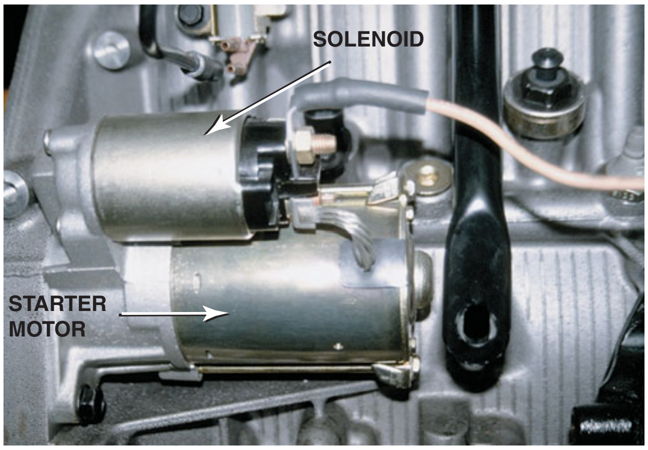

FIGURE 52–1 A typical solenoid-operated starter.

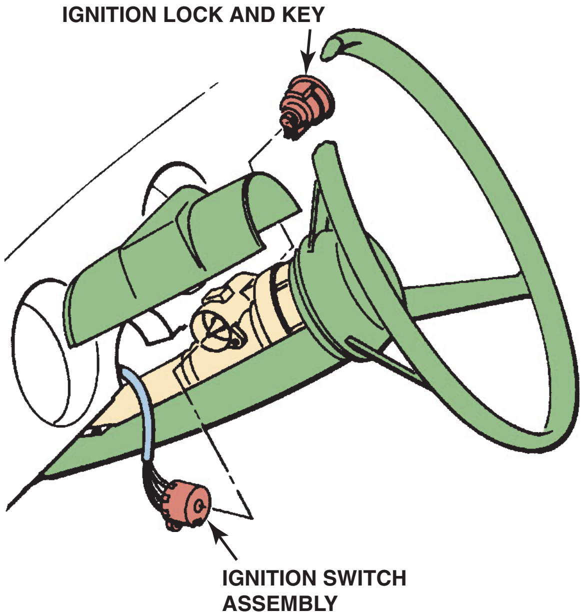

FIGURE 52–2 Some column-mounted ignition switches act directly on the electrical ignition switch itself, whereas others use a link from the lock cylinder to the ignition switch.

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 current to the starter.
4. **Starter drive.** The starter drive uses a small pinion gear that contacts the engine flywheel gear teeth 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 FIGURE 52–2.**

CONTROL CIRCUIT PARTS AND OPERATION 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, or the clutch pedal is depressed on manual transmission/transaxle vehicles. This is to prevent an accident that might result from the vehicle moving forward or rearward when the engine is started. The types of controls that are

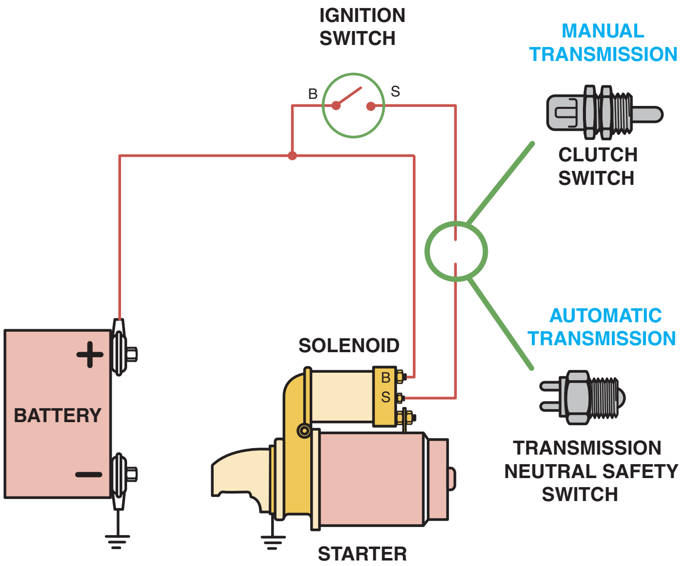

FIGURE 52–3 To prevent the engine from cranking, an electrical switch is usually installed to open the circuit between the ignition switch and the starter solenoid.

used to be sure that the vehicle will not move when being cranked include the following:

- Many automobile manufacturers use an electric switch called a **neutral safety switch,** which 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 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. This switch is commonly called the *clutch safety switch.* ● **SEE FIGURE 52–3**.

COMPUTER-CONTROLLED STARTING

OPERATION 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 powertrain control module (PCM). 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.

A typical push-button start system includes the following sequence.

- 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.

FIGURE 52–4 Instead of using an ignition key to start the engine, some vehicles are using a start button which is also used to stop the engine, as shown on this Jaguar.

FIGURE 52–5 The top button on this key fob is the remote start button.

- 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 that stops the starter motor.

Computer-controlled starting is almost always part of the system if a push-button start is used. ● **SEE FIGURE 52–4.**

REMOTE STARTING Remote starting, sometimes called **remote vehicle start (RVS),** is a system that allows the driver to start the engine of the vehicle from inside the house or a building at a distance of about 200 ft (65 m). The doors remain locked to reduce the possibility of theft. This feature allows the heating or air-conditioning system to start before the driver arrives. ● **SEE FIGURE 52–5.**

NOTE: Most remote start systems will turn off the engine after 10 minutes of run time unless reset by using the remote.

STARTER MOTOR OPERATION

PRINCIPLES A starter motor uses electromagnetic principles to convert electrical energy from the battery (up to 300 amperes) to mechanical power (up to 8 horsepower [6 kilowatts]) to crank the engine. Current for the starter motor or power circuit is controlled by a solenoid or relay, which is itself controlled by the driver-operated ignition switch.

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.

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 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 52–6 AND 52–7.**

The difference in magnetic field strength 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

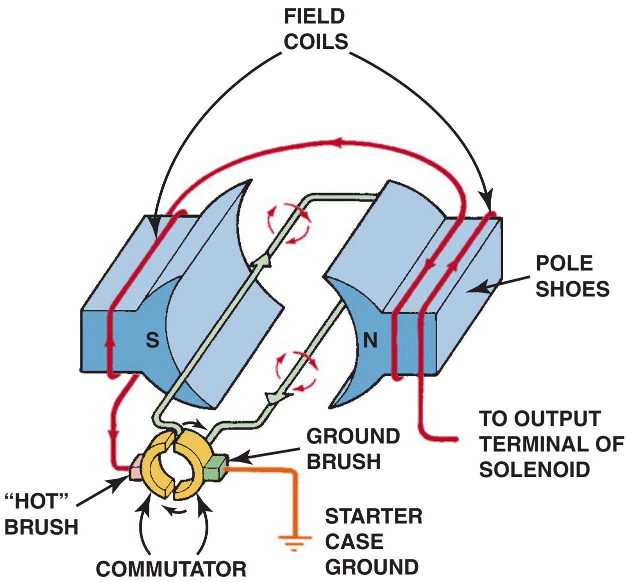

FIGURE 52–6 This series-wound electric motor shows the basic operation with only two brushes: one hot brush and one ground brush. The current flows through both field coils, then through the hot brush and the loop winding of the armature, before reaching ground through the ground brush.

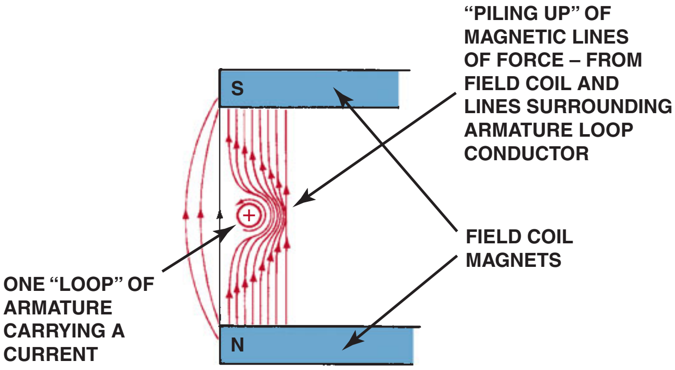

FIGURE 52–7 The interaction of the magnetic fields of the armature loops and field coils creates a stronger magnetic field on the right side of the conductor, causing the armature loop to move toward the left.

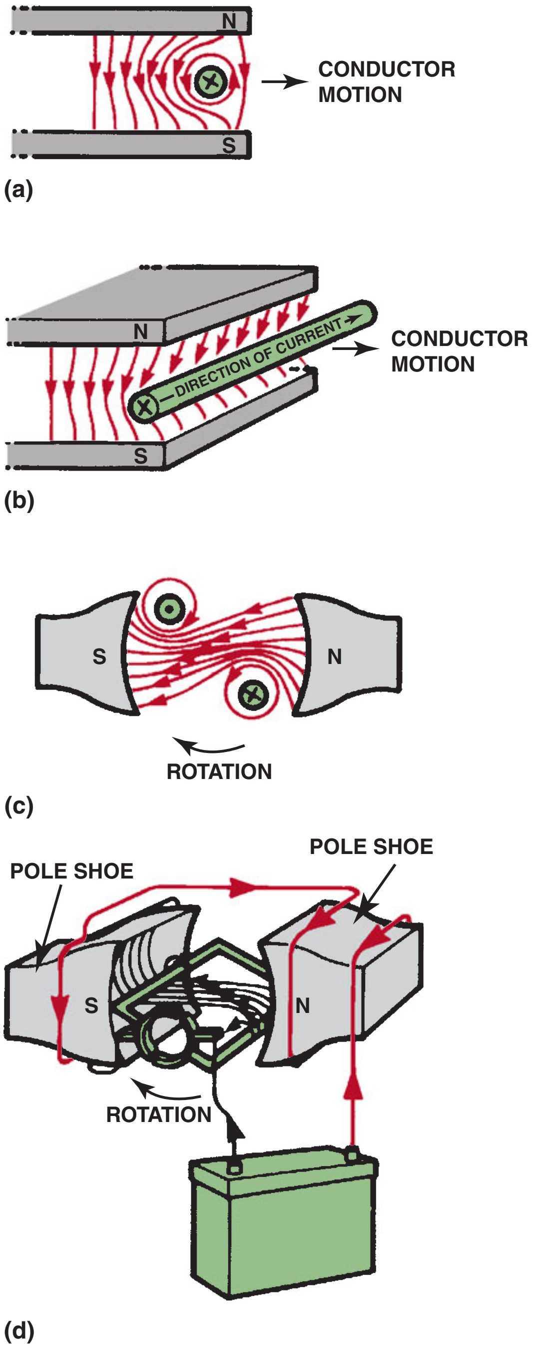

FIGURE 52–8 The armature loops rotate due to the difference in the strength of the magnetic field. The loops move from a strong magnetic field strength toward a weaker magnetic field strength.

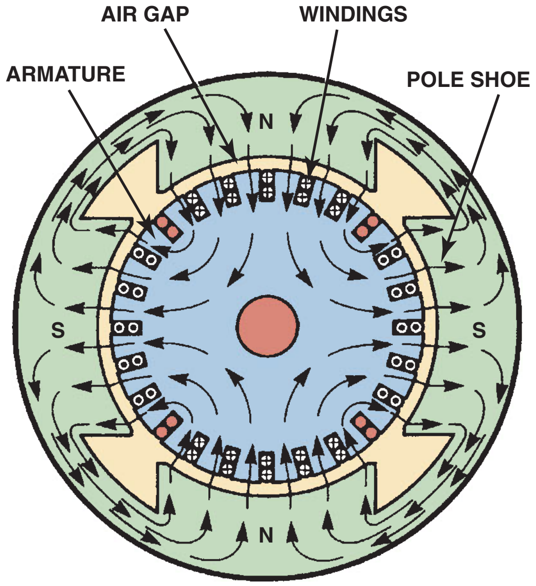

FIGURE 52–9 Magnetic lines of force in a four-pole motor.

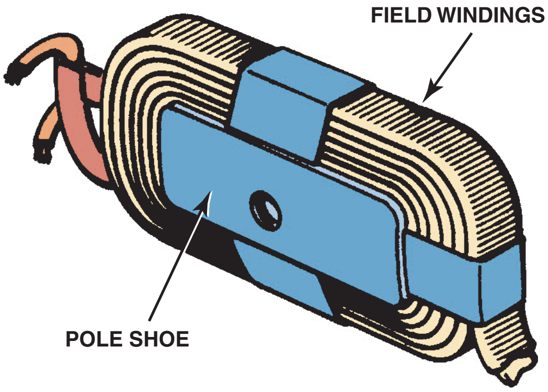

FIGURE 52–10 A pole shoe and field winding.

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 is 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 52–8.**

● **FIGURE 52–9** 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 52–10.**

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.

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 counterelectromotive force, or **CEMF.** This CEMF 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.
- 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. A series-wound starter also draws less current at higher speeds and will keep increasing in speed under light loads. This could lead to the destruction of the starter motor unless controlled or prevented. ● **SEE FIGURE 52–11.**

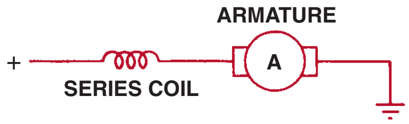

FIGURE 52–11 This wiring diagram illustrates the construction of a series-wound electric motor. Notice that all current flows through the field coils, then through the armature (in series) before reaching ground.

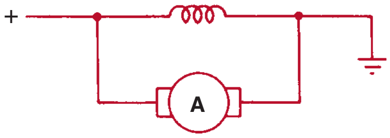

FIGURE 52–12 This wiring diagram illustrates the construction of a shunt-type electric motor, and shows the field coils in parallel (or shunt) across the armature.

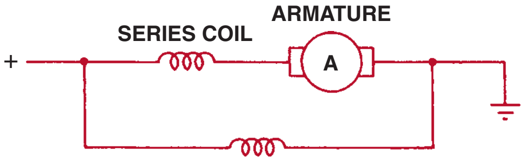

FIGURE 52–13 A compound motor is a combination of series and shunt types, using part of the field coils connected electrically in series with the armature and some in parallel (shunt).

SHUNT MOTORS Shunt-type electric motors have the field coils in parallel (or shunt) across the armature.

A shunt-type motor has the following features.

- 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. Some small electric motors, such as used for windshield wiper motors, use a shunt motor but most use permanent magnets rather than electromagnets.

  ● **SEE FIGURE 52–12**.

PERMANENT MAGNET MOTORS A **permanent magnet (PM) starter** uses permanent magnets that maintain constant field strength, the same as a shunt-type motor, so they have similar operating characteristics. To compensate for the lack of torque, all PM starters use gear reduction to multiply starter motor torque. The permanent magnets used are an alloy of neodymium, iron, and boron, and are almost 10 times more powerful than previously used permanent magnets.

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.

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 older Ford positive engagement–type starters. ● **SEE FIGURE 52–13**.

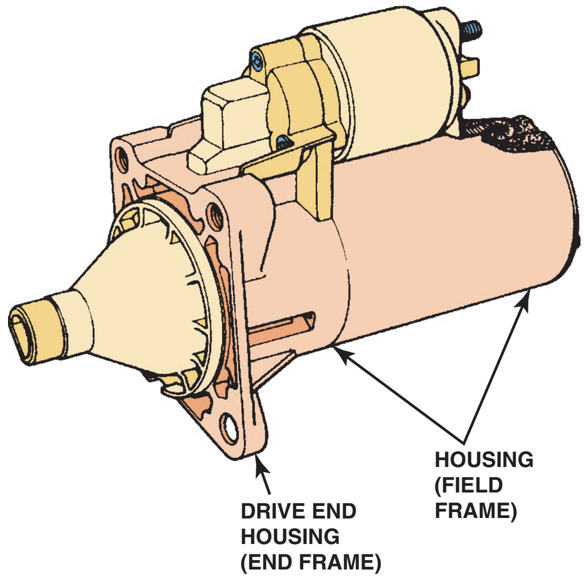

FIGURE 52–14 A typical starter motor showing the drive-end housing.

HOW THE STARTER MOTOR WORKS

PARTS INVOLVED A starter consists of the main structural support of a starter called the 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 52–14**.

- **Field coils.** The steel housing of the starter motor contains permanent magnets or four electromagnets that are connected directly to the positive post of the battery to provide a strong magnetic field inside the starter. The four electromagnets use heavy copper or aluminum wire wrapped around a soft-iron core, which 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.** ● **SEE FIGURE 52–15**.
- **Armature.** Inside the field coils is an **armature** that is supported with either bushings or ball bearings 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. ● **SEE FIGURE 52–16**.

Insulation between the laminations helps to increase the magnetic efficiency in the core. For reduced resistance, the armature conductors are made of a thick copper wire. The two ends of each conductor are attached to two adjacent commutator bars.

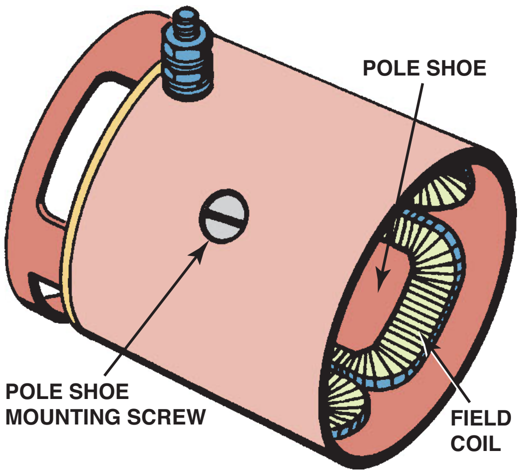

FIGURE 52–15 Pole shoes and field windings installed in the housing.

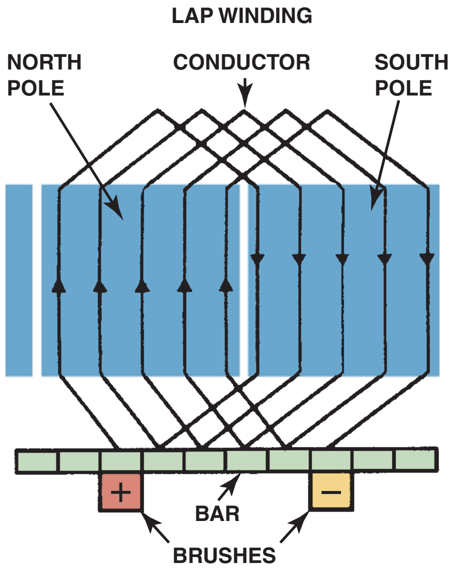

FIGURE 52–17 An armature showing how its copper wire loops are connected to the commutator.

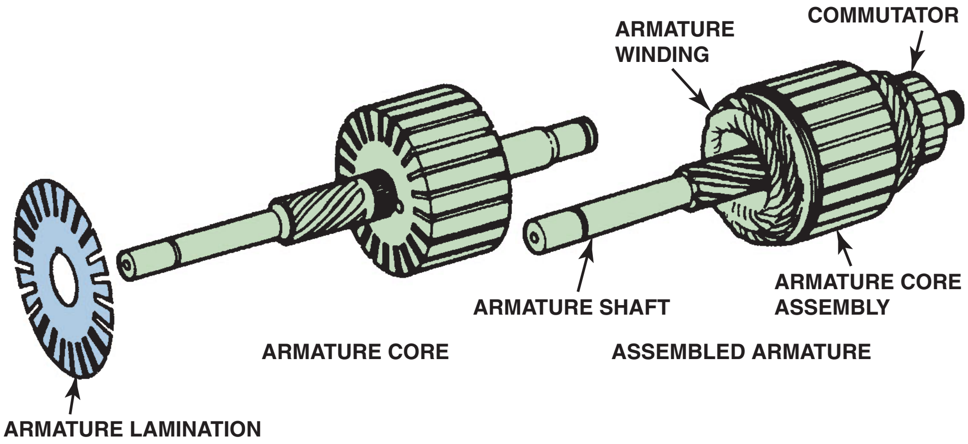

FIGURE 52–16 A typical starter motor armature. The armature core is made from thin sheet metal sections assembled on the armature shaft, which is used to increase the magnetic field strength.

The commutator is made of copper bars insulated from each other by mica or some other insulating material. ● **SEE FIGURE 52–17.**

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.

STARTER BRUSHES 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.

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.
- 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.

The two sets of brushes include:

1. Two **insulated brushes,** which are in holders and are insulated from the housing.
2. Two **ground brushes,** which use bare, stranded copper wire connections to the brushes. The ground brush holders are not insulated and attach directly to the field housing or brush-end housing.

● **SEE FIGURE 52–18.**

PERMANENT MAGNET FIELDS Permanent magnets are used in place of the electromagnetic field coils and pole shoes in many starters today. This eliminates the motor field circuit, which in turn eliminates the potential for field coil faults and other electrical problems. The motor has only an armature circuit.

GEAR-REDUCTION STARTERS

PURPOSE AND FUNCTION Gear-reduction starters are used by many automotive manufacturers. The purpose of the gear reduction (typically 2:1 to 4:1) is to increase starter motor speed and provide the torque multiplication necessary to crank an engine.

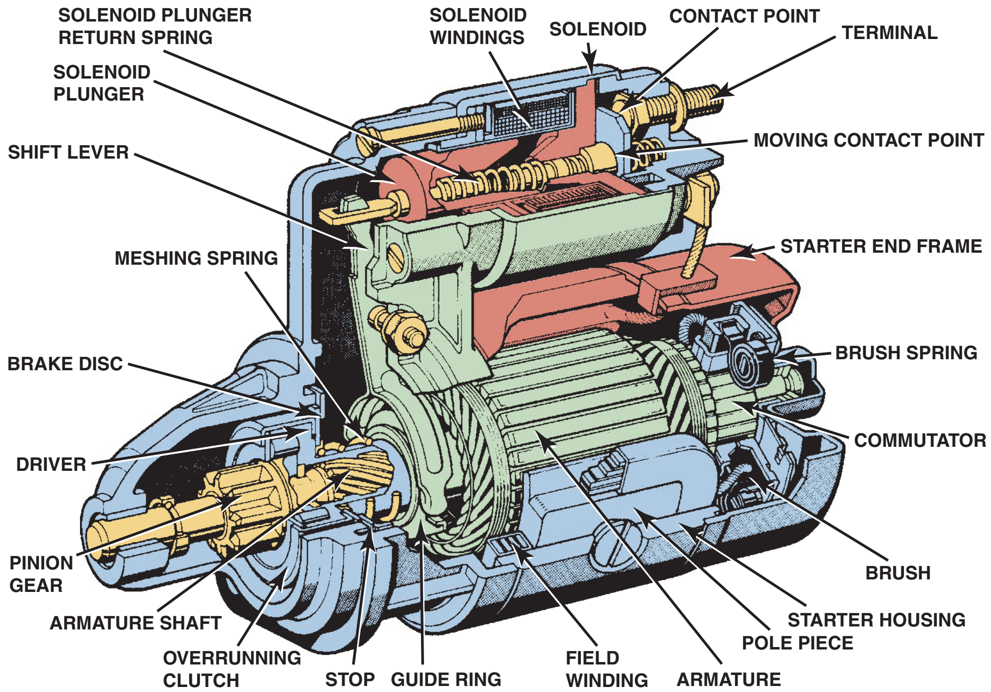

FIGURE 52–18 A cutaway of a typical starter motor showing the commutator, brushes, and brush spring.

FIGURE 52–19 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 total replacement is the only solution in this case.

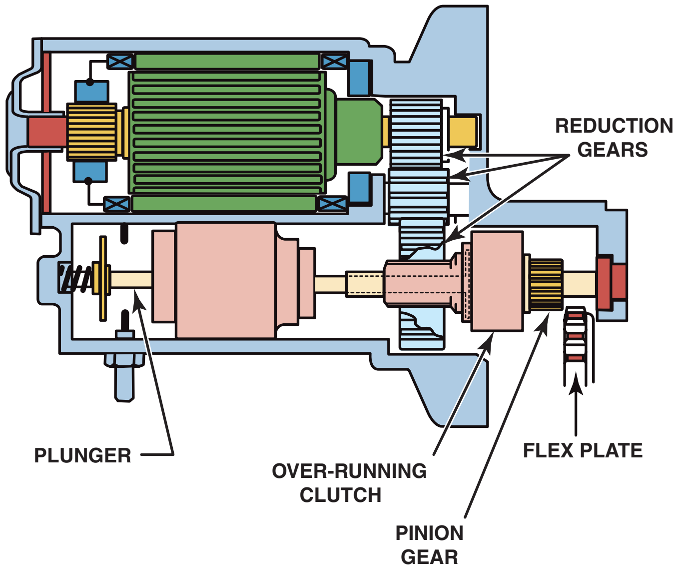

FIGURE 52–20 A typical gear-reduction starter.

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 starters today 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 52–19.**

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 0 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. Many permanent magnet starters use a planetary gear set (a type of gear reduction) to provide the necessary torque for starting. ● **SEE FIGURE 52–20.**

STARTER DRIVES

PURPOSE AND FUNCTION A **starter drive** includes small pinion gears that mesh with and rotate the larger gear on the engine flywheel or flex plate for starting. The pinion gear must engage with

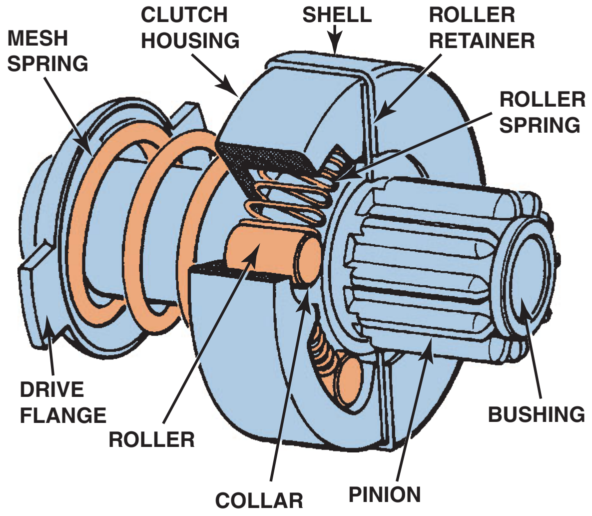

FIGURE 52–21 A cutaway of a typical starter drive showing all of the internal parts.

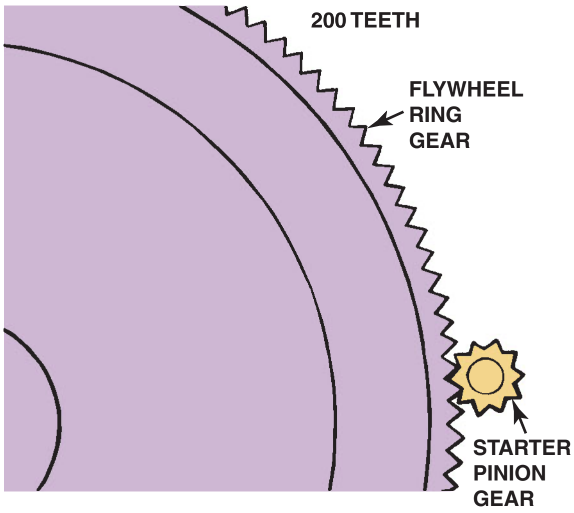

FIGURE 52–22 The ring gear to pinion gear ratio is usually 15:1 to 20:1.

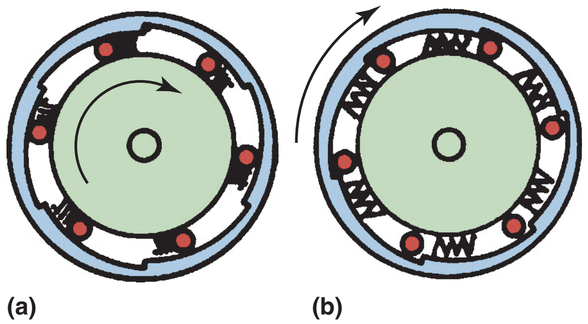

FIGURE 52–23 Operation of the overrunning clutch. (a) Starter motor is driving the starter pinion and cranking the engine. The rollers are wedged against spring force into their slots. (b) The engine has started and is rotating faster than the starter armature. Spring force pushes the rollers so they can rotate freely.

?

FREQUENTLY ASKED QUESTION

What Is a Bendix?

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. The Bendix drive mechanism has generally not been used since the early 1960s, but some technicians use this term when describing a starter drive.

the engine gear slightly *before* the starter motor rotates, to prevent serious damage to either the starter gear or the engine, but 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 52–21**.

STARTER DRIVE GEAR RATIO The ratio of the number of teeth on the engine ring 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 an engine ring 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 (varies from 70 to 250 RPM). This means that the starter motor speed is 18 times faster, or 3600 starter RPM ($200 \times 18 = 3600$). If the engine starts and is accelerated to 2000 RPM (normal cold engine speed), the starter will be destroyed by the high speed (36,000 RPM) if the starter was not disengaged from the engine. ● **SEE FIGURE 52–22**.

STARTER DRIVE OPERATION All starter drive mechanisms use a type of one-way clutch that allows the starter to rotate the engine, but then turns freely if the engine speed is greater than the starter motor speed. This clutch, called an **overrunning clutch,** 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 52–23**.

This taper forces the balls or rollers tightly into the notch, when rotating in the direction necessary to start the engine. When 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 (overrun).

The spring between the drive tang or pulley and the overrunning clutch and pinion is called a **mesh spring.** It helps to cushion and control the engagement of the starter drive pinion with the 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.

FAILURE MODE A starter drive is generally a dependable unit and does not require replacement unless 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 and then stop cranking the engine and creating 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

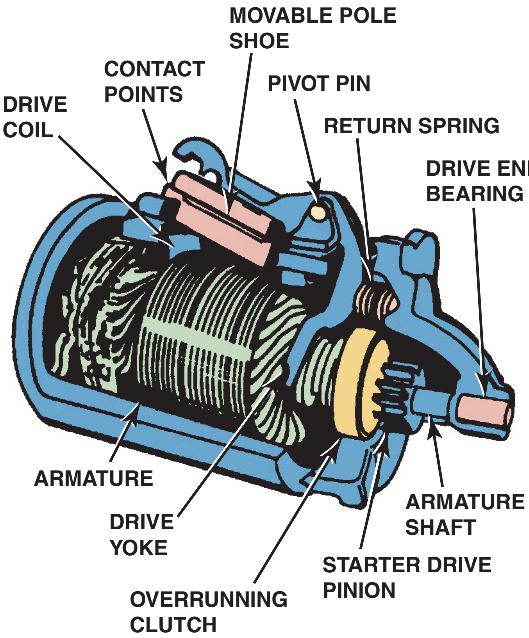

FIGURE 52–24 A Ford movable pole shoe starter.

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.

POSITIVE ENGAGEMENT STARTERS

OPERATION Positive engagement starters (direct drive) were used on Ford engines from 1973 to 1990. These starters use the shunt coil winding and a movable pole shoe 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.

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, called the *holding coil*, is strong enough to hold the starter drive engaged while permitting the flow of the maximum possible current to operate the starter. ● **SEE FIGURE 52–24**.

ADVANTAGES The movable metal pole shoe is attached to and engages the starter drive with a lever (called the plunger lever). As a result, this type of starter does not use a solenoid to engage the starter drive.

DISADVANTAGES 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.

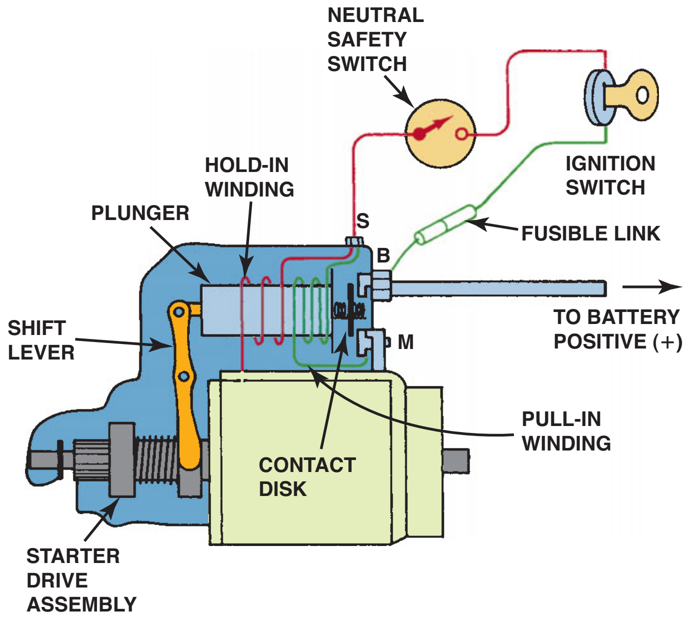

FIGURE 52–25 Wiring diagram of a typical starter solenoid. Notice that both the pull-in winding and the hold-in winding are energized when the ignition switch is first turned to the "start" position. As soon as the solenoid contact disk makes electrical contact with both the B and M terminals, the battery current is conducted to the starter motor and electrically neutralizes the pull-in winding.

SOLENOID-OPERATED STARTERS

SOLENOID OPERATION A **starter solenoid** is an electromagnetic switch containing two separate, but connected, electromagnetic windings. This switch is used to engage the starter drive and control the current from the battery to the starter motor.

SOLENOID WINDINGS The two internal windings contain approximately the same number of turns but are made from different-gauge wire. Both windings together produce a strong magnetic field that pulls a metal plunger into the solenoid. The plunger is attached to the 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.

1. The heavier-gauge winding (called the **pull-in winding**) is needed to draw the plunger into the solenoid and is grounded through the starter motor.
2. The lighter-gauge winding (called the **hold-in winding**), which is grounded through the starter frame, 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. ● **SEE FIGURE 52–25**.

OPERATION

1. The solenoid operates as soon as the ignition or computer-controlled relay energizes the "S" (start) terminals. At that