

# 9

## Starting System Operation

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### LEARNING OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- Define the two circuits of the automotive starting system.
- Identify the basic starting systems parts and explain their function in the system.
- Define the different designs of starting systems used by the different automotive manufacturers.
- Identify the internal components of an automotive starter motor and explain their operation.
- Define the term magnetic repulsion and explain how a DC starter motor operates.
- Define the terms *series*, *shunt (parallel)*, and *compound (series-parallel)* as they apply to starter motor internal circuitry.
- Explain the operation of the armature and fields.
- Define starter motor drives and explain their operation.
- Define the different designs of starting motors used by the different automotive manufacturers.
- Explain the operation of the overrunning clutch.

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### KEY TERMS

Armature  
Brushes  
Clutch Start Switch  
Compound Motor  
Detented  
Ignition Switch  
Lap Winding  
Magnetic Repulsion  
Magnetic Switch  
Overrunning Clutch  
Pinion Gear  
Series Motor  
Shunt Motor  
Solenoid  
Solenoid-Actuated Starter  
Starter Drive  
Starting Safety Switch  
Torque

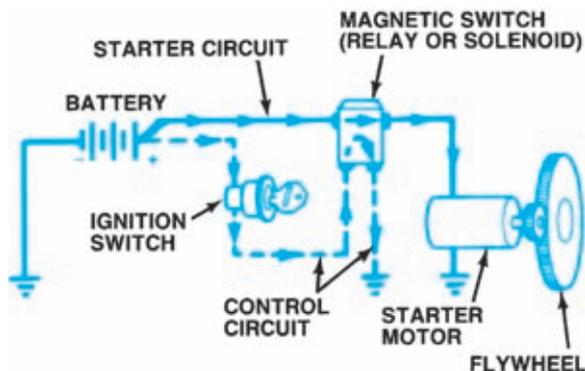
## INTRODUCTION

The engine must be rotated before it will start and run under its own power. The starting system is a combination of mechanical and electrical components that work together to start the engine. The starting system is designed to change electrical energy that is being stored in the battery into mechanical energy. To accomplish this conversion, a starter motor is used. This chapter will explain how the starting system and its components operate.

## STARTING SYSTEM CIRCUITS

The starting system draws a large amount of current from the battery to power the starter motor. To handle this current safely and with a minimum voltage loss from resistance, the cables must be the correct size, and all connections must be clean and tight. The driver through the ignition switch controls the starting system. If the heavy cables that carry current to the starter were routed to the instrument panel and the switch, they would be so long that the starter would not get enough current to operate properly. To avoid such a voltage drop, the starting system has the following two circuits, as shown in Figure 9-1:

- Starter circuit
- Control circuit



**Figure 9-1.** In this diagram of the starting system, the starter circuit is shown as a solid line and the control circuit is shown as a dashed line. (Delphi Automotive Systems)

## Starter Circuit

The starter circuit, or motor circuit, (shown as the solid lines of Figure 9-1) consists of the following:

- Battery
- Magnetic switch
- Starter motor
- Heavy-gauge cables

The circuit between the battery and the starter motor is controlled by a magnetic switch (a relay or **solenoid**). Switch design and function vary from system to system. A gear on the starter motor armature engages with gear teeth on the engine flywheel. When current reaches the starter motor, it begins to turn. This turns the car's engine, which can quickly fire and run by itself. If the starter motor remained engaged to the engine flywheel, the starter motor would be spun by the engine at a very high speed. This would damage the starter motor. To avoid this, there must be a mechanism to disengage the starter motor from the engine. There are several different designs that will do this, as we will see in this chapter.

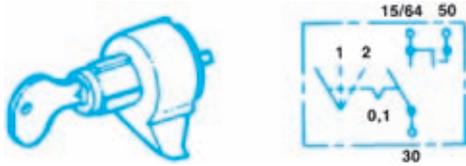
## Control Circuit

The control circuit is shown by the dashed lines in Figure 9-1. It allows the driver to use a small amount of battery current, about three to five amperes, to control the flow of a large amount of battery current to the starter motor. Control circuits usually consist of an ignition switch connected through normal-gauge wiring to the battery and the magnetic switch. When the ignition switch is in the start position, a small amount of current flows through the coil of the magnetic switch. This closes a set of large contact points within the magnetic switch and allows battery current to flow directly to the starter motor. For more information about control circuits, see the "Starter Control Circuit Devices" section in Chapter 9 of the *Shop Manual*.

## BASIC STARTING SYSTEM PARTS

We have already studied the battery, which is an important part of the starting system. The other circuit parts are as follows:

- Ignition switch
- Starting safety switch (on some systems)



**Figure 9-2.** This ignition switch acts directly on the contact points. (Reprinted by permission of Robert Bosch GmbH)

- Relays or solenoids (magnetic switches)
- Starter motor
- Wiring

## Ignition Switch

The **ignition switch** has jobs other than controlling the starting system. The ignition switch normally has at least four positions:

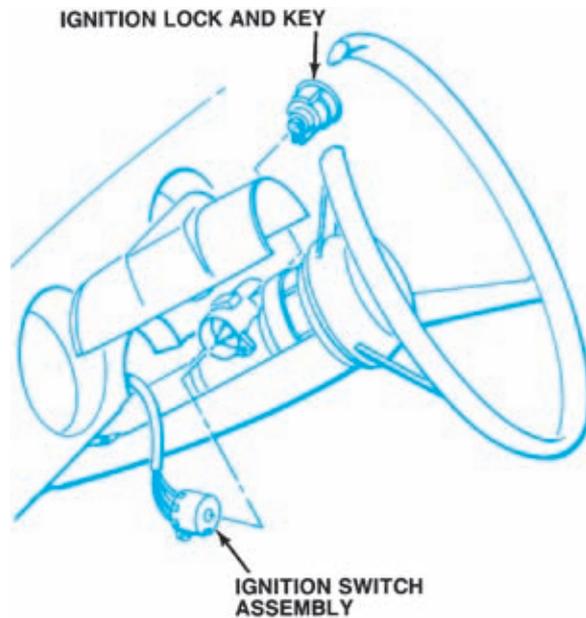
- ACCESSORIES
- OFF
- ON (RUN)
- START

Switches on late-model cars also have a **LOCK** position to lock the steering wheel. All positions except **START** are **detented**. That is, the switch will remain in that position until moved by the driver. When the ignition key is turned to **START** and released, it will return to the **ON (RUN)** position. The **START** position is the actual starter switch part of the ignition switch. It applies battery voltage to the magnetic switch.

There are two types of ignition switches in use. On older cars, the switch is mounted on the instrument panel and contains the contact points (Figure 9-2). The newer type, used on cars with locking steering columns, is usually mounted on the steering column. Many column-mounted switches operate remotely mounted contact points through a rod. Other column-mounted switches operate directly on contact points (Figure 9-3). Older domestic and imported cars sometimes used separate push-button switches or cable-operated switches that controlled the starting system separately from the ignition switch.

## Starting Safety Switch

The **starting safety switch** is also called a neutral start switch. It is a normally open switch that prevents the starting system from operating when the automobile's transmission is in gear. If the car has no starting safety switch, it is possible to spin



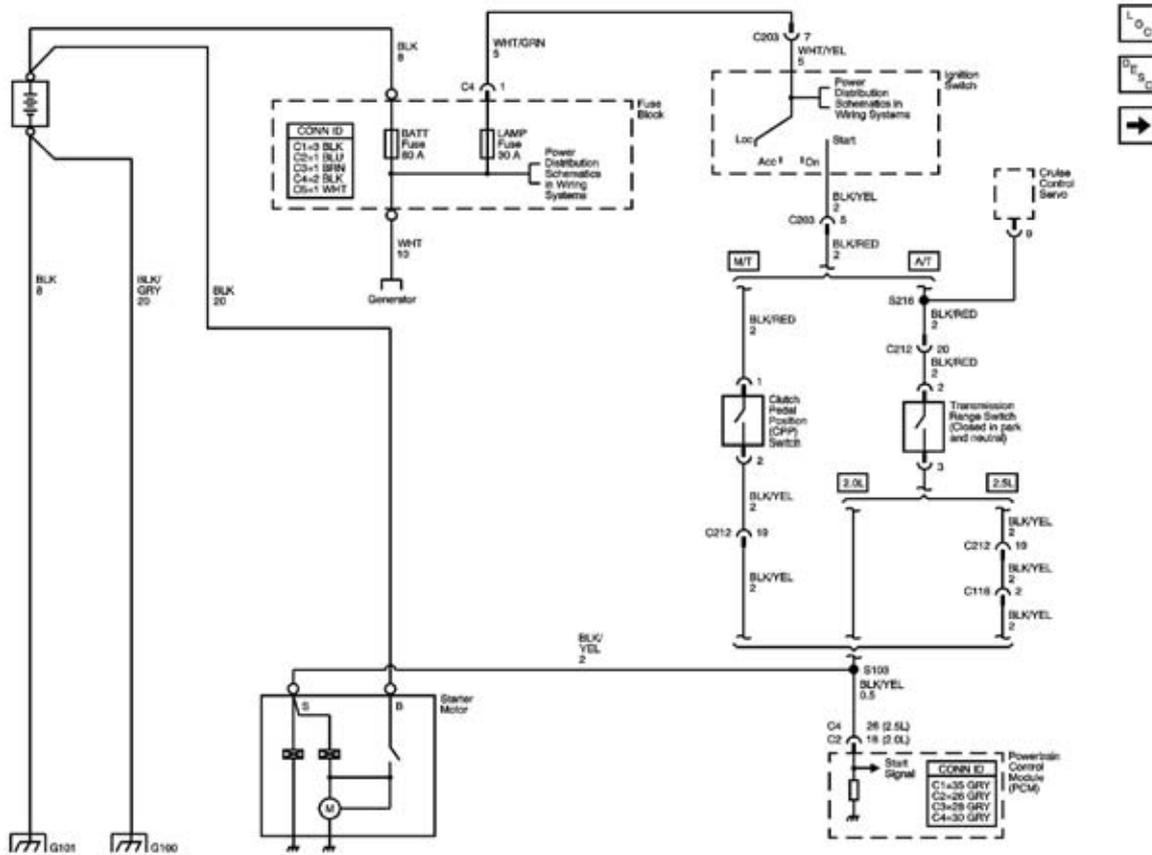
**Figure 9-3.** Column-mounted switches act directly on the contact points.

the engine with the transmission in gear. This makes the car lurch forward or backward, which could be dangerous. Safety switches or interlock devices are now required by law with all automatic and manual transmissions.

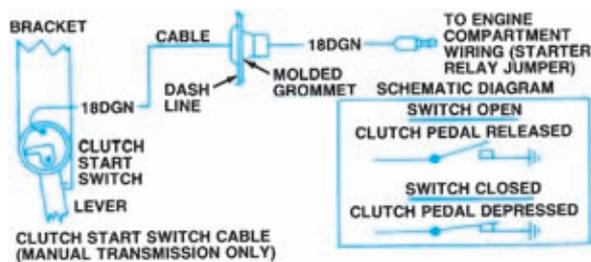
Starting safety switches can be connected in two places within the starting system control circuit. The safety switch can be placed between the ignition switch and the magnetic switch, as shown in Figure 9-4, so that the safety switch must be closed before current can flow to the magnetic switch. The safety switch also can be connected between the magnetic switch and ground (Figure 9-5), so that the switch must be closed before current can flow from the magnetic switch to ground. Where the starting safety switch is installed depends upon the type of transmission used and whether the gearshift lever is column-mounted or floor-mounted.

## Automatic Transmissions/Transaxles

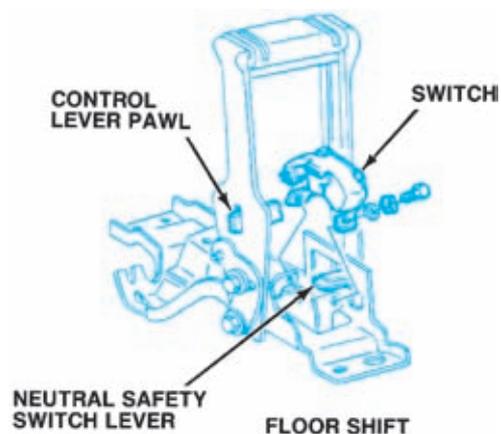
The safety switch used with an automatic transmission or transaxle can be either an electrical switch or a mechanical device. Electrical/electronic switches have contact points that are closed only when the gear lever is in **PARK** or **NEUTRAL**, as shown in Figure 9-4. The switch can be mounted near the gearshift lever, as in Figures 9-6 and 9-7, or on the transmission-housing, as in Figure 9-8. The



**Figure 9-4.** This starting safety switch must be closed before battery current can reach the magnetic switch. (GM Service and Parts Operations)



**Figure 9-5.** The clutch switch must be closed before battery current can flow from the magnetic switch to ground. (DaimlerChrysler Corporation)



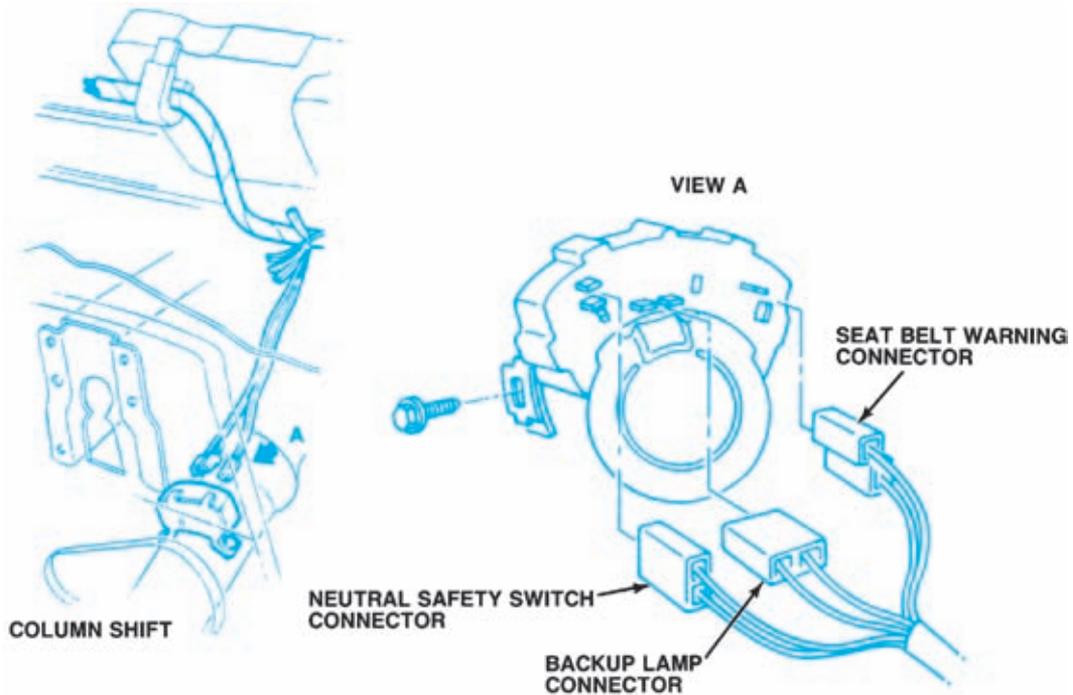
**Figure 9-6.** An electrical safety switch installed near the floor-mounted gearshift lever. (GM Service and Parts Operations)

contacts are in series with the control circuit, so that no current can flow through the magnetic switch unless the transmission is out of gear.

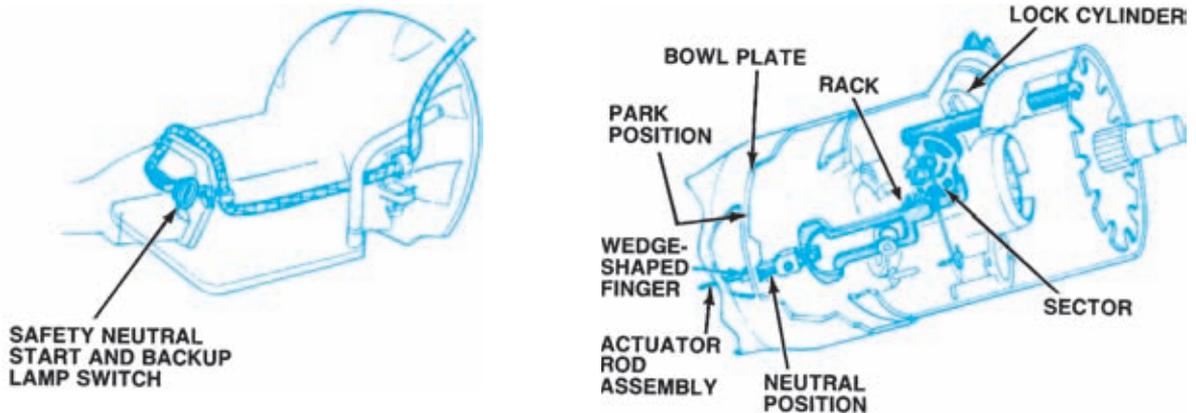
Mechanical interlock devices physically block the movement of the ignition key when the transmission is in gear, as shown in Figures 9-9 and 9-10. The key can be turned only when the gearshift lever is in PARK or NEUTRAL. Some manufacturers use an additional circuit in the neutral start switch to light the backup lamps

when the transmission is placed in REVERSE (Figures 9-7 and 9-8).

Ford vehicles equipped with an electronic automatic transmission or transaxle use an additional circuit in the neutral safety switch to inform



**Figure 9-7.** Column-mounted neutral safety switch near gearshift tube. (GM Service and Parts Operations)



**Figure 9-8.** Transmission-mounted safety switch. (DaimlerChrysler Corporation)

**Figure 9-9.** A mechanical device within the steering column blocks the movement of the ignition switch.

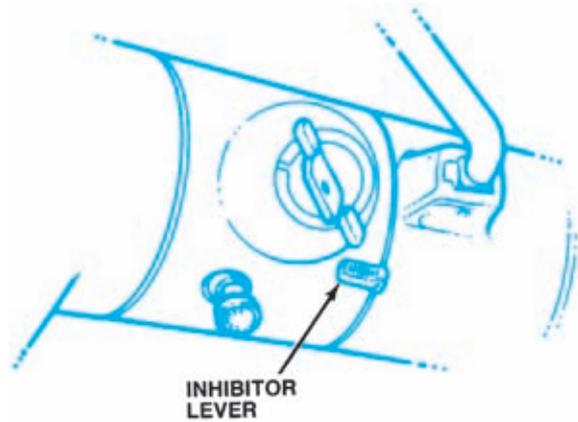
the microprocessor of the position of the manual lever shaft. This signal is used to determine the desired gear and electronic pressure control. The switch is now called a manual lever position switch (MLPS).

General Motors has done essentially the same as Ford, renaming the PARK/NEUTRAL switch used on its 4T65E and 4T80E transaxles. It now is called either a PRNDL switch or a PARK/NEUTRAL position switch and provides input to the PCM regarding torque converter clutch slip. This input allows the PCM to make

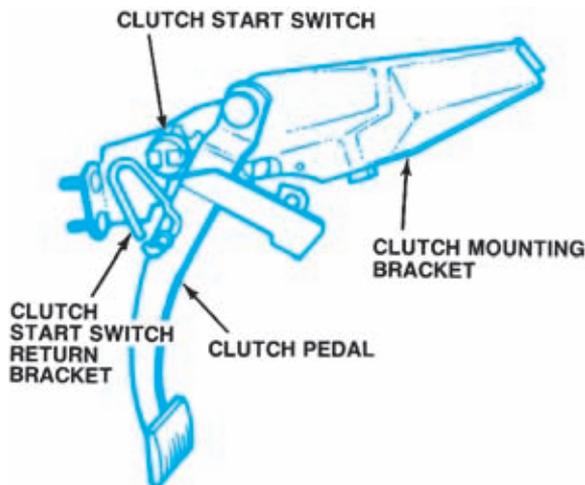
the necessary calculations to control clutch apply and release feel.

## Manual Transmissions/ Transaxles

The starting safety switch used with a manual transmission on older vehicles is usually an electrical switch similar to those shown in Figures 9-7 and 9-8. A **clutch start switch** (also called an interlock switch) is commonly used with manual



**Figure 9-10.** A lever on the steering wheel blocks the movement of the ignition key when the transmission is in gear.



**Figure 9-11.** The clutch pedal must be fully depressed to close the clutch switch and complete the control circuit.

transmissions and transaxles on late-model vehicles. This is an electric switch mounted on the floor or firewall near the clutch pedal. Its contacts are normally open and close only when the clutch pedal is fully depressed (Figure 9-11).

## Relays and Solenoids

A **magnetic switch** in the starting system allows the control circuit to open and close the starter circuit. The switch can be either of the following:

- A relay, which uses the electromagnetic field of a coil to attract an armature and close the contact points

- A solenoid, which uses the electromagnetic field of a coil to pull a plunger into the coil and close the contact points

In addition to closing the contact points, solenoid-equipped circuits often use the movement of the solenoid to engage the starter motor with the engine flywheel. We will explain this in Chapter 10. The terminology used with relays and solenoids is often confusing. Technically, a relay operates with a hinged **armature** and does only an electrical job; a solenoid operates with a movable plunger and usually does a mechanical job. Sometimes, a solenoid is used only to open and close an electric circuit; the movement of the plunger is not used for any mechanical work. Manufacturers sometimes call these solenoids “starter relays.” Figure 9-12 shows a commonly used Ford starter relay. We will continue to use the general term *magnetic switch*, and will tell you if the manufacturer uses a different name for the device.

For more information about magnetic switches, see the following sections in Chapter 9 of the *Shop Manual*: “Inspection and Diagnosis,” “Starter Control Circuit Devices,” and “Unit Removal.”

## Wiring

The starter motor circuit uses heavy-gauge wiring to carry current to the starter motor. The control circuit carries less current and thus uses lighter-gauge wires.

## SPECIFIC STARTING SYSTEMS

Various manufacturers use different starting system components. The following paragraphs briefly describe the circuits used by major manufacturers.

### Delco-Remy (Delphi) and Bosch

Delco-Remy and Bosch starter motors are used by General Motors. The most commonly used Delco-Remy and Bosch automotive starter motor depends upon the movement of a solenoid both to control current flow in the starter circuit and to engage the starter motor with the engine flywheel. This is called a **solenoid-actuated starter**. The



Figure 9-12. The Ford starter relay or magnetic switch.

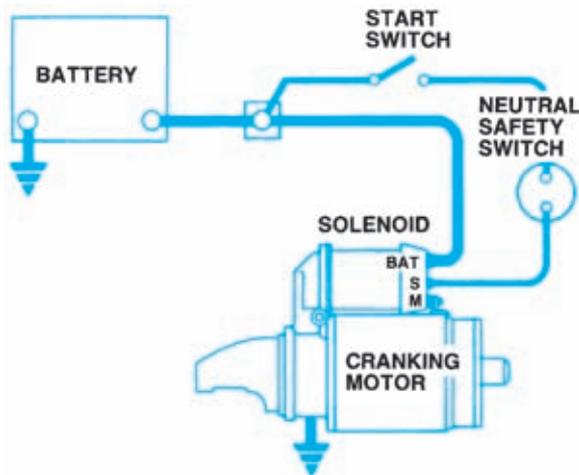


Figure 9-13. GM Starter circuit. (Delphi Automotive Systems)

solenoid is mounted on, or enclosed with, the motor housing (Figure 9-13).

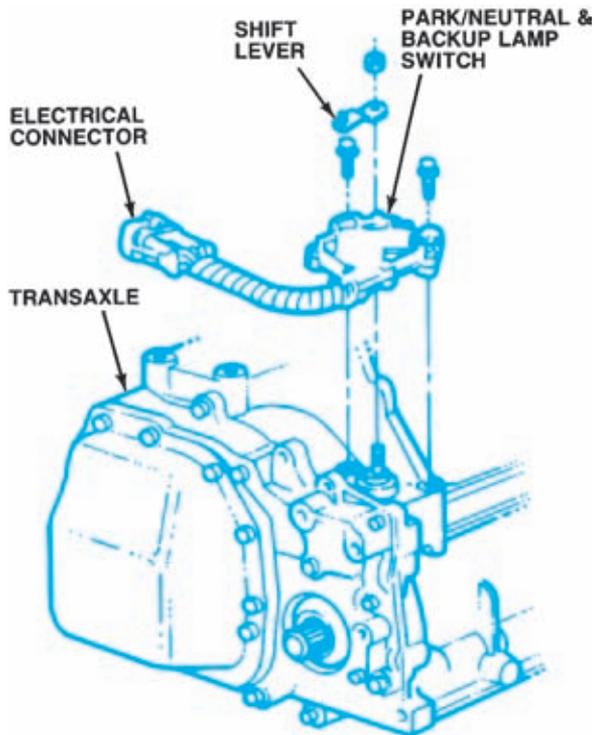
The type and location of starting safety switches vary within the GM vehicle platforms. Larger-size GM cars use a mechanical blocking device in the steering column (Figure 9-9). The intermediate and smaller cars with automatic transmissions have electrical switches mounted near the shift lever. These are either on the column, as shown in Figure 9-7, or on the floor (Figure 9-6). On front-wheel-drive

(FWD) cars with automatic transmissions, the PARK/NEUTRAL or PRNDL switch is an electrical switch mounted on the transaxle case manual lever shaft (Figure 9-14). GM cars with floor-shift manual transmissions use a clutch pedal-operated safety switch. With column-shift manual transmissions, an electric switch is mounted on the column.

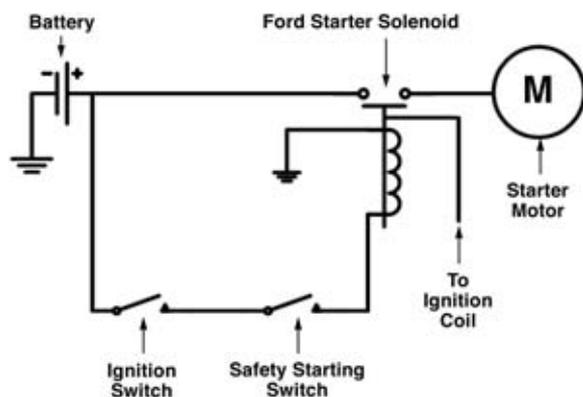
## Ford Motorcraft

Ford has used three types of starter motors, and therefore has several different starting system circuits. The Motorcraft positive engagement starter has a movable-pole shoe that uses electro-magnetism to engage the starter motor with the engine. This motor does not use a solenoid to *move* anything, but it uses a solenoid to open and close the starter circuit as a magnetic switch (Figure 9-15). Ford calls this solenoid a starter relay.

The Motorcraft solenoid-actuated starter is very similar to the Delco-Remy unit and depends upon the movement of a solenoid to engage the starter motor with the engine. The solenoid is mounted within the motor housing and receives battery current through the same type of starter relay used in the positive engagement system. Although the motor-mounted solenoid could do the job of this additional starter relay, the second relay is installed



**Figure 9-14.** GM PRNDL/Park-neutral switch on a GM Transaxle. (GM Service and Parts Operations)



**Figure 9-15.** The Ford starting system circuit with the positive engagement starter.

on many Ford automobiles to make the cars easier to build. Motorcraft solenoid-actuated starters were used on Ford cars and trucks with large V8 engines. The Motorcraft permanent magnet gear-reduction (PMGR) starter is a solenoid-actuated design that operates much like the Motorcraft solenoid-actuated starter previously described. However, the starter circuit may or may not use a starter relay, depending on the car model.

Rear-wheel-drive (RWD) Ford automobiles with manual transmissions have no starting safety

switch. Front-wheel-drive (FWD) models with manual transaxles have a clutch interlock switch. If a Ford car with an automatic transmission has a column-mounted shift lever, a blocking interlock device prevents the ignition key from turning when the transmission is in gear. If the automatic transmission shift lever is mounted on the floor, an electrical switch prevents current from flowing to the starter relay when the transmission is in gear. The switch may be mounted on the transmission case or near the gearshift lever.

## DaimlerChrysler

Chrysler uses a solenoid-actuated starter motor. The solenoid is mounted inside the motor housing and receives battery current through a starter relay, as shown in Figure 9-16. Chrysler starter relays used prior to 1977 have four terminals, as shown in Figure 9-17A. In 1977, a second set of contacts and two terminals were added (Figure 9-17B). The extra contacts and terminals allow more current to flow through the relay to the ignition system and to the exhaust gas recirculation (EGR) timer. This has no effect on the operation of the relay within the starting system. These starter relays generally were mounted on the firewall.

Current Chrysler starting systems use a standard five-terminal Bosch relay (Figure 9-18) but only four terminals are used in the circuit (Figure 9-19). The relay is located at the front of the driver's-side strut tower in a power distribution center or cluster.

Chrysler automobiles with manual transmissions have a clutch interlock switch, as shown in Figure 9-20. Current from the starter relay can flow to ground only when the clutch pedal is fully depressed. Cars with automatic transmissions have an electrical neutral start switch mounted on the transmission housing (Figure 9-21). When the transmission is out of gear, the switch provides a ground connection for the starter control circuit.

## Toyota and Nissan

Toyota and Nissan use a variety of solenoid-actuated direct drive and reduction-gear starter designs manufactured primarily by Hitachi and Nippondenso, as shown in Figures 9-22 and 9-23. The neutral start switch (called an inhibitor switch by the Japanese automakers) incorporates a relay in its circuit.

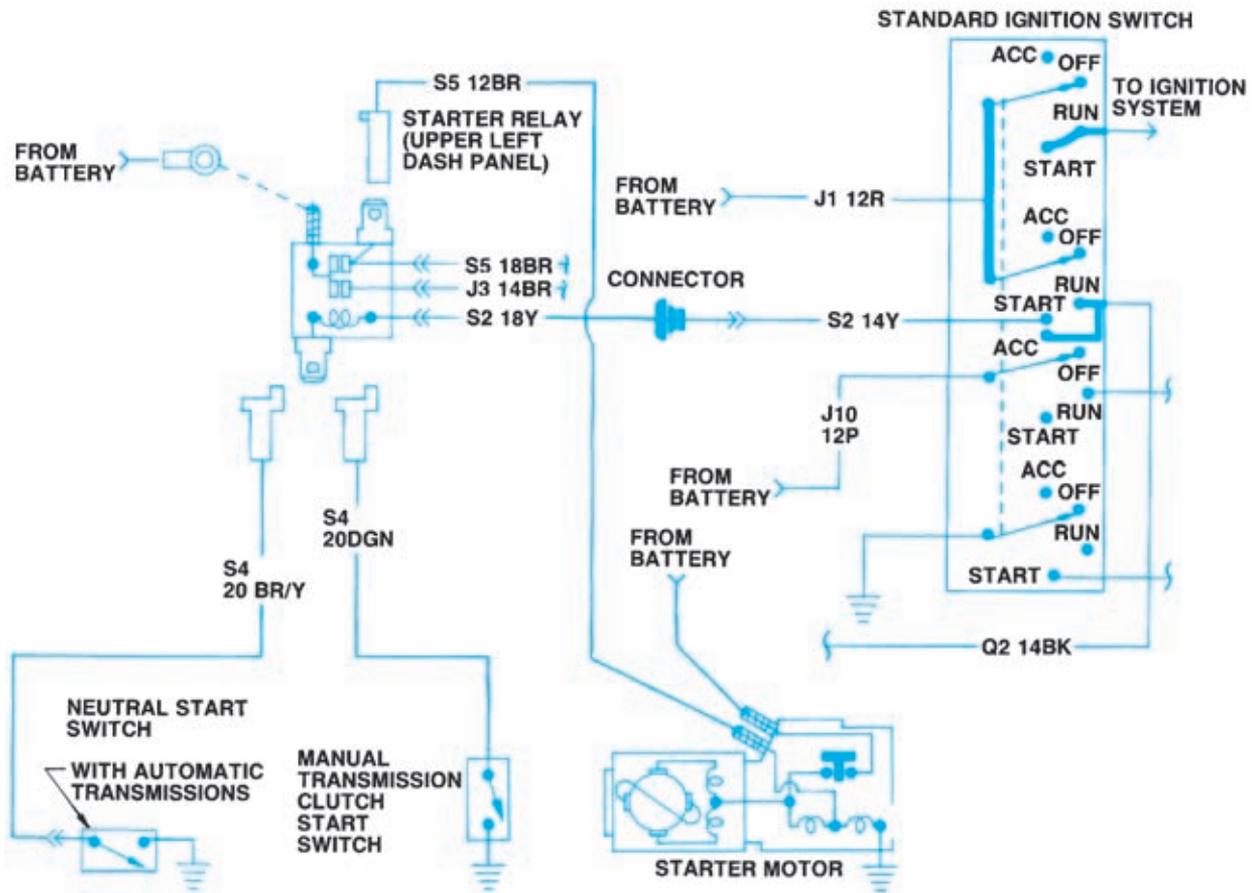


Figure 9-16. Typical DaimlerChrysler starting system. (DaimlerChrysler Corporation)

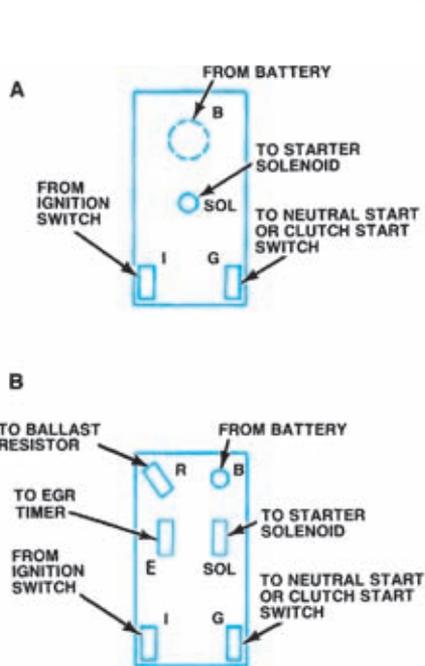


Figure 9-17. Comparison of the terminals on a pre-1977 starter relay (A) and a 1977 or later relay (B). (DaimlerChrysler Corporation)

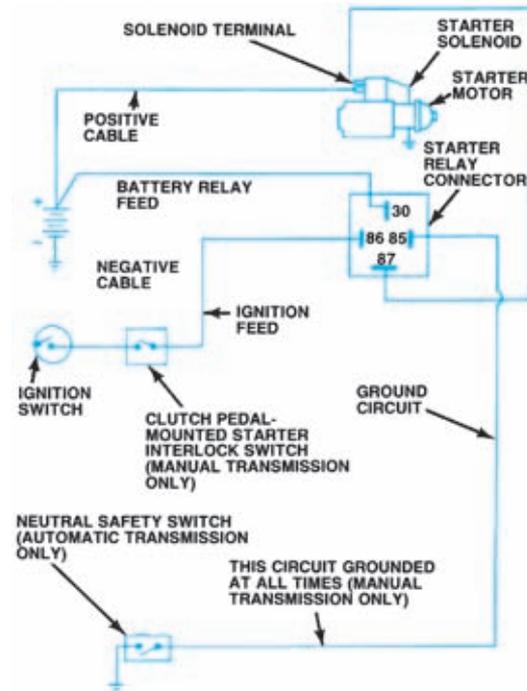
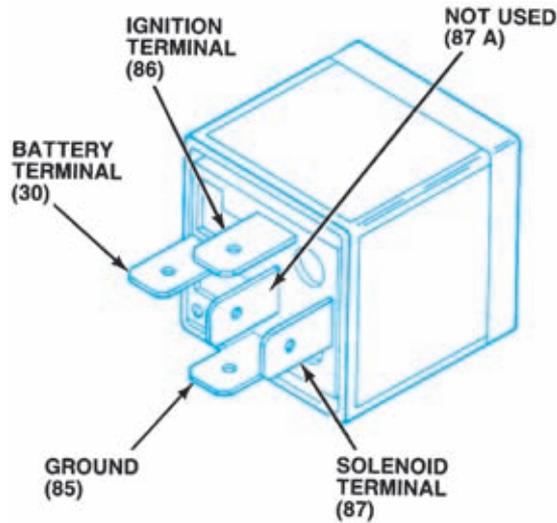
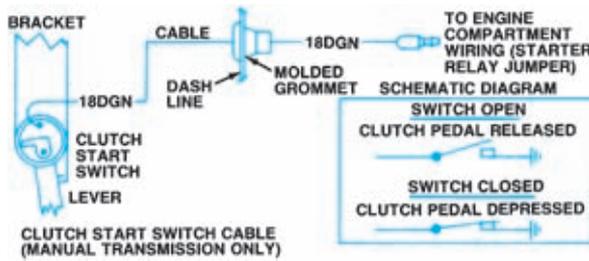


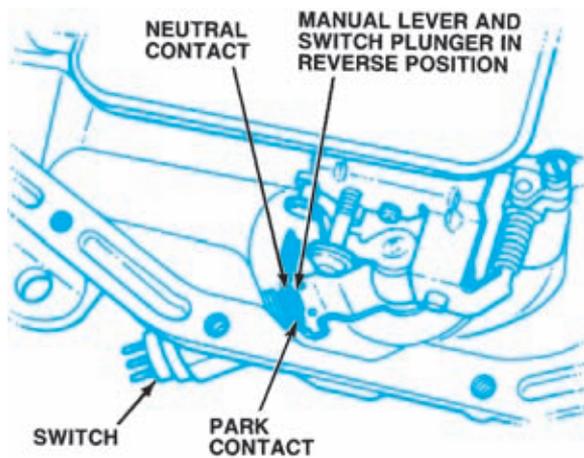
Figure 9-18. DaimlerChrysler starting system with a five-terminal relay. (DaimlerChrysler Corporation)



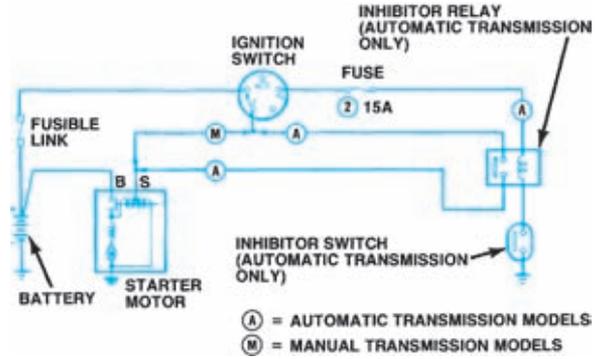
**Figure 9-19.** Only four of the five relay terminals are used when the Bosch relay is installed. (DaimlerChrysler Corporation)



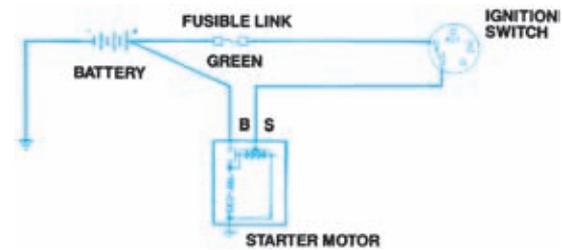
**Figure 9-20.** DaimlerChrysler clutch switch. (DaimlerChrysler Corporation)



**Figure 9-21.** When the automatic transmission is in PARK or NEUTRAL, a transmission lever touches the contact and completes the control circuit to ground. (DaimlerChrysler Corporation)



**Figure 9-22.** Typical Nissan starting system used on gasoline engines. (Courtesy of Nissan North America, Inc.)



**Figure 9-23.** A typical Nissan diesel starting system. (Courtesy of Nissan North America, Inc.)

## STARTER MOTORS

### Starter Motor Purpose

The starter motor converts the electrical energy from the battery into mechanical energy for cranking the engine. The starter is an electric motor designed to operate under great electrical loads and to produce very high horsepower. The starter consists of housing, field coils, an armature, a commutator and brushes, end frames, and a solenoid-operated shift mechanism.

### FRAME AND FIELD ASSEMBLY

The frame, or housing, of a starter motor (Figure 9-24) encloses all of the moving motor parts. It supports the parts and protects them from dirt, oil, and other contamination. The part of the frame that encloses the pole shoes and field windings is made of iron to provide a path for magnetic flux lines (Figure 9-25). To reduce weight, other parts of the frame may be made of cast aluminum.

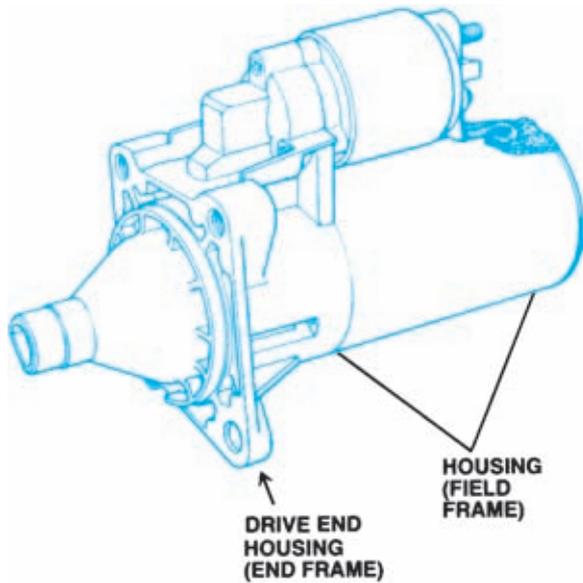


Figure 9-24. Starter motor housing.

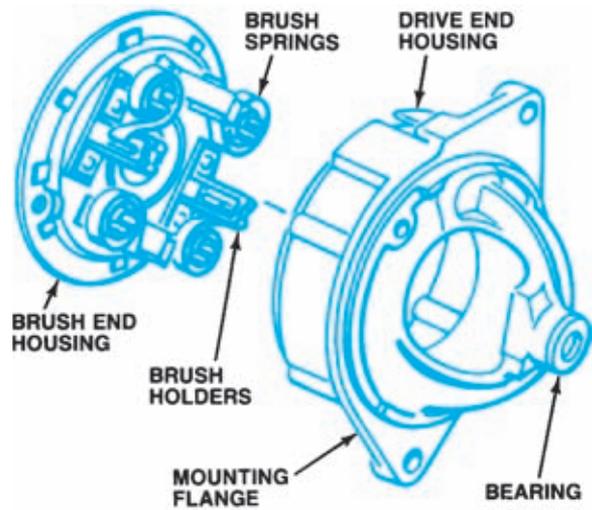


Figure 9-26. Brush end and end housing.

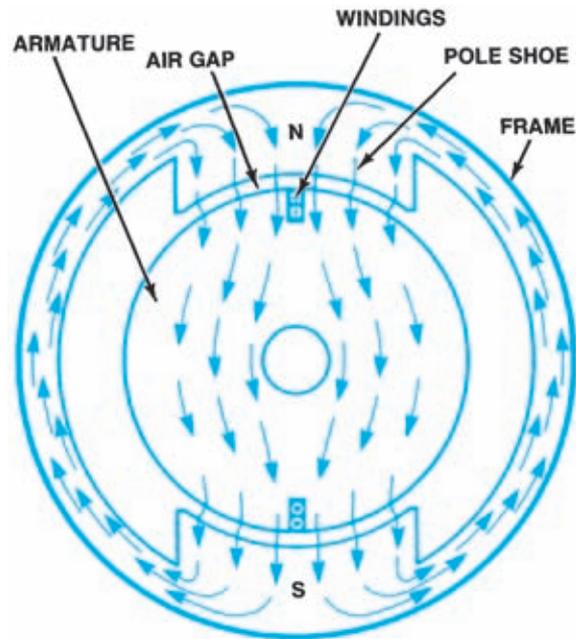


Figure 9-25. The motor frame is a path for flux lines.

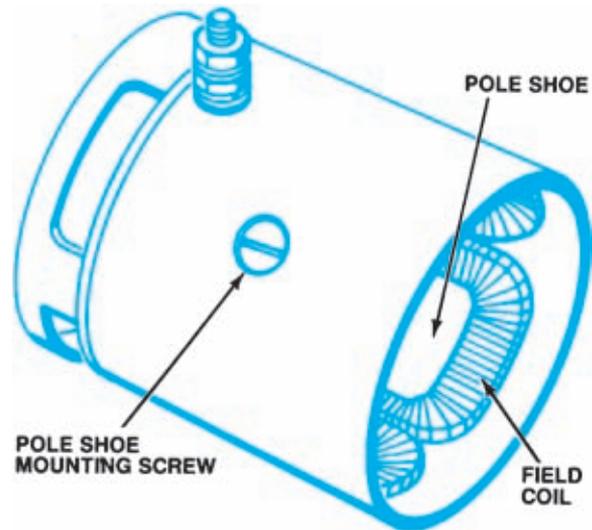


Figure 9-27. Pole shoes and field windings in housing.

One end of the housing holds one of the two bearings or bushings in which the armature shaft turns. On most motors, it also contains the **brushes** that conduct current to the armature (Figure 9-26). This is called the brush, or commutator, end housing. The other end housing holds the second bearing or bushing in which the

armature shaft turns. It also encloses the gear that meshes with the engine flywheel. This is called the drive end housing. The drive end housing often provides the engine-to-motor mounting points. These end pieces may be made of aluminum because they do not have to conduct magnetic flux.

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 (Figure 9-27). Figure 9-28 shows the paths of magnetic flux lines within a four-pole motor. The field windings are usually made of a heavy

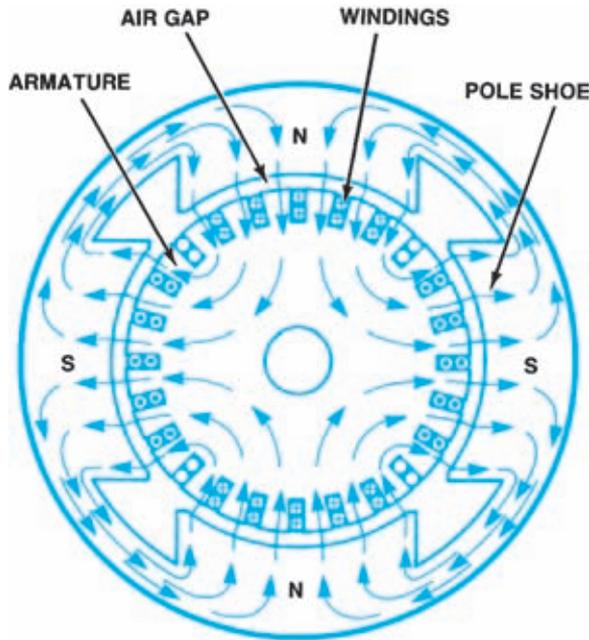


Figure 9-28. Flux path in a four-pole motor.

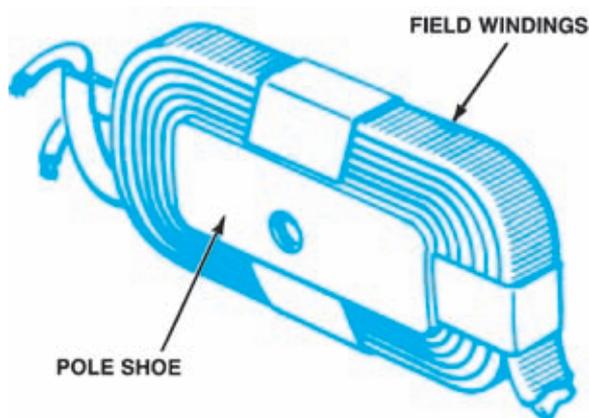


Figure 9-29. Pole shoe and field winding removed from housing.

copper ribbon (Figure 9-29) to increase their current-carrying capacity and electromagnetic field strength. 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.

**Torque** is the force of a starter motor, a force applied in a rotary, or circular direction. The torque, speed, and current draw of a motor

are related. As speed increases in most automotive starter motors, torque and current draw decrease. These motors develop maximum torque just before the engine begins to turn. Once the engine begins to turn, the motor speed increases and torque decreases. The maximum amount of torque produced by a motor depends upon the strength of its magnetic fields. As field strength increases, torque increases.

## DC STARTER MOTOR OPERATION

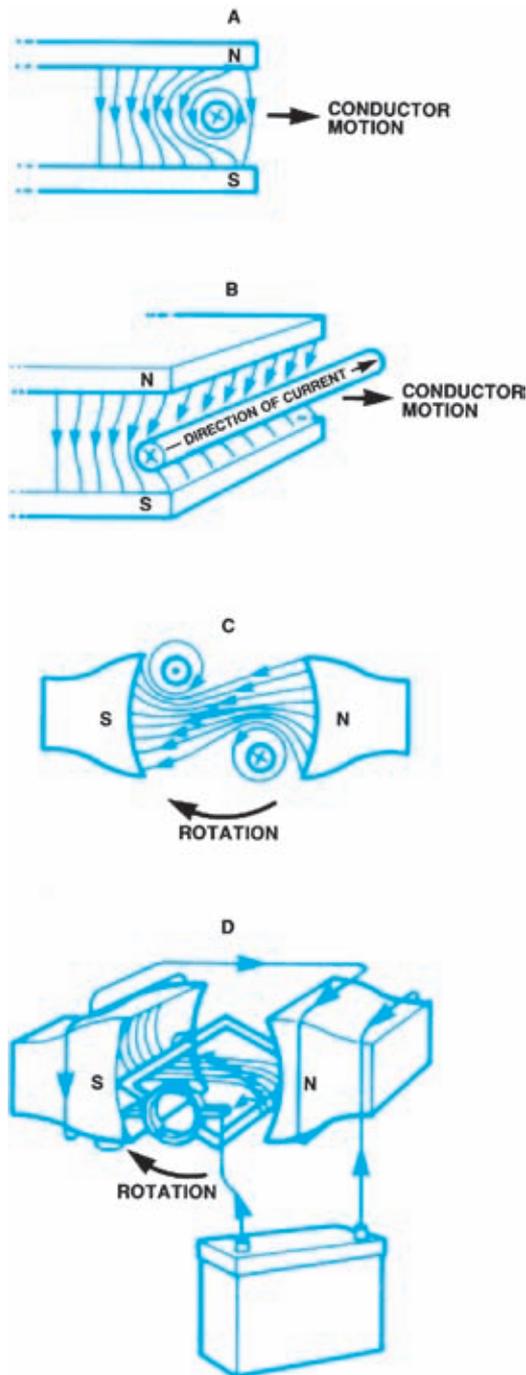
DC starter motors (Figure 9-30) work on the principle of magnetic repulsion. This principle states that **magnetic repulsion** occurs when a straight rod conductor composed of the armature, commutator, and brushes is located in a magnetic field (field windings) and current is flowing through the rod. This situation creates two separate magnetic fields: one produced by the magnet (pole shoes of the magnetic field winding) and another produced by the current flowing through the conductor (armature/commutator/brushes).

Figure 9-30 shows the magnet's magnetic field moving from the N pole to the S pole and the conductor's magnetic field flowing around the conductor. The magnetic lines of force have a rubber-band characteristic. That is, they stretch and also try to shorten to minimum length.

Figure 9-30 shows a stronger magnetic field on one side of the rod conductor (armature/commutator/brushes) and a weak magnetic field on the other side. Under these conditions, the conductor (armature) will tend to be repulsed by the strong magnetic field (pole shoes and field winding) and move toward the weak magnetic field. As current in the conductor (armature) and the strength of the magnet (field windings) increases, the following happens:

- More lines of magnetism are created on the strong side.
- More repulsive force is applied to the conductor (armature).
- The conductor tries harder to move toward the weak side in an attempt to reach a balanced neutral state.
- A greater amount of electrical heat is generated.

**NOTE:** The combination of the U-shaped conductor loop and the split copper ring are called the commutator because they rotate together. Together they become the armature.



**Figure 9-30.** Motor principle.

Current flows from the positive (+) battery terminal through the brush and copper ring nearer the N pole, through the conductor (armature) to the copper ring and brush nearer the S pole and back to the negative (-) battery terminal. This electrical flow causes the portion of the loop near the S pole to push downward and the N pole to push upward. With a strong field on one side of the conductor and a weak field on the other side, the conductor will move from the strong to the weak. Put another way, the weaker magnetic field between the S and N poles on one side of the conductor is repulsed by the stronger magnetic field on the other side of the conductor. The commutator then rotates. As it turns, the two sides of the conductor loop reverse positions and the two halves of the split copper ring alternately make contact with the opposite stationary brushes. This causes the flow direction of electrical current to reverse (alternating current) through the commutator and the commutator to continue to rotate in the same direction.

In order to provide smooth rotation and to make the starter powerful enough to start the engine, many armature commutator segments are used. As one segment rotates past the stationary magnetic field pole, another segment immediately takes its place.

When the starter operates, the current passing through the armature produces a magnetic field in each of its conductors. The reaction between the magnetic field of the armature and the magnetic fields produced by the field coils causes the armature to rotate.

## Motor Internal Circuitry

Because field current and armature current flow to the motor through one terminal on the housing, the field and armature windings must be connected in a single complete circuit. The internal circuitry of the motor (the way in which the field and armature windings are connected) gives the motor some general operating characteristics.

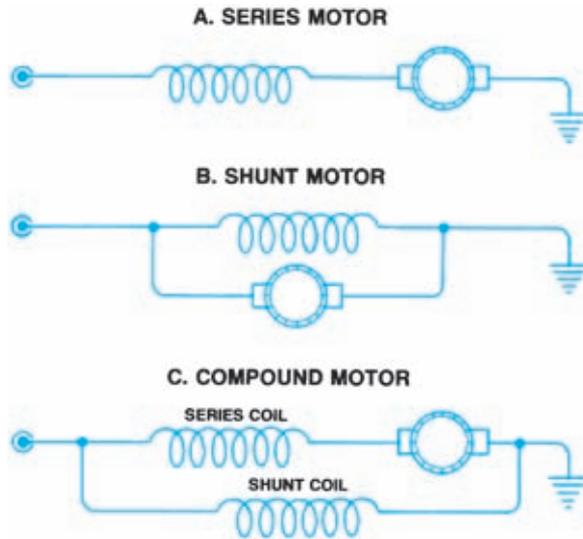


Figure 9-31. Basic motor circuitry.

Figure 9-31 shows the three general types of motor internal circuitry, as follows:

- Series
- Shunt (parallel)
- Compound (series-parallel)

All automotive starter motors in use today are the series type or the compound type. The **series motor** (Figure 9-31A) has only one path for current. As the armature rotates, its conductors cut magnetic flux lines. A counter-voltage is induced in the armature windings, opposing the original current through them. The counter-voltage decreases the total current through both the field and the armature windings, because they are connected in series. This reduction of current also reduces the magnetic field strength and motor torque. Series motors produce a great amount of torque when they first begin to operate, but torque decreases as the engine begins to turn (Figure 9-32). Series motors work well as automotive starters because cranking an engine requires a great amount of torque at first, and less torque as cranking continues.

The **shunt motor** (Figure 9-31B) does not follow the increasing-speed/decreasing-torque relationship just described. The counter-voltage within the armature does not affect field current, because field current travels through a separate circuit path. A shunt motor, in effect, adjusts its torque output to the imposed load and operates at a constant speed. Shunt motors are not used as automotive starters because of their low

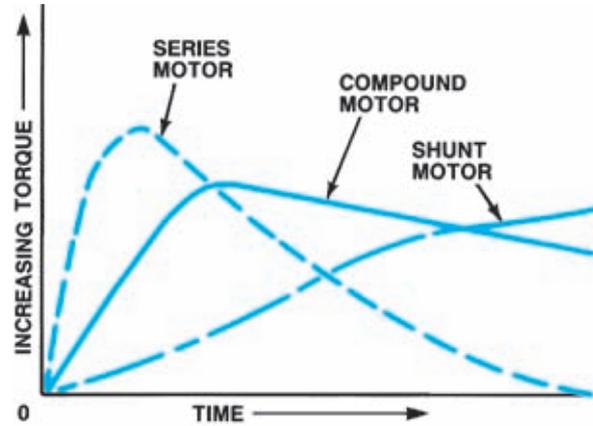


Figure 9-32. Torque output characteristics of series, shunt, and compound motors.

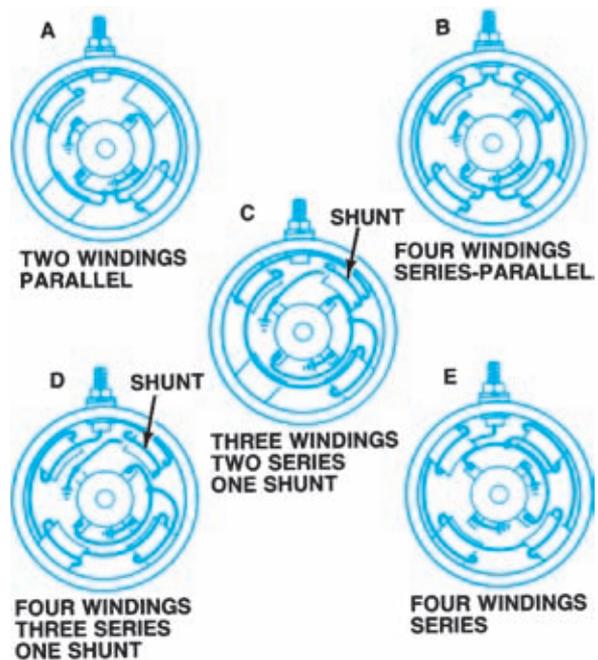


Figure 9-33. Actual relationships of field and armature windings in different types of motors.

initial torque (Figure 9-32), but are used to power other automotive accessories.

The **compound motor**, shown in Figure 9-31C, has both series and shunt field windings. It combines both the good starting torque of the series-type and the relatively constant operating speed of the shunt-type motor (Figure 9-32). A compound motor is often used as an automotive starter. Figure 9-33 shows the actual relationships of field and armature windings in different types of motors.

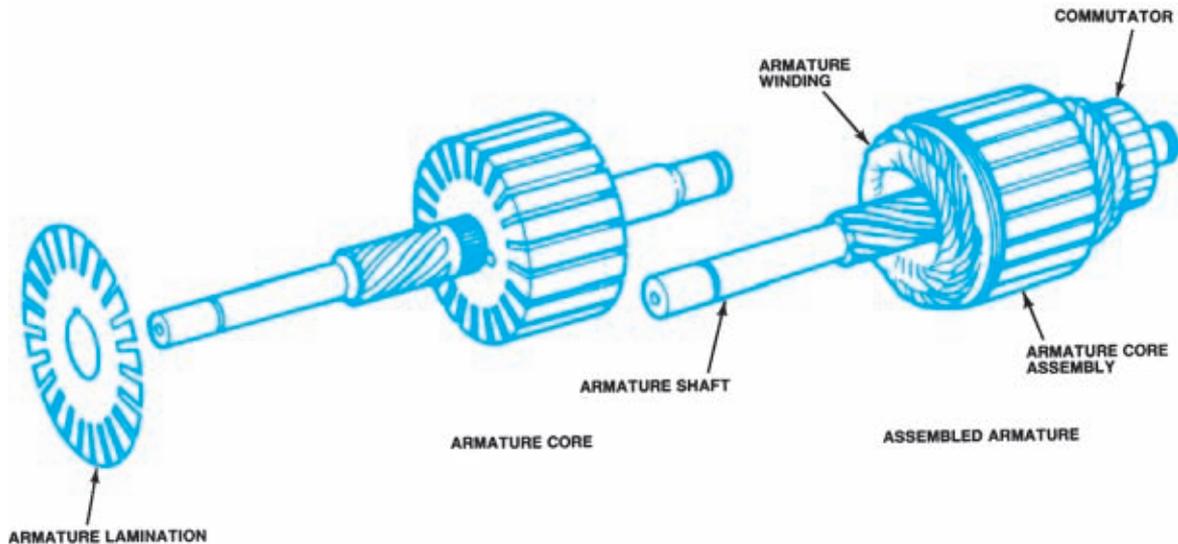


Figure 9-34. Motor armature.

## ARMATURE AND COMMUTATOR ASSEMBLY

The motor armature (Figure 9-32) 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 (Figure 9-35). 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), as shown in Figure 9-36. 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 engine flywheel ring gear (Figure 9-37). 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 (Figure 9-38). Most automotive starters have two grounded and two insulated brushes. The brushes are held against the commutator by spring force.

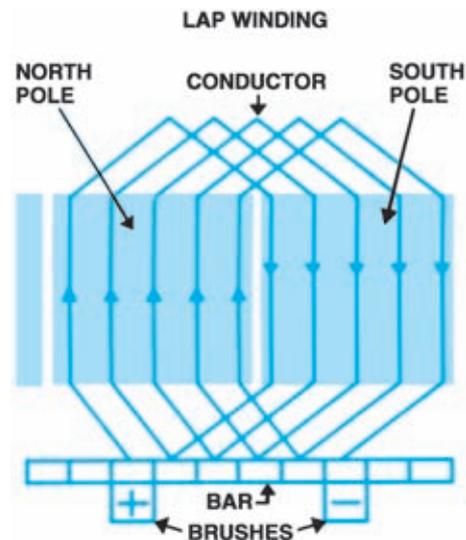


Figure 9-35. Armature lap winding. (Delphi Automotive Systems)

## PERMANENT-MAGNET FIELDS

The permanent magnet, planetary-drive starter motor is the first significant advance in starter design in decades. It was first introduced on some 1986 Chrysler and GM models, and in 1989 by Ford on Continental and some Thunderbird models. Permanent magnets are used in place of the electromagnetic field coils and pole shoes. This eliminates

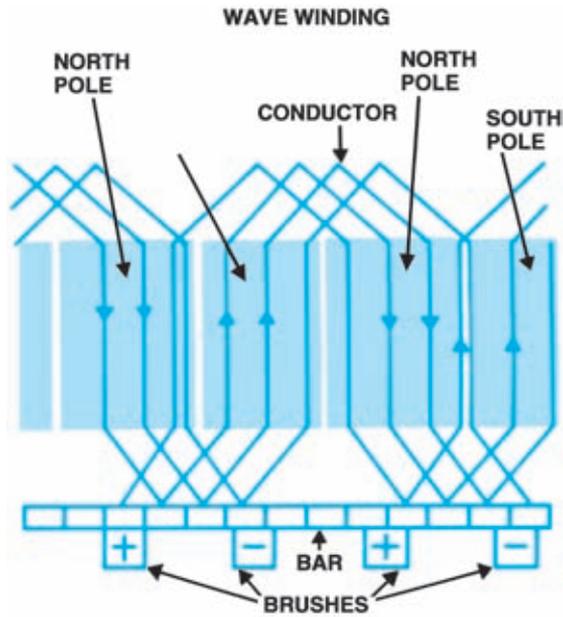


Figure 9-36. Armature wave winding.

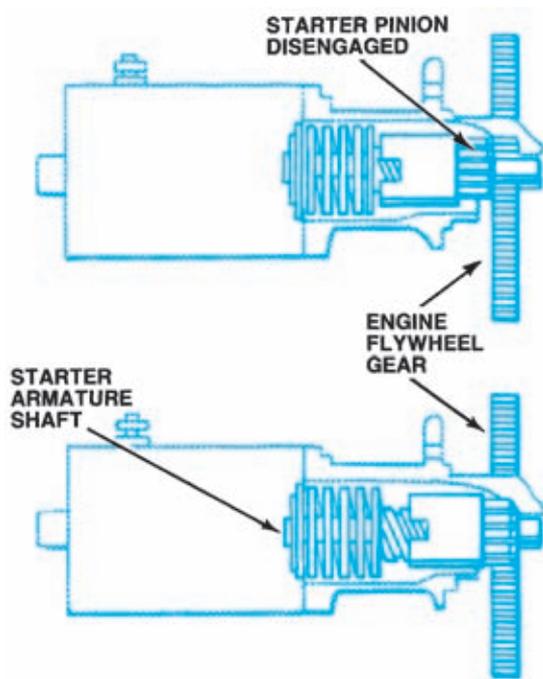


Figure 9-37. The pinion gear meshes with the flywheel ring gear.

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. Because the smaller armature in permanent magnet starters uses reinforcement bands, it has a longer life than the armature in wound-field starter motors.

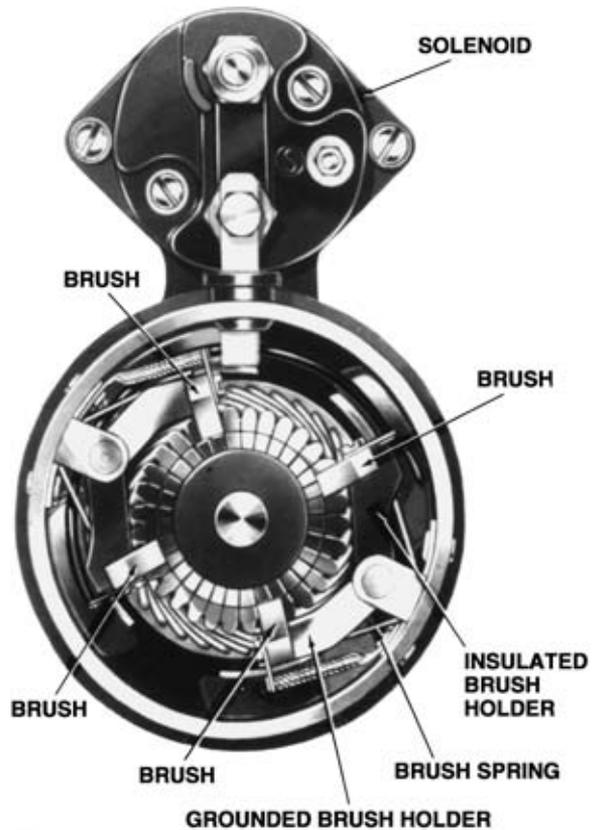


Figure 9-38. A four-brush motor. (Delphi Automotive Systems)

The magnetic field of the starter motor is provided by four or six small permanent magnets. These magnets are made from an alloy of iron and rare-earth materials that produces a magnetic field strong enough to operate the motor without relying on traditional current-carrying field coil windings around iron pole pieces. Removing the field circuit not only minimizes potential electrical problems, the use of permanent-magnet fields allows engineers to design a gear-reduction motor half the size and weight of a conventional wound-field motor without compromising cranking performance.

See Chapter 9 of the *Shop Manual* for service and testing.

## STARTER MOTOR AND DRIVE TYPES

Starter motors, as shown in Figure 9-39 are direct-current (DC) motors that use a great amount of current for a short time. The starter motor circuit is a simple one containing just the

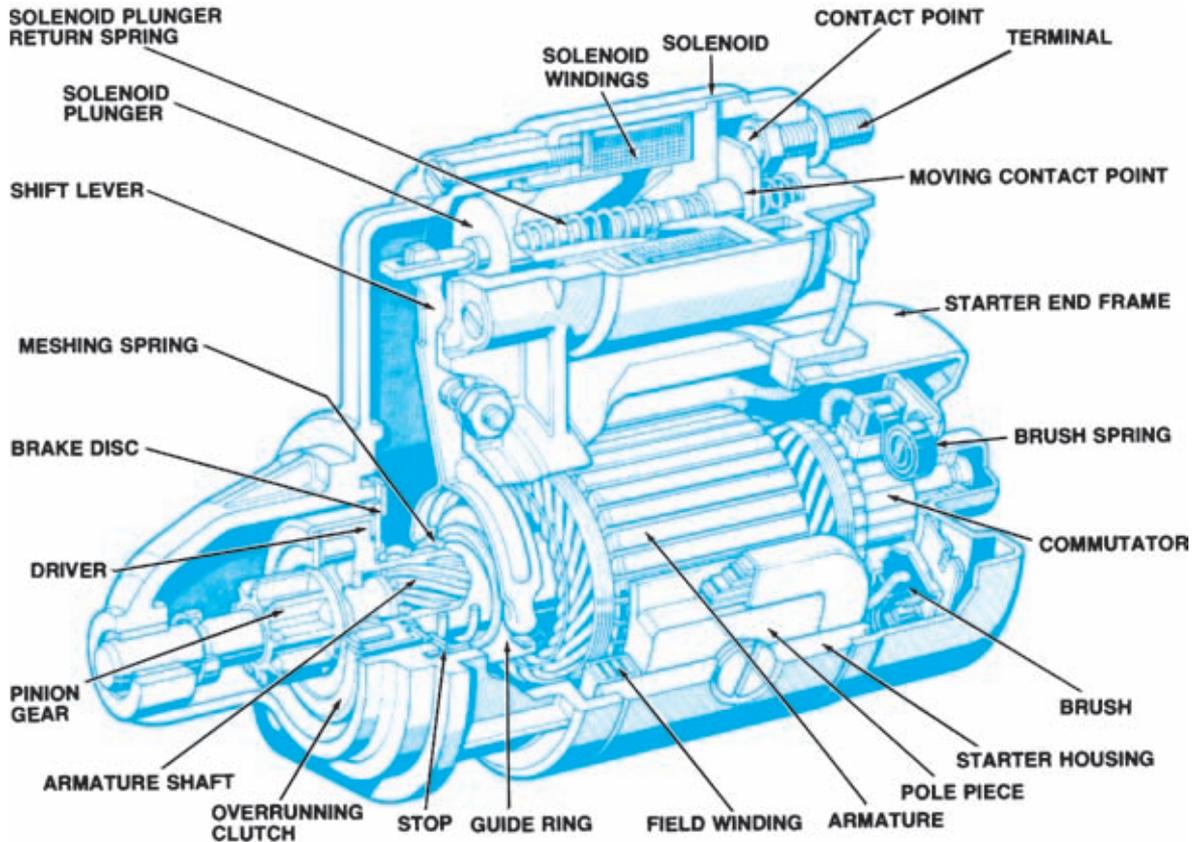


Figure 9-39. Starter motor cutaway.

starter motor and a solenoid or relay. This circuit is a direct path for delivering the momentary high current required by the starter motor from the battery.

The starter motor cranks the engine through a pinion gear that engages a ring gear on the engine flywheel. The pinion gear is driven directly off the starter armature (Figure 9-39) or through a set of reduction gears (Figure 9-40) that provides greater starting torque, although at a lower rpm.

For the starter motor to be able to turn the engine quickly enough, the number of teeth on the flywheel ring gear, relative to the number of teeth on the motor pinion gear, must be between 15 and 20 to 1 (Figure 9-41).

When the engine starts and runs, its speed increases. If the starter motor were permanently engaged to the engine, the motor would be spun at a very high speed. This would throw armature windings off the core. Thus, the motor must be disengaged from the engine as soon as the engine turns more rapidly than the starter motor has cranked it. This job is done by the **starter drive**.

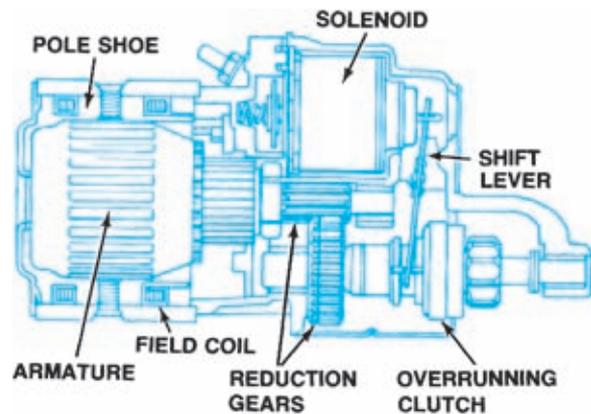
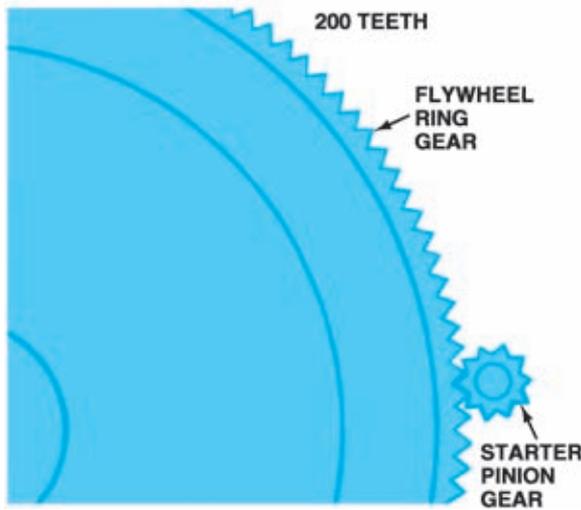


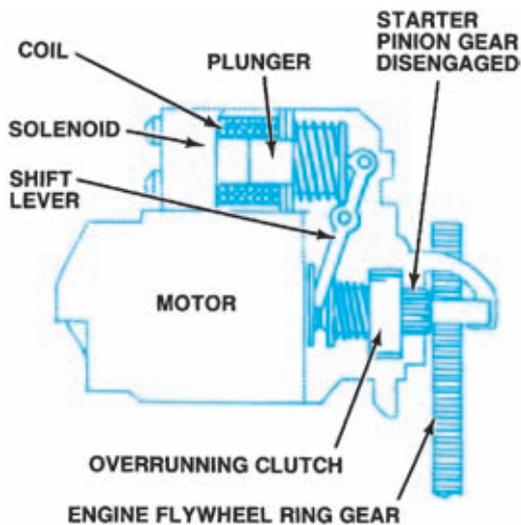
Figure 9-40. The Chrysler reduction-gear starter motor. (DaimlerChrysler Corporation)

Four general kinds of starter motors are used in late-model automobiles:

- Solenoid-actuated, direct drive
- Solenoid-actuated, reduction drive
- Movable-pole shoe
- Permanent-magnet, planetary drive



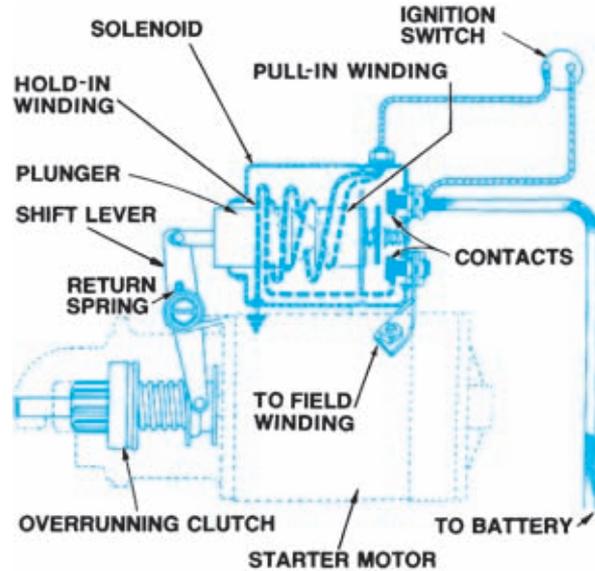
**Figure 9-41.** The ring-gear-to-pinion-gear ratio is about 20 to 1.



**Figure 9-42.** A typical solenoid-actuated drive.

## Solenoid-Actuated, Direct Drive

The main parts of a solenoid-actuated, direct-drive starter (Figure 9-42), are the solenoid, the shift lever, the overrunning clutch, and the starter pinion gear. The solenoid used to actuate a starter drive has two coils: the pull-in winding and the hold-in, or holding, winding (Figure 9-43). The pull-in winding consists of few turns of a heavy wire. The winding is grounded through the motor armature and grounded brushes. The hold-in



**Figure 9-43.** The solenoid has a heavy-gauge pull-in winding and a lighter-gauge hold-in winding. (Delphi Automotive Systems)

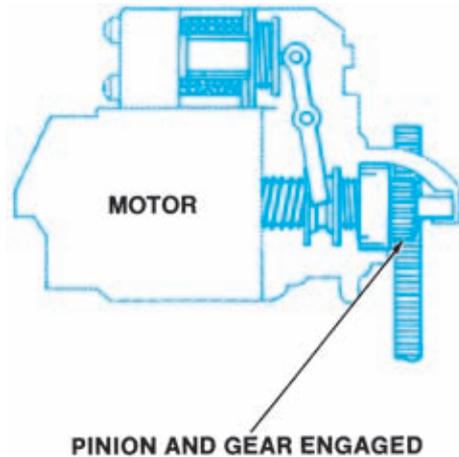
winding consists of many turns of a fine wire and is grounded through the solenoid case.

When the ignition switch is turned to the start position, current flows through both windings. The solenoid plunger is pulled in, and the contacts are closed. This applies battery voltage to both ends of the pull-in winding, and current through it stops. The magnetic field of the hold-in winding is enough to keep the plunger in place. This circuitry reduces the solenoid current draw during cranking, when both the starter motor and the ignition system are drawing current from the battery.

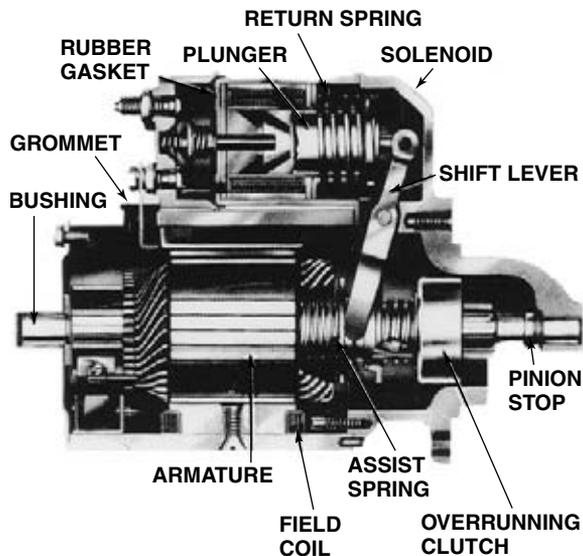
The solenoid plunger action, transferred through the shift lever, pushes the pinion gear into mesh with the flywheel ring gear (Figure 9-44). When the starter motor receives current, its armature begins to turn. This motion is transferred through the overrunning clutch and pinion gear to the engine flywheel.

The teeth on the pinion gear may not immediately mesh with the flywheel ring gear. If this happens, a spring behind the pinion compresses so that the solenoid plunger can complete its stroke. When the motor armature begins to turn, the pinion teeth line up with the flywheel, and spring force pushes the pinion to mesh.

The Delco-Remy MT series, as shown in Figure 9-45, is the most common example of this type of starter motor and has been used for decades on almost all GM cars and light trucks. While this motor is manufactured in different sizes



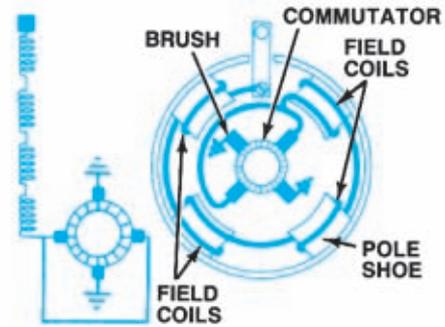
**Figure 9-44.** The movement of the solenoid plunger meshes the pinion gear and the flywheel ring gear.



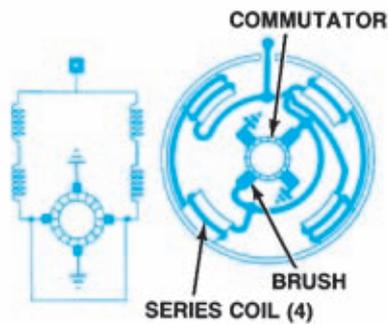
**Figure 9-45.** The Delco-Remy solenoid-actuated drive motor. (Delphi Automotive Systems)

for different engines (Figure 9-46), the most common application is a four-pole, four-brush design.

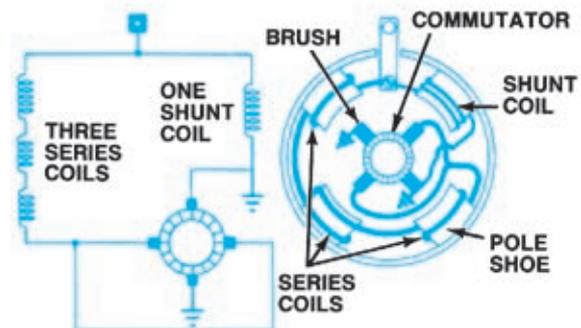
The solenoid plunger action, in addition to engaging the pinion gear, closes contact points to complete the starter circuit. To avoid closing the contacts before the pinion gear is fully engaged, the solenoid plunger is in two pieces (Figure 9-47). When the solenoid windings are magnetized, the first plunger moves the shift lever. When the pinion gear reaches the flywheel, the first plunger has moved far enough to touch the second plunger. The first plunger con-



**STARTER MOTOR — INLINE-6 AND V6 ENGINE**



**STARTER MOTOR — 455 CID ENGINE**



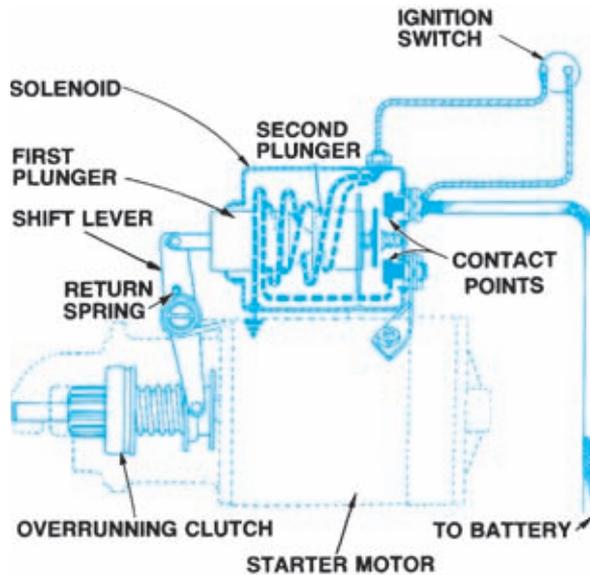
**STARTER MOTOR — 260 AND 350 CID ENGINE**

**Figure 9-46.** Delco-Remy provides differently connected starter motors for use with various engines. (GM Service and Parts Operations)

tinues to move into the solenoid, pushing the second plunger against the contact points.

A similar starter design has been used by Ford on diesel engines and older large-displacement V8 gasoline engines. It operates in the same way as the starter just described. The solenoid action closes a set of contact points.

Because Ford installs a remotely mounted magnetic switch in all of its starting circuits, the solenoid contact points are not required to control the circuit. The solenoid contact points are physically linked, so that they are always “closed.”



**Figure 9-47.** The Delco-Remy solenoid plunger is in two pieces. (Delphi Automotive Systems)

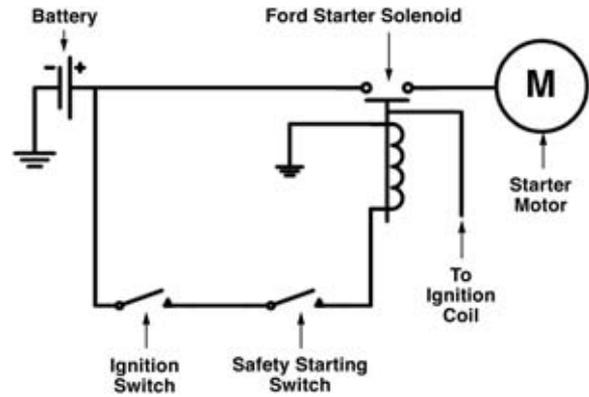
In the early 1970s, Chrysler also manufactured fully enclosed direct-drive starter motor. It works in the same way as the solenoid-actuated starters previously described. The solenoid plunger closes contact points to complete the motor circuitry, but the system also has a remotely mounted starter relay. Reduction-drive starters are usually compound motors. Most Bosch and all Japanese starter motors operate on the same principles.

## Solenoid-Actuated, Reduction Drive

The Chrysler solenoid-actuated, reduction-drive starter uses a solenoid to engage the pinion with the flywheel and close the motor circuit. The motor armature does not drive the pinion directly, however; it drives a small gear that is permanently meshed with a larger gear. The armature-gear-to-reduction-gear ratio is between 2 and 3.5 to 1, depending upon the engine application. This allows a small, high-speed motor to deliver increased torque at a satisfactory cranking rpm. Solenoid and starter drive operation is basically the same as a solenoid-actuated, direct-drive starter.

## Movable-Pole-Shoe Drive

Manufactured by the Motorcraft Division of Ford, the movable-pole-shoe starter motor is used on



**Figure 9-48.** Circuit diagram of a system using a movable-pole-shoe starter.

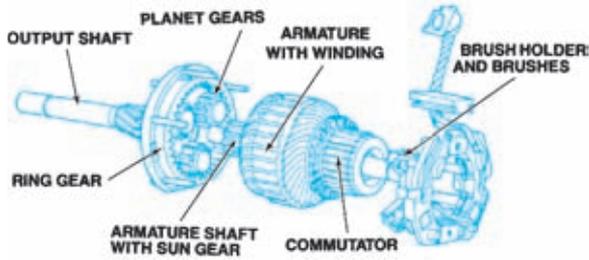
most Ford automobiles (Figure 9-48). One of the motor-pole shoes pivots at the drive end housing. The field winding of this shoe also contains a holding coil, wired in parallel and independently grounded. When the starter relay is closed, battery current flows through the field windings and the holding coil of the pole shoe to ground. This creates a strong magnetic field, and the pole shoe is pulled down into operating position. The motion is transferred through a shift lever, or drive yoke, to mesh the pinion gear with the ring gear.

When the pole shoe is in position, it opens a set of contacts. These contacts break the ground connection of the field windings. Battery current is allowed to flow through the motor's internal circuitry, and the engine is cranked. During cranking, a small amount of current flows through the holding coil directly to ground to keep the shoe and lever assembly engaged.

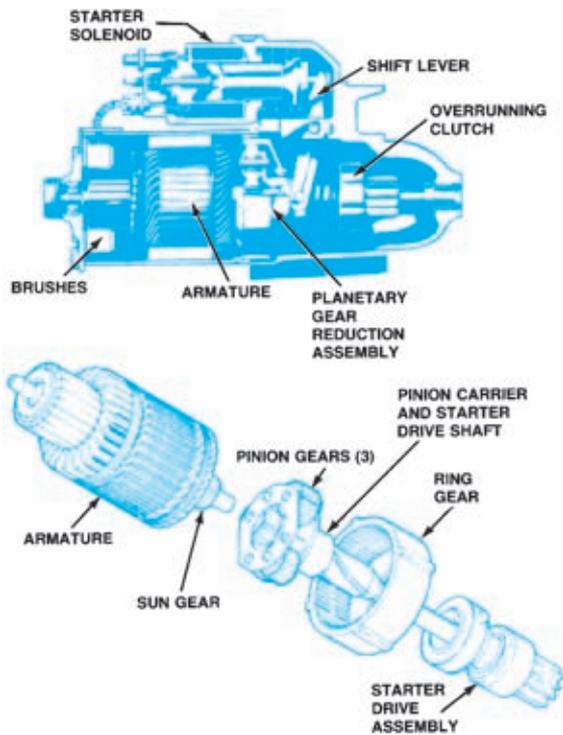
An overrunning clutch prevents the starter motor from being turned by the engine. When the ignition switch moves out of the start position, current no longer flows through the windings of the movable pole shoe or the rest of the motor. Spring force pulls the shoe up, and the shift lever disengages the pinion from the flywheel.

## Permanent-Magnet Planetary Drive

The high-speed, low-torque permanent-magnet planetary-drive motor operates the drive mechanism through gear reduction provided by a simple planetary gearset. Figure 9-49 shows the Bosch gear reduction design, which is similar to that used in Chrysler starters. Figure 9-50 shows the



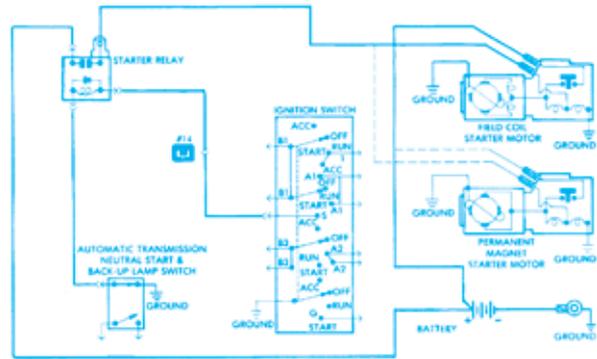
**Figure 9-49.** Bosch permanent-magnet gear-reduction starter components. (Reprinted by permission of Robert Bosch GmbH)



**Figure 9-50.** Delco-Remy permanent-magnet, gear-reduction starter components. (Delphi Automotive Systems)

gear reduction design used in the Delco-Remy permanent-magnet, gear-reduction (PMGR) starter. All PMGR starter designs use a solenoid to operate the starter drive and close the motor armature circuit. The drive mechanism is identical to that used on other solenoid-actuated starters already described. Some models, however, use lightweight plastic shift levers.

The planetary gearset between the motor armature and the starter drive reduces the speed and increases the torque at the drive pinion. The compact gearset is only 1/2 to 3/4 inch (13 to 19 mm) deep and is mounted inline with the armature and



**Figure 9-51.** Field coils and permanent-magnet starters use the same electrical wiring.

drive pinion. An internal ring gear is keyed to the field frame and held stationary in the motor. The armature shaft drives the sun gear for the planetary gearset. The sun gear meshes with three planetary pinions, which drive the pinion carrier in reduction as they rotate around the ring gear. The starter driveshaft is mounted on the carrier and driven at reduced speed and increased torque. This application of internal gear reduction through planetary gears delivers armature speeds in the 7,000-rpm range. The armature and drive-shaft ride on roller or ball bearings rather than bushings.

Permanent-magnet, planetary-drive starters differ mechanically in how they do their job, but their electrical wiring is the same as that used in the field-coil designs (Figure 9-51).

Although PMGR motors are lighter in weight and simpler to service than traditional designs, they do require special handling precautions. The material used for the permanent magnet fields is quite brittle. A sharp impact caused by hitting or dropping the starter can destroy the fields.

## OVERRUNNING CLUTCH

Regardless of the type of starter motor used, when the engine starts and runs, its speed increases. The motor must be disengaged from the engine as soon as the engine is turning more rapidly than the starter motor that has cranked it. With a movable-pole-shoe or solenoid-actuated drive, however, the pinion remains engaged until power stops flowing to the starter. In these applications,

the starter is protected by an over-running clutch (Figure 9-52).

The **overrunning clutch** consists of rollers that ride between a collar on the pinion gear and an outer shell. The outer shell has tapered slots for the rollers so that the rollers either ride freely or wedge tightly between the collar and the shell. Figure 9-53 shows the operation of an overrunning clutch. In Figure 9-53A, the armature is turning, cranking the engine. The rollers are wedged against spring force into their slots. In Figure 9-53B, the engine has started and is turning faster than the motor armature. Spring force pushes the rollers so that they float freely. The engine's motion is not transferred to the motor armature. These devices are sometimes called one-way clutches because they transmit motion in one direction only.

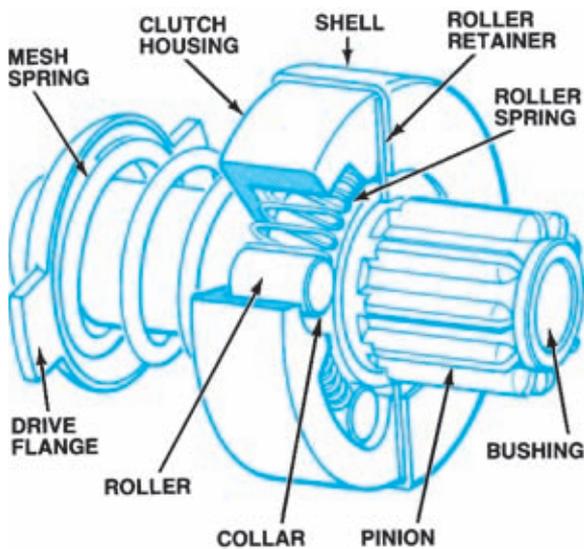


Figure 9-52. Cutaway view of an overrunning clutch.

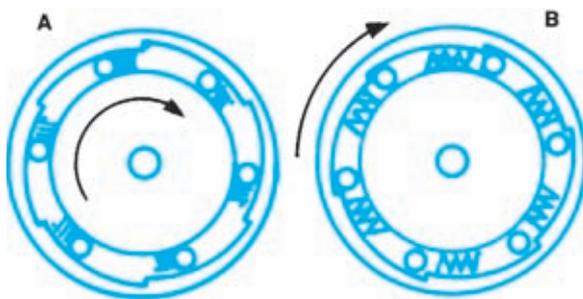


Figure 9-53. The operation of an overrunning clutch.

Once the engine starts, the ignition switch is to be released from the start position. The solenoid hold-in winding is demagnetized, and a return spring moves the plunger out of the solenoid. This moves the shift lever back so that the overrunning clutch and pinion gear slide away from the flywheel. For more information about overrunning clutches, see the following sections of Chapter 9 in the *Shop Manual*, “Bench Tests” and “Starter Motor Overhaul Procedure.”

## SUMMARY

Electrical starting systems consist of a high-current starter circuit controlled by a low-current control circuit. The ignition switch includes contacts that conduct battery current to the magnetic switch. The magnetic switch may be a relay or a solenoid and may have other jobs besides controlling the starter circuit current flow. The starter motor and connecting wires are also included in the system. Variations are common among the starting systems used by the various manufacturers. Magnetic repulsion occurs when a straight-rod conductor composed of the armature, commutator, and brushes is located in a magnetic field (field windings) and current is flowing through the rod.

When the starter operates, the current passing through the armature produces a magnetic field in each of its conductors. The reaction between the magnetic field of the armature and the magnetic fields produced by the field coils causes the armature to rotate.

Traditional starter motors have pole pieces wound with heavy copper field windings attached to the housing. A new design, the permanent-magnet planetary drive, uses small permanent magnets to create a magnetic field instead of pole pieces and field windings.

One end housing holds the brushes; the other end housing shields the pinion gear. The motor armature windings are installed on a laminated core and mounted on a shaft. The commutator bars are mounted on, but insulated from, the shaft.

The solenoid-actuated drive uses the movement of a solenoid to engage the pinion gear with the ring gear. Delco-Remy, Chrysler, Motorcraft, and many foreign manufacturers use this type of starter drive. The movable-pole-shoe drive, used by Ford, has a pivoting pole piece that is moved by electromagnetism to engage the pinion gear

with the ring gear. In the planetary-gear drive used by Chrysler, Ford, and GM, an armature-shaft sun gear meshes with the planetary pinions, which drive the pinion carrier in reduction as they rotate around the ring gear. The starter

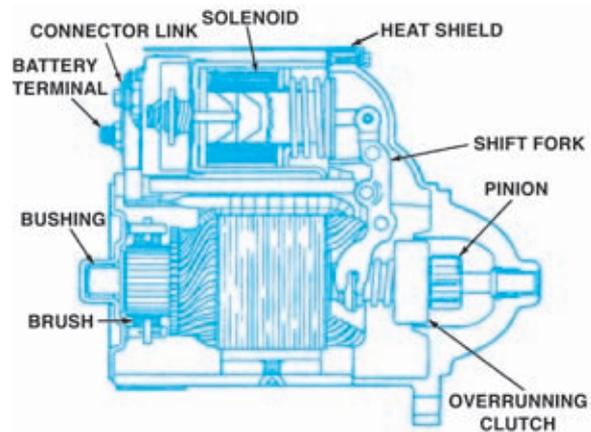
driveshaft is mounted on the carrier and driven at reduced speed and increased torque. An overrunning clutch is used with all starter designs to prevent the engine from spinning the motor and damaging it.

# Review Questions

- All of these are part of the control circuit *except*:
  - A starting switch
  - An OCP thermostat
  - A starting safety switch
  - A magnetic switch
- Which of the following is a component of a starting circuit?
  - Magnetic switch
  - Ballast resistor
  - Voltage regulator
  - Powertrain control module (PCM)
- Two technicians are discussing the operation of a DC automotive starter. Technician A says the principle of magnetic repulsion causes the motor to turn. Technician B says the starter uses a mechanical connection to the engine that turns the armature. Who is right?
  - A only
  - B only
  - Both A and B
  - Neither A nor B
- All of these are part of a starter motor *except*:
  - An armature
  - A commutator
  - Field coils
  - A regulator
- The starting system has \_\_\_\_\_ circuits to avoid excessive voltage drop.
  - Two
  - Three
  - Four
  - Six
- The starter circuit consists of which of the following?
  - Battery, ignition switch, starter motor, large cables
  - Battery, ignition switch, relays or solenoids, large cables
  - Battery, magnetic switch, starter motor, primary wiring
  - Battery, magnetic switch, starter motor, large cables
- Which of the following is *not* part of the starter control circuit?
  - The ignition switch
  - The starting safety switch
  - The starter relay
  - The starter motor
- The ignition switch will *not* remain in which of the following positions?
  - ACCESSORIES
  - OFF
  - ON (RUN)
  - START
- The starting safety switch is also called a:
  - Remote-operated switch
  - Manual-override switch
  - Neutral-start switch
  - Single-pole, double-throw switch
- Safety switches are most commonly used with:
  - Automatic transmissions
  - Imported automobiles
  - Domestic automobiles
  - Manual transmissions
- Starting safety switches used with manual transmissions are usually:
  - Electrical
  - Mechanical
  - Floor-mounted
  - Column-mounted
- Which of the following is not true of solenoids?
  - They use the electromagnetic field of a coil to pull a plunger into the coil.
  - They are generally used to engage the starter motor with the engine flywheel.
  - They operate with a movable plunger and usually do a mechanical job.
  - They send electronic signals to the control module and have no moving parts.
- Starter motors usually have how many pole shoes?
  - Two
  - Four
  - Six
  - Eight
- The rotational force of a starter motor is:
  - Polarized
  - Rectified

- c. Torque
  - d. Current
15. Which of the following is true of a shunt motor?
- a. It has high initial torque.
  - b. It operates at variable speed.
  - c. It has only one path for current flow.
  - d. It is not often used as a starting motor.
16. Which of the following is true of a compound motor?
- a. It has low initial torque.
  - b. It operates at variable speeds.
  - c. It has only one path for current flow.
  - d. It is often used as a starting motor.
17. In a lap-wound motor armature, the two ends of each conductor are attached to commutator segments that are:
- a. Adjacent
  - b. 45 degrees apart
  - c. 90 degrees apart
  - d. 180 degrees apart
18. Most automotive starters have \_\_\_\_\_ grounded and \_\_\_\_\_ insulated brushes.
- a. 2, 2
  - b. 2, 4
  - c. 4, 4
  - d. 4, 8
19. The ratio between the number of teeth on the flywheel and the motor pinion gear is about:
- a. 1:1
  - b. 5:1
  - c. 20:1
  - d. 50:1
20. The overrunning clutch accomplishes which of the following?
- a. Separates the starter motor from the starter solenoid
  - b. Brings the starter motor into contact with the ignition circuit
  - c. Lets the starter motor rotate in either direction
  - d. Protects the starter motor from spinning too rapidly
21. A starting motor must have \_\_\_\_\_ brushes as poles.
- a. The same number of
  - b. Twice as many

- c. One-half as many
- d. Three times as many



(Delphi Automotive Systems)

22. The preceding illustration shows a:
- a. Permanent-magnet planetary-gear starter
  - b. Movable-pole-shoe starter
  - c. Direct-drive, solenoid-actuated starter
  - d. Reduction-gear drive, solenoid-actuated starter
23. Which type of starter drive is *not* used on late-model cars?
- a. Direct drive
  - b. Bendix drive
  - c. Reduction drive
  - d. Planetary drive
24. A solenoid uses two coils. Their windings are called:
- a. Push-in and pull-out
  - b. Pull-in and push-out
  - c. Push-in and hold-out
  - d. Pull-in and hold-in
25. Which of the following is true of a reduction drive?
- a. The motor armature drives the pinion directly.
  - b. The sun gear is mounted on the armature shaft.
  - c. The overrunning clutch reduces battery current.
  - d. The small gear driven by the armature is permanently meshed with a larger gear.

26. The planetary drive starter uses:
- a. Permanent magnets
  - b. Field coils
  - c. Both A and B
  - d. Neither A nor B
27. Which of the following is *not* required of a permanent magnet starter?
- a. Brush testing
  - b. Commutator testing
  - c. Field circuit testing
  - d. Armature testing