoelectric switch An electrical switch designed to actuate at a specified temperature.

Thermoelectricity The production of current flow created by heating the connection of two dissimilar metals.

Thermostat A device that controls the flow in a system such as the engine cooling system based on temperature.

Thick-film integration (TFI) Type of Ford electronic ignition system.

Thickness gauge See feeler gauge.

Thimble The part of a micrometer that is rotated to move the spindle.

Third-class lever A type of lever where the fulcrum is located at the end of the lever and the force is applied to the middle of the lever.

Threaded insert A type of thread repair where the original threads are replaced by an insert that contains the same size threads as the original on the inside of the insert.

Three Cs Technicians need to complete the work order by informing the customers of the three Cs—complaint (concern), cause, and the correction.

Three-quarter floating A type of rear drive axle where some of the weight of the vehicle is supported by the axle shaft.

Threshold voltage Another name for barrier voltage or the voltage difference needed to forward bias a diode.

Throttle body A housing containing a valve to regulate the airflow through the intake manifold.

Throttle position (TP) sensor Signals the computer as to the position of the throttle.

Through bolts The bolts used to hold the parts of a starter motor together. The long bolts go though field housing and into the drive-end housing.

Throws The term used to describe the number of output circuits there are in a switch.

Thrust angle The angle between the geometric centerline of the vehicle and the thrust line.

Thrust line The direction the rear wheels are pointed as determined by the rear wheel toe.

THS Toyota Hybrid System.

Tie bars Rubber segments molded between grooves of a tire to help support tread blocks.

Tie rod A rod connecting the steering arms together.

Tier A level of environmental regulation created by the EPA. Tier 1 is gradually being phased out in favor of stricter Tier 2 regulations.

Tight A term used to describe an understeering condition.

Tilt steering column A type of steering column that can be moved upward or downward to fit the driver.

Time base The setting of the amount of time per division when adjusting a scope.

Tin snips A hand tool used to cut sheet metal, thin cardboard, or similar material.

Tinnerman nuts Used to keep the brake drums on at the assembly plant. Can be removed and discarded when servicing the drum brake for the first time.

Tire rotation A term used to describe moving wheel/tire assemblies from one position on a vehicle to another.

Tire slip The difference between the actual speed and the rate at which the tire tread moves across the road surface.

TLEV Transitional Low-Emission Vehicle.

Toe The inward or outward angle of the front or rear wheels as viewed from overhead.

Toe-in The difference in measurement between the front of the wheels and the back of the wheels (the front are closer than the back).

Toe-out The back of the tires are closer than the front.

Tolerance adjustment An alignment method that involves loosening all suspension mounting fasteners and retightening.

Tone generator tester A type of tester used to find a shorted circuit that uses a tone generator. Headphones are used along with a probe to locate where the tone stops which indicates where in the circuit the fault is located.

Tone ring A notched wheel used as a reluctor for the wheel speed sensor.

TOOT Toe out on turns.

Top dead center (TDC) The highest point in the cylinder that the piston can travel. The measurement from bottom dead center (BDC) to TDC determines the stroke length of the crankshaft.

Top tier gasoline Gasoline with a higher detergent content than that specified by the U.S. EPA.

Torque A twisting force measured in pounds-feet (lb-ft) or Newton-meters (N-m) which may result in motion.

Torque arm An arm that attaches the rear differential assembly to the body of the vehicle.

Torque converter A special form of fluid coupling in which torque is increased.

Torque converter clutch A clutch located inside the torque converter that locks the turbine and the impeller together to prevent any slippage. Also called a lockup torque converter.

Torque prevailing nut A type of nut that does not loosen, but rather retains its holding torque.

Torque steer Torque steer occurs in front-wheel-drive vehicles when engine torque causes a front wheel to change its angle (toe) from straight ahead. The resulting pulling effect of the vehicle is most noticeable during rapid acceleration, especially whenever upshifting of the transmission creates a sudden change in torque.

Torque wrench A wrench that registers the amount of applied torque.

Torsion bar A type of spring in the shape of a straight bar. One end is attached to the frame of the vehicle, and the opposite end is attached to a control arm of the suspension. When the wheels hit a bump, the bar twists and then untwists.

Torx A type of fastener which features a star-shaped indentation for a tool. A registered trade mark of the Camcar Division of Textron.

Total circuit resistance (R_T) The total resistance in a circuit.

Total toe The total (combined) toe of both wheels, either front or rear.

TP Throttle position sensor. The sensor that provides feedback concerning the position of the throttle plate.

TPC Tire Performance Criteria.

TPD Tire problem detector.

TPMS Tire pressure monitoring system.

TRAC Traction control. A function of the vehicle antilock brake system that enables application of the brake on wheels that have lost traction.

Trace The displayed waveform that shows the variations of the input signal as a function of time.

Track The distance between the center line of the wheels as viewed from the front or rear.

Track rod A horizontal steel rod or bar attached to rear axle housing at one end and the frame at the other to keep the center of the rear axle centered on the body. Also known as a panhard rod.

Tracking Used to describe the fact that the rear wheels should track directly behind the front wheels.

Traction The friction (traction) between tires and the pavement.

Traction control The electromechanical parts used to control wheel slip during acceleration.

Traction motor A motor-generator in a hybrid electric vehicle that is responsible for propelling or assisting the internal combustion engine.

Trade number The number stamped on an automotive light bulb. All bulbs of the same trade number have the same candlepower and wattage, regardless of the manufacturer of the bulb.

Trailing arm A rear suspension arm that attaches to the frame or body in front of the rear axle.

Trailing shoe The rear facing drum brake shoe on a leading/trailing type of drum brake.

Trainer A beginning service technician just learning about the trade.

Tramp An up and down vibration of a tire/wheel assembly usually due to out-of-round tire or out-of-balance condition.

Transducer An electrical and mechanical speed sensing and control unit used on cruise control systems.

Transistor A semiconductor device that can operate as an amplifier or an electrical switch.

Tread The rubber part of a tire that touches the road.

Trigger Determines the beginning point of a waveform.

Trigger level The voltage level that a waveform must reach to start display.

Trigger slope The voltage direction that a waveform must have to start display. A positive slope requires the voltage to be increasing as it crosses the trigger level; a negative slope requires the voltage to be decreasing.

Trigger source The test tool input that supplies the signal to provide the trigger.

Troposphere The earth's lower atmosphere. The layer above the troposphere is known as the stratosphere.

Trouble light A light used for close viewing of dark areas. Also called a work light.

Troxler effect The Troxler effect is a visual effect where an image remains on the retina of the eye for a short time after the image has been removed. The effect was discovered in 1804 by Igney Paul Vital Troxler (1780–1866), a Swiss physician. Because of the Troxler effect, headlight glare can remain on the retina of the eye and create a blind spot.

Trunnions The four arms of a typical universal joint.

TSB Technical service bulletin.

TSBs See technical service bulletin.

TTL Transistor-Transistor Logic

Tube-nut wrench See fitting wrench.

Turbocharger An exhaust-powered supercharger.

Turbulence The state of being violently disturbed, as in an engine; the rapid swirling motion of the air-fuel mixture entering the cylinder.

Turning radius Refers to the angle of the steering knuckles that allow the inside wheel to turn at a sharper angle than the outside wheel whenever turning a corner. Also known as toe out on turns (TOOT) or the Ackerman angle.

Turns ratio The ratio between the number of turns used in the primary winding of the coil to the number of turns used in the secondary winding. In a typical ignition coil the ratio is 100:1.

TV Thickness variation.

Tweeter A type of speaker used in a audio system that is designed to transmit high frequency sounds.

Twisted pair A pair of wires that are twisted together from 9 to 16 turns per foot of length. Most are twisted once every inch (12 per foot) to help reduce electromagnetic inference from being induced in the wires as one wire would tend to cancel out any interference pickup up by the other wire.

TXV Thermostatic expansion valve. An A/C system component that acts as a refrigerant expansion device.

UART Universal Asynchronous Receive/Transmit, a type of serial data transmission.

UBP UART based protocol.

UCG Underground coal gasification.

U-joints Universal joints.

ULEV Ultra-Low-Emission Vehicle.

ULEV II Ultra Low-Emission Vehicle certified under the Phase II LEV standard.

ULSD Ultra-Low-Sulfur Diesel. Diesel fuel with a maximum sulfur content of 15 parts per million.

Ultraviolet radiation A spectrum of radiation emitted by the sun that is mostly absorbed in the earth's upper ozone layer. Ultraviolet radiation is a major contributor to health issues such as cataracts and skin cancer.

UNC Unified national coarse.

Undercut A process of cutting the insulation, usually mica, from between the segments of a starter commutator.

Underinflation A term used to describe a tire with too little tire pressure (less than minimum allowable pressure).

Understeer A term used describe the handling of a vehicle where the driver must turn the steering wheel more and more while turning a corner.

UNF Unified national fine.

Unit body A type of vehicle construction first used by the Budd Company of Troy, Michigan, that does not use a separate frame. The body is built strong enough to support the engine and the power train, as well as the suspension and steering system. The outside body panels are part of the structure. Also see Space frame construction.

Universal joint A joint in a steering or drive shaft that allows torque to be transmitted at an angle.

Universal joint wrench A hand tool that is used with a socket and ratchet to allow use at an angle. A joint is a steering shaft or drive shaft that allows torque to be applied through an angle.

Unsprung weight The parts of a vehicle not supported by the suspension system. Examples of items that are typical unsprung weight include wheels, tires, and brakes.

Used oil Any petroleum-based or synthetic oil that has been used.

UST Underground storage tank.

Utility knife A handheld knife that uses replaceable blades.

UTQGS Uniform Tire Quality Grading System.

UVA Ultraviolet radiation from the sun that is not absorbed by the ozone layer and is not damaging to biological organisms.

UVB Ultraviolet radiation from the sun that is only partially absorbed by the ozone layer. UVB can cause damage to biological organisms.

VAC Vacuum sensor.

Vacuum Any pressure less than atmospheric pressure (14.7 psi).

Vacuum advance A spark advance unit that advances the ignition timing in relation to engine vacuum.

Vacuum bleeding Using a vacuum source to draw air from a brake hydraulic system.

Vacuum booster A vacuum power brake unit.

Vacuum kicker A computer-controlled throttle device used to increase idle RPM during certain operating conditions, such as when the air conditioning system is operating.

Vacuum, manifold Vacuum in the intake manifold that develops as a result of the intake stroke of the cylinders.

Vacuum, ported A vacuum that develops on the intake side of the throttle plate as air moves past it.

Vacuum power unit A device utilizing engine manifold vacuum to assist application of the brakes, reducing pedal effort.

Vacuum servo A vacuum controlled parking brake release mechanism controlled by an electrical solenoid.

Valence ring The outer most ring or orbit of electrons around a nucleus of an atom.

Valve overlap The amount of time, in degrees of crank rotation, the intake and exhaust valves are both open.

Valvetrain The collection of parts that make the valves operate. The valvetrain includes the camshaft(s), related drive components, the various parts that convert the camshaft's rotary motion into reciprocating motion, and the valves and their associated parts.

Variable-delay wipers Windshield wipers whose speed can be varied.

Variable fuel sensor See Fuel compensation sensor.

Variable ratio A steering gear design that provides a variable steering gear ratio.

Varistors Resistors whose resistance depends on the amount of voltage applied to them.

VATS Vehicle Antitheft System. A system used on some General Motors vehicles.

VCM Variable cylinder management. A function of some Honda HEVs that allows some ICE cylinders to be disabled in order to enhance regenerative braking action.

VDIM Vehicle Dynamic Integrated Management.

VECI Vehicle emission control information. This sticker is located under the hood on all vehicles and includes emission-related information that is important to the service technician.

Vehicle control module (VCM) The on-board computer that controls the engine management, transmission, and other vehicle systems such as antilock brakes.

Vehicle identification number (VIN) Alphanumeric number identifying vehicle type, assembly plant, powertrain, etc.

Vehicle stability enhancement system The name for a General Motors electronic stability control system.

Vent port The Society of Automotive Engineers (SAE) term for the front port of a master cylinder, also called the compensating port or bypass.

Vertical scale The scale used for vertical display (vertical sensitivity) expressed in certain units per division.

VES Variable effort steering.

V-FFV Virtual Flexible Fuel Vehicle. This fuel system design does not use a fuel compensation sensor and instead uses the vehicle's oxygen sensor to adjust for different fuel compositions.

VI Viscosity index. An index of the change in a motor oil's viscosity between hot and cold extremes.

Vibration An oscillation, shake or movement that alternates in opposite directions.

Vibration order A description used to help define a vibration.

VIN Vehicle identification number.

Viscous coupling A type of device used to allow a limited difference in speed of two axles.

VISE GRIPS® A brand name for locking pliers.

VOC Volatile organic compounds. These compounds include gases emitted from paints, solvents, glass, and many other products.

Voice recognition A system which uses a microphone and a speaker connected to an electronic module which can control the operation of electronic devices in a vehicle.

Volatility A measurement of the tendency of a liquid to change to vapor. Volatility is measured using RVP, or Reid Vapor Pressure.

Volt The unit of measurement for the amount of electrical pressure; named for Alessandro Volta (1745–1827).

Voltage drop Voltage loss across a wire, connector, or any other conductor. Voltage drop equals resistance in ohms times current in amperes (Ohm's law).

Voltage regulator An electronic or mechanical unit that controls the output voltage of an electrical generator or alternator by controlling the field current of the generator.

Voltmeter An electrical test instrument used to measure volts (unit of electrical pressure). A voltmeter is connected in parallel with the unit or circuit being tested.

Volumetric efficiency The ratio between the amount of air-fuel mixture that actually enters the cylinder and the amount that could enter under ideal conditions expressed in percent.

VPW Variable pulse width, a type of data transmission to a scan tool.

VRLA battery Valve regulated lead-acid battery. A sealed battery that is both spill proof and leakproof. AGM and gelled electrolyte are both examples of VRLA batteries.

VS sensor Vehicle speed sensor.

VSC Vehicle stability control.

VSES Vehicle Stability Enhancement System.

VSS Vehicle speed sensor.

VTEC Variable Valve Timing and Lift Electronic Control. A valve train control system developed by Honda Motor Company to enhance engine output and efficiency over a wide RPM range.

VTF Vacuum-tube fluorescent.

Vulcanization A process where heat and pressure combine to change the chemistry of rubber.

Wander A type of handling which requires constant steering wheel correction to keep the vehicle going straight.

Warning light A light on the instrument panel to alert the driver when one half of a split hydraulic system fails as determined by the pressure differential switch.

Washers Flat or shaped pieces of round metal with a hole in the center used between a nut and a part or casting.

Water fade A lack of braking caused by water getting between the friction material and the brake drum or rotor.

Water jacket The coolant passages around the cylinders that are used to absorb and transfer heat away from the ICE assembly.

Water pump A mechanical device responsible for circulating coolant through a liquid cooling system.

Water pump pliers See multiple-groove adjustable pliers.

Watt An electrical unit of power; 1 watt equals current (amperes) × voltage (1/746 hp). Named after James Watt, a Scottish inventor.

Watt's Law The formula for Watts is the voltage times the amperes in the circuit which represents the electrical power in the circuit.

Watt's link A type of track rod which uses two horizontal rods pivoting at the center of the rear axle.

Waveform The pattern defined by an electrical signal.

Ways Places where the disc brake caliper contacts on a sliding-type caliper design.

Wear bars See Wear indicators.

Wear indicator Bald area across the tread of a tire when 2/32" or less of tread depth remains.

Wear indicator ball-joint A ball-joint design with a raised area around the grease fitting. If the raised area is flush or recessed with the surrounding area of the ball-joint, the joint is worn and must be replaced.

Wear indicators bald area across the tread of a tire when only 2/32" or less of tread depth remains.

Web The stiffening member of the shoe to which the shoe table is attached.

Weight bias The amount of weight on the front compared to the rear of a vehicle.

Weight-carrying ball-joint See load-carrying ball-joint.

Weight transfer The movement of weight forward during braking.

Wheelbase The distance between the center line of the two wheels as viewed from the side.

Wheel brakes Brakes at each wheel of a vehicle that slows and stops the rotation of that wheel.

Wheel cover A functional and decorative cover over the entire wheel. Also see hub cap.

Wheel cylinder The part of the hydraulic system that receives pressure from the master cylinder and applies the brake shoes to the drums.

Wheel speed sensors Sensors used to detect the speed of the wheels. Used by an electronic controller for antilock brakes (ABS) and/or traction control.

Wheel mounting torque The amount of torque applied to the lug nuts.

Wheel rate Similar to spring rate, but includes the ratio of wheel travel to spring travel to determine the force per inch rate.

WHMIS Workplace Hazardous Materials Information Systems.

Wide-band oxygen sensor An oxygen sensor design that is capable of detecting actual air-fuel ratios. This is in contrast to a conventional oxygen sensor that only changes voltage when a stoichiometric air-fuel ratio has been achieved.

Wind farm An area of land that is populated with wind-generating plants.

Window regulator A mechanical device that transfers the rotating motion of the window hand crank or electric motor to a vertical motion to raise and lower a window in a vehicle.

Windshield wipers The assembly of motor, motor control, operating linkage plus the wiper arms and blades which are used to remove rain water from the windshield.

Wire brush wheel A wire brush wheel is often mounted on one end of a grinder and is used for cleaning parts and other similar operations.

Wiring schematic A drawing showing the wires and the components in a circuit using symbols to represent the components.

Wishbone suspension See SLA.

Witness mark A mark made by an object which indicates where a noise or vibration could be located.

W/O Without.

Wood alcohol See Methanol.

Work The transfer of energy from one physical system to another. Actually moving an object is work.

Work experience Two years of work experience as a service technician is needed plus passing one or more tests to be certified by ASE.

Work light See trouble light.

Work order Contains all vehicle and customer information plus what service work is requested by the customer. Also called a repair order.

Worm and roller A steering gear that uses a worm gear on the steering shaft. A roller on one end of the cross shaft engages the worm.

Worm and sector A steering gear that uses a worm gear that engages a sector gear on the cross shaft.

Worm gear A type of gear used in an older type of steering gear, which is attached to the steering shaft.

WOT Wide-open throttle.

WOW display A dash display when it first comes on and lights all possible segments. Can be used to test the dash display for missing lighted segments.

Wrench A hand tool used to grasp and rotate a threaded fastener.

WSS Wheel speed sensor.

WWFC World Wide Fuel Charter. A fuel quality standard developed by vehicle and engine manufacturers in 2002.

Wye wound A type of stator winding in which all three coils are connected to a common center connection. Called a wye because the connections look like the letter Y.

Xenon headlights Headlights that use an arc tube assembly that has a xenon gas inside which produces a bright bluish light.

Yaw rate sensor An input sensor usually located in the center of the vehicle that detects yaw as part of an electronic suspension system.

Zener diode A specially constructed (heavily doped) diode designed to operate with a reverse-bias current after a certain voltage has been reached. Named for Clarence Melvin Zener.

Zerk A name commonly used for a grease fitting. Named for its developer, Oscar U. Zerk, in 1922, an employee of the Alamite Corporation. Besides a Zerk fitting, a grease fitting is also called an Alamite fitting.

ZEV Zero-Emission Vehicle. This rating is typically only achieved by battery-powered vehicles or those powered by fuel cells.

Zinc-air A type of battery design that uses a positive electrode of gaseous oxygen and a negative electrode made of zinc.

Zone valve An electrically operated valve for controlling refrigerant flow in A/C systems with multiple evaporators.

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