

## chapter 7

# DIESEL ENGINE STARTING SYSTEMS

### LEARNING OBJECTIVES

**After reading this chapter, the student should be able to:**

1. Identify all main components of a diesel engine starting system
2. Describe the similarities and differences between air, hydraulic, and electric starting systems
3. Identify all main components of an electric starter motor assembly
4. Describe how electrical current flows through an electric starter motor
5. Explain the purpose of starting systems interlocks
6. Identify the main components of a pneumatic starting system
7. Identify the main components of a hydraulic starting system
8. Describe a step-by-step diagnostic procedure for a slow cranking problem
9. Describe a step-by-step diagnostic procedure for a no crank problem
10. Explain how to test for excessive voltage drop in a starter circuit

### KEY TERMS

Armature 220	Hold in 240
Field coil 220	Starter interlock 234
Brushes 220	Starter relay 225
Commutator 223	Disconnect switch 237
Pull in 240	

**SAFETY FIRST** Some specific safety concerns related to diesel engine starting systems are as follows:

- Battery explosion risk
- Burns from high current flow through battery cables
- Strain injuries from lifting heavy starters and batteries (some are over 65 lb)
- Burns from battery electrolyte
- Fire hazards from sparks and hot wires
- Unexpected cranking or starting of engine
- Injuries from sudden release of stored energy (electrical, hydraulic, air pressure)

**THE IMPORTANCE OF STARTING SYSTEMS** A functional machine needs a running engine, and if the engine doesn't crank, it doesn't start. A properly operating and reliable starting system is a must for keeping a machine productive. For many years, diesel engines have mostly used electric motors to crank them over to start the combustion process. For some applications, an air or hydraulic motor will create the torque needed to turn the engine over.

Many years ago, diesel engines were sometimes started with a smaller gas engine called a pup engine. ● **SEE FIGURE 7-1** for a pup engine on an older diesel engine. Another way to get a diesel engine started was to start it on gasoline and then switch it over to run on diesel fuel. This was a complex solution to a simple task because the engine had to have a way to vary its compression ratio, and it needed a spark ignition system and a carburetor. As 12V electrical systems became more popular and electric motor design improved, electric starters were



**FIGURE 7-1** A pup engine starter motor.

able to get the job done. Many large diesel engines will use a 24V starting system for even greater cranking power. ● **SEE FIGURE 7-2** for a typical arrangement of a heavy-duty electric starter on a diesel engine.

A diesel engine needs to rotate between 150 and 250 rpm to start. The purpose of the starting system is to provide the torque needed to achieve the necessary minimum cranking speed. As the starter motor starts to rotate the flywheel, the crankshaft is turned, which then starts piston movement. For a small four-cylinder engine, there doesn't need to be a great deal of torque generated by a starter. But as engines get more cylinders and bigger pistons, a huge amount of torque will be needed to get the required cranking speed. Some heavy-duty 24V starters will create over 200 ft-lb of torque. This torque then gets multiplied by the gear reduction factor between the starter motor pinion gear and ring gear on the engine's flywheel. This is usually around 20:1. ● **SEE FIGURE 7-3** for how a starter assembly pinion engages with the flywheel ring gear.



**FIGURE 7-2** A typical arrangement of a heavy-duty electric starter on a diesel engine.



**FIGURE 7-3** A starter assembly engaging with a flywheel ring gear.



**FIGURE 7-4** A double starter assembly arrangement.

Some larger engines will need two or more starters to do this. Some starters for large diesel engines will create over 15 kW or 20 hp! ● **SEE FIGURE 7-4** for a double starter arrangement.

When a starter motor starts to turn the engine over, its pistons start to travel up in the cylinders on compression stroke. There needs to be between 350 and 600 psi of pressure created on top of the piston. This is the main resistance that the starter has to overcome. This pressure is what is needed to create the necessary heat in the cylinder so that when fuel is injected it will ignite. If the starting system can't crank the engine fast enough, then the compression pressure and heat won't be high enough to ignite the fuel. If the pistons are moving too slowly, there will be time for the compression to leak by the piston rings. Also the rings won't get pushed against the cylinder, which again allows compression pressure to leak into the crankcase. When this happens, the engine won't start or it starts with incomplete combustion. Incomplete combustion equals excessive emissions. This is another reason to have a properly operating starting system.

The faster a starter can crank a diesel engine, the faster it starts and the quicker it runs clean.

This engine cranking task is much more difficult in colder temperatures especially if the engine is directly driving other machine components such as hydraulic pumps, a torque converter, or a PTO (power take-off) drive shaft. Cold engine oil adds to the load on the starter, and this load may increase by three to four times what it would normally be in warmer weather. Engine oil that is the wrong viscosity (too thick) for the temperature will greatly increase the engine's rolling resistance. Adding to this problem is the fact that a battery is less efficient in cold temperatures.

When engineers design a cranking system, they must take into account cold weather cranking conditions and will quite often offer a cold weather starting option. This would likely include one or more of the following: bigger or more batteries, higher output starter, larger battery cables, battery blankets, oil heaters, diesel fired coolant heater, electric immersion coolant heater (block heater), and one or more starting aids like an ether injection system or an inlet heater.

One more recent difficulty added to starting systems is a result of electronic controls on some engines. Some ECMs may need to see a minimum number of engine revolutions at a minimum speed before it will energize the fuel system. This equates to longer cranking times and more strain on the cranking system. Some electronic engines will crank for five seconds or longer even when the engine is warm before the ECM starts to inject fuel and the engine starts.

It's important that a machine's starting system works properly and you should be aware of how the main components of a system work. This will give you the knowledge needed to make a proper diagnosis when you get a complaint of an engine cranking slowly or not at all.

If an engine doesn't start, then a machine isn't working, and instead of making money, it's costing money. The better you know how to diagnose and repair a starting system problem, the more valuable you will be as an HDET. There are lots of technicians who are good at changing starters whether the starter is faulty or not. Many times the cause of a starting complaint is something other than the starter.

If a starter is used properly, it will last for well over 10,000 starts. The biggest factor in reducing the life of an electric starter is overheating from over-cranking. *Never* run the starter for more than a 30-second stretch, and if it does run that long, then wait at least two minutes between cranks to allow the starter to cool.

For engines up to 500 hp, electric starting systems will be used for 99% of the applications. For any size engine, air and hydraulic starting systems are an option; however, they will likely only be used for special applications and usually for engines over 500 hp.



## TECH TIP

This chapter focuses on diesel engine starting systems because at this time they are the most popular type of engine used for heavy equipment. However, there may be some other types of engines used in the future such as natural gas-powered engines.

Natural gas engines are used for many stationary power applications, and many are similar to diesel engines but with lower compression ratios, different fuel system, and a spark ignition system. Because of the lower compression ratio, they will put a lower demand on the starting system.

The job of any starter motor assembly is to take a stored energy (electric, air, or hydraulic) and convert it into mechanical rotation to crank the engine fast enough to begin the engine's ignition sequence.

## NEED TO KNOW

The most common type of starting system uses electrical energy; however, compressed air and hydraulic energy can be used as well.

The following are the main comparable components of the three main types of starting systems:

ELECTRIC STARTING SYSTEM	AIR STARTING SYSTEM	HYDRAULIC STARTING SYSTEM
Electric starter motor assembly	Air motor starter assembly	Hydraulic motor starter assembly
Battery cables	Air lines	Hydraulic hoses
Starter relay	Relay valve	Directional control valve
Starter interlock system	Starter interlock system	Starter interlock system
Battery(ies) or capacitor	Air tank	Hydraulic accumulator
Starter switch	Starter switch or valve	Starter switch or valve
Wiring harness	Wiring harness (optional)	Wiring harness (optional)

We'll first examine the different electric starter motor designs, next discuss air and hydraulic starter motors, and then look at the control circuit for starters.

An electric starter will take stored electrical energy from a battery (or sometimes a capacitor) and convert it into torque at the starter's pinion gear. The pinion then engages with the ring gear that is part of the engine's flywheel and turns the flywheel that rotates the engine's crankshaft. ● **SEE FIGURE 7-5** for a cutaway of a starter and its main parts.

There are two main types of electric starter motor assemblies:

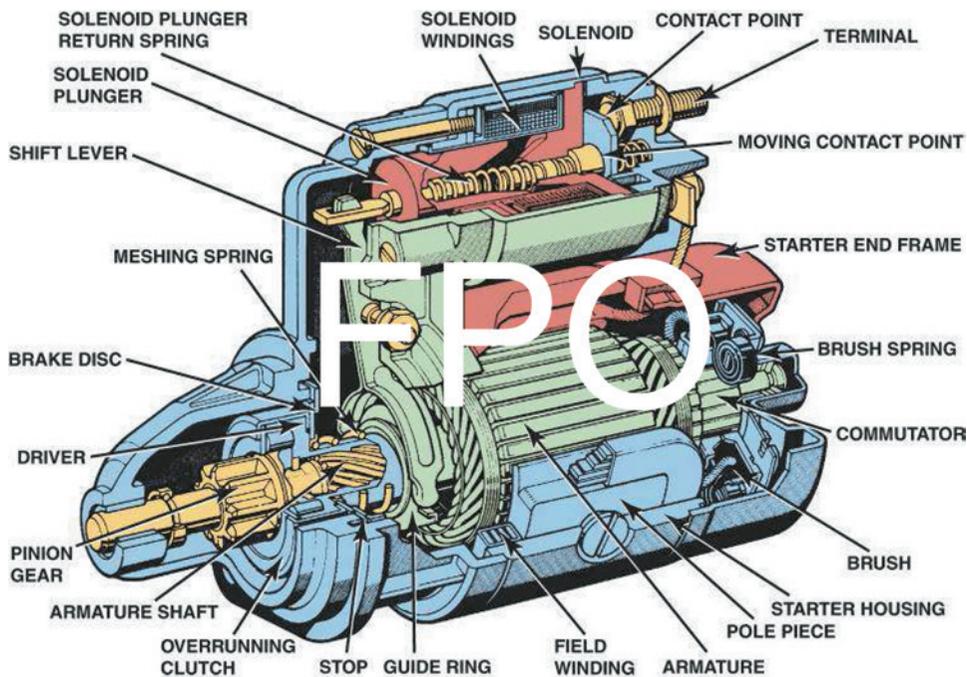
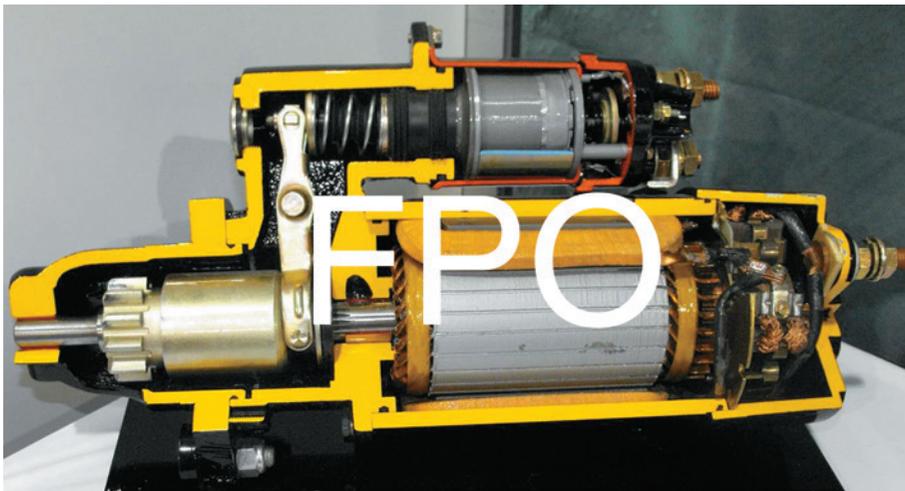
**Direct drive (pinion is driven directly by the armature):** A direct drive electric starter has a motor that is designed to generate high torque at low speed and operate at high speed with low torque (the motor will sometimes exceed 5000 rpm) for a short length of time. It will use a solenoid actuated shift lever to push out the pinion to engage it with the ring gear before or just as the armature (rotating shaft in the motor assembly) starts turning.

**Gear reduction (higher speed motor output to a gear reduction and then to pinion):** A gear reduction starter (planetary or pinion reduction) is designed to use a smaller higher speed electric motor to produce higher cranking torque with the same or less electrical power consumed. The heaviest and bulkiest part of a direct drive starter is the motor so by reducing motor size and weight the engineers have saved space and weight. Some direct drive starters are twice the weight as a comparable output gear reduction starter. Although this isn't a big concern for a large machine, you will be thankful for the lighter weight whenever it comes time to change the starter.

Gear reduction starter motor assemblies can have their motor offset from the output shaft or use planetary gears and have the motor shaft in-line with the output shaft.

## DIRECT DRIVE STARTER COMPONENTS

- Starter housing: Center section that holds the pole shoes and field coils in place.



**FIGURE 7-5** An electric starter cutaway (Halderman, *Automotive Technology*, 5th ed., Fig. 52-18).

- **Nose piece:** The drive end of the starter where the pinion gear is located. Holds the shift lever in place and supports the armature shaft with a bushing.
- **End cap:** Opposite end of the starter from the nose piece. Supports brush holder assembly and the other armature shaft bushing.
- **Armature:** The rotating part of the motor that has several windings that have each of their ends loop to a commutator bar. It will have splines to drive the starter drive.
- **Brushes:** Contact the commutator bars and transfer electrical current to the armature.
- **Brush holders:** Spring loaded to keep the brushes in contact with the armature.
- **Field coils:** Heavy copper windings that create a strong magnetic field when current flows through them.
- **Pole shoes:** Iron cores for the field coils that help to increase magnetism.
- **Solenoid:** Has two windings (pull-in and hold-in) that get energized by the starter control circuit and magnetically move a plunger. The plunger is connected to a heavy contact disc that is a switch. The switch will send current from the battery terminal to the field coils. The plunger could also be connected to a shift lever that will move the pinion.
- **Pinion gear:** The starter output that engages with the flywheel and cranks the engine.

- Overrunning clutch: Drives the pinion from the armature shaft but will not allow the armature to be driven by the ring gear.
- Shift lever: Used to push the pinion out to engage with the ring gear.

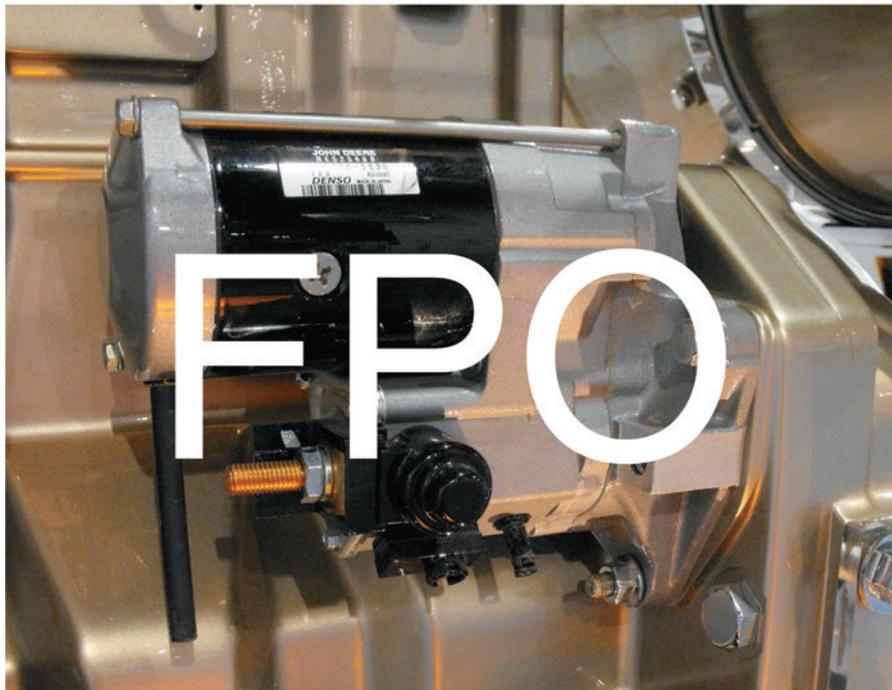
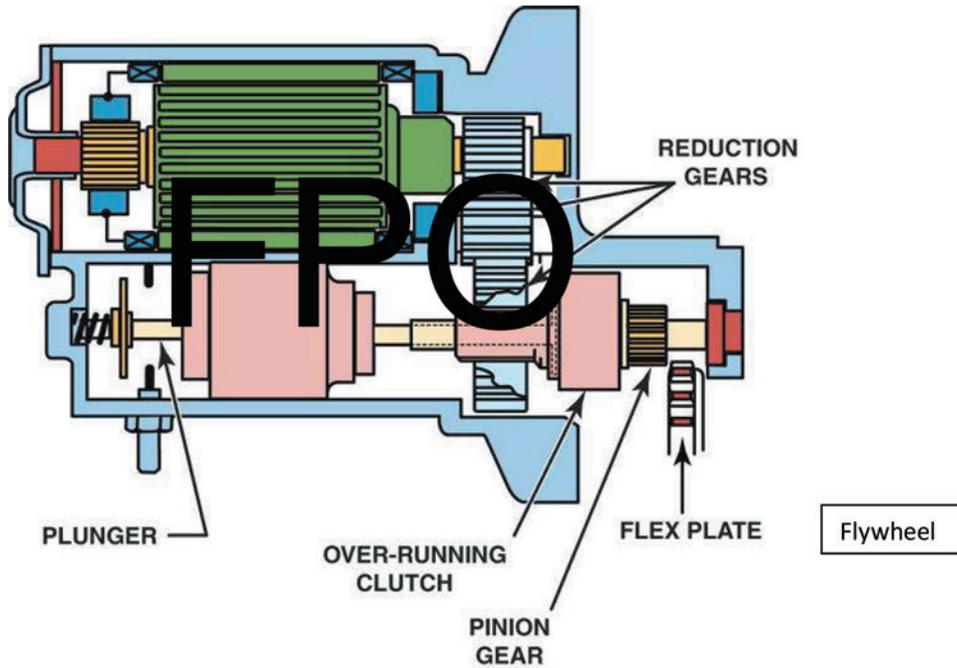
### GEAR REDUCTION STARTER COMPONENTS

- Motor components (armature, brushes, brush holder, field coils, pole shoes) are the same as a direct drive starter.

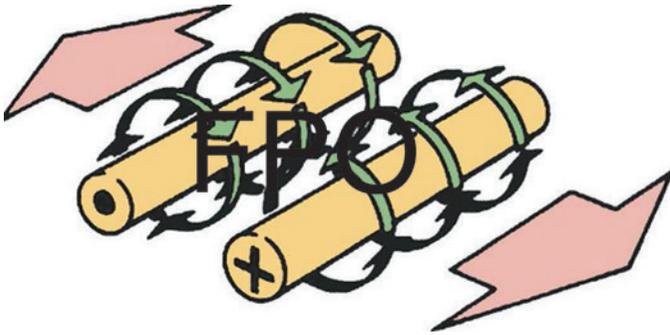
- Gear reduction: The armature shaft will have a gear output that will drive an intermediate gear that drives the pinion gear shaft.
- Solenoid: The solenoid performs the same electrical functions as the direct drive starter but may directly push the pinion gear out.

- Overrunning clutch: Same as direct drive.

● SEE FIGURE 7-6 for a gear reduction starter.



**FIGURE 7-6** A gear reduction starter (Halderman, *Automotive Technology*, 5th ed., Fig. 52-20).



**FIGURE 7-7** Current flow causing opposing magnetic fields (Halderman, *Automotive Technology*, 5th ed., Fig. 47-11 or 52-8).

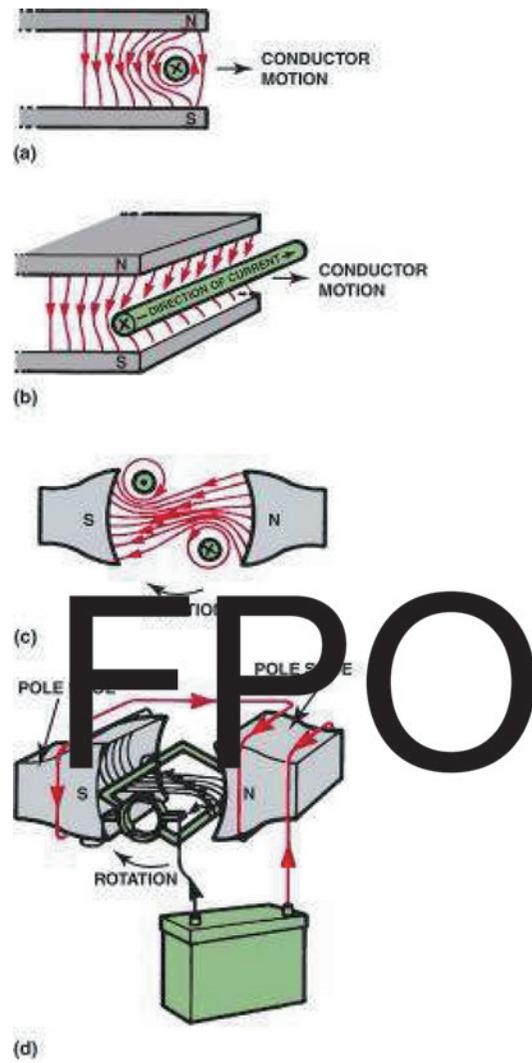
**ELECTRIC MOTOR OPERATION** The action of the motor section of the electric starter assembly is the same as any brush-type motor used on a heavy equipment machine. Some other applications of motors that use brushes could be supplementary steering or brake pump motors, windshield wiper motors, and hood lift motors.

The basic principle behind any electric motor operation is the arranging of opposing magnetic fields so that rotation is created. This is the same force that will try to keep two like poles of permanent magnets apart. If you have ever played with magnets, you will be familiar with this force. ● **SEE FIGURE 7-7** for how current flow can cause opposing magnetic fields.

As discussed in Chapter 5, if current is flowing through a conductor, then there will be a magnetic field created around the conductor. If you want to build a stronger magnetic field, then loop an insulated wire into coils, put an iron core through the middle of the coil, and increase the current flow through the wire.

If opposing or attracting magnetic fields can be arranged between two components, then relative motion occurs. This of course can only happen if the magnetic forces are strong enough to overcome the resistance that it is opposing. Opposing magnetic fields are also used to make solenoid plungers move.

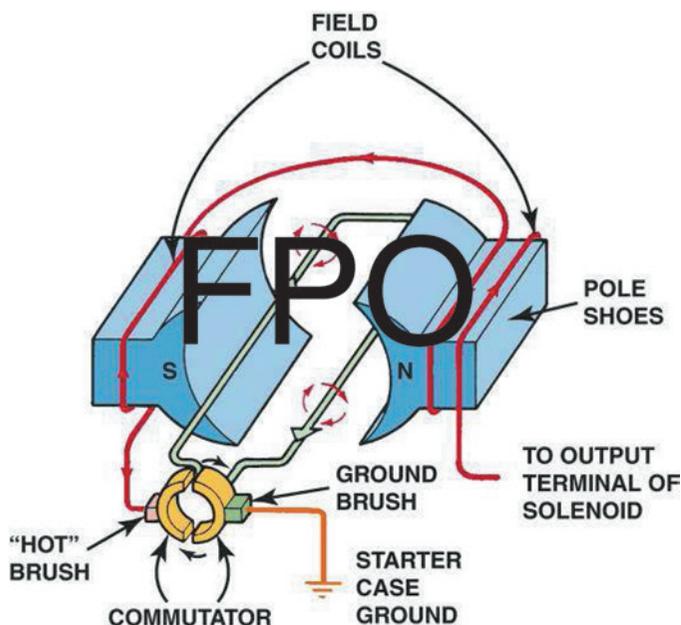
We'll start to look at a simple motor with one pair of field coils and an armature with one loop of wire. In a simple DC electric starter motor, one magnetic field is created in the stationary motor housing and is generated between a pair of field coil/pole shoe electromagnets. ● **SEE FIGURE 7-8** for the field coils/pole shoes in a starter motor housing. The pole shoes are the iron core of the electromagnet, and when the field coils are energized, a strong magnetic field is created. One field coil will act like a north pole and the field coil opposite will act like a south pole. This magnetic field is like the field occurring between the ends of a horseshoe magnet. The field windings are heavy flat copper and appear to be bare wire but are coated



**FIGURE 7-8** The field coils/pole shoes in a starter motor housing (Halderman, *Automotive Technology*, 5th ed., Fig. 52-6).

with a thin varnish to keep the loops insulated from itself and from the pole shoe. If this insulation fails, there will be a short circuit fault.

The other magnetic field in the simple starter motor is created in a loop of wire (winding) that is the armature. The



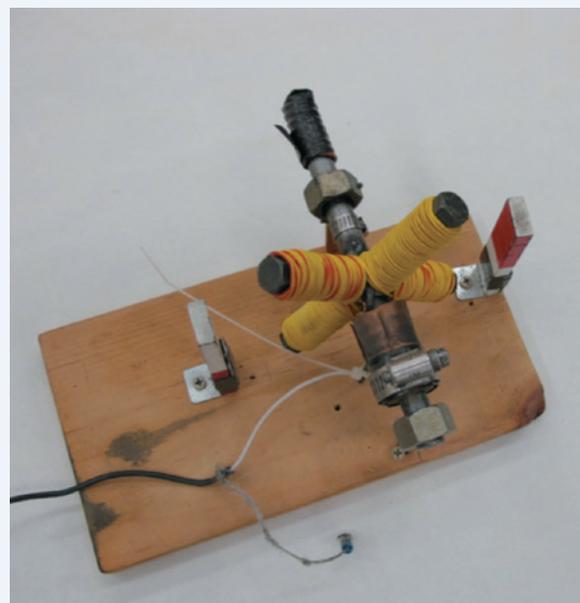
**FIGURE 7-9** How do the armature winding interact with the field poles (Halderman, *Automotive Technology*, 5th ed., Fig. 52-6)?

armature operates inside the magnetic field that has been created by the field coil/pole shoes. When the armature winding is energized, its surrounding magnetic field interacts with the pole shoe/field coil magnetic field. The armature shaft is supported on two bearings in each end of the motor assembly to allow rotation. When the two opposing magnetic fields create an unbalance, the armature will rotate to try to become magnetically balanced. If the magnetic fields are timed correctly to oppose each other at the proper location, then the armature will rotate. In other words, as the loop of armature winding is energized, it will have a surrounding magnetic field on each of the two longest sections of the winding that run parallel to the armature shaft. These sections of the winding will react to the field coils' magnetic fields and the reacting force will try to push the armature winding away. As the armature rotates, the winding will have its direction of current flow reverse as soon as the ends of the winding swap places with the brushes feeding it current. This allows the same loop of wire to be continuously pushed away from the field coil magnetic field. ● **SEE FIGURE 7-9** for how the armature winding interacts with the field poles.

The armature shaft is the rotating output of any electric motor. The armature windings are embedded into grooves that run along the length of the armature core. The armature core serves the same purpose as the field coils/pole shoes—that is, to increase the magnetic field surrounding the energized windings. The windings are insulated from each other and from the core by a thin coat of varnish. Shorts and grounds may occur if this varnish coating fails and exposes the bare copper.

Search the Internet for homemade electric motors and you will see a variety of simple designs. Why not see if you can make your own motor. Hopefully curiosity will get the better of you. This will also help you to understand how magnetism and electricity work together to make mechanical movement.

It's not hard to make an electric motor. ● **SEE FIGURE 7-10** for a simple homemade motor. The field magnets are permanent magnets but could be made stronger with field coils.



**FIGURE 7-10** A simple homemade electric motor.

● **SEE FIGURE 7-11** for a typical armature and how the loops of wire are embedded into the core. Each end of an armature winding is connected to one **commutator** bar. The commutator bars are insulated from each other but are exposed on their outer surface to allow connection to the motor brushes. You should also note that the windings are offset to the commutator bars that they connect to. This is to place the winding at the correct location relative to the field coil magnetic field so that maximum torque is created on the armature by the opposing magnetic fields.

You've probably noticed by looking at the photo of the armature that there is more than one loop of wire and more than one set of commutator bars. To provide continuous and steady rotation of an electric motor, there needs to be a constant opposing magnetic field. As more windings are added to the armature, it's possible to do this. As one loop of wire's

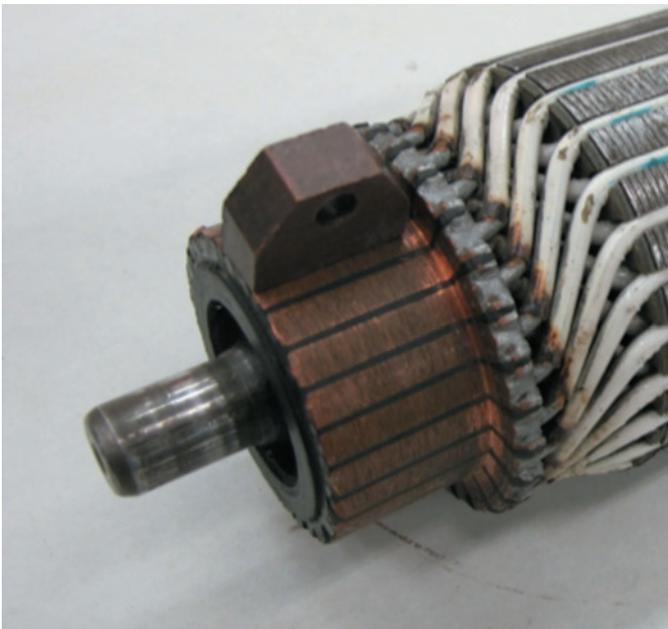


**FIGURE 7-11** A typical armature and how the loops of wire are embedded into the core.



**WEB ACTIVITY**

Search the Internet for commutation and see if you can find an animation of an electric motor working. This should help you understand the interaction between the armature windings, commutator bars, and brushes.



**FIGURE 7-12** A set of brushes riding on an armature commutator.

commutator bars comes into contact with a set of brushes to get energized, the rotation it creates moves another set out of contact.

To get current flowing to an armature winding, there must be a connection that can allow relative motion in order for the armature to be able to rotate. The motor's brushes and the armature's commutator bars create this connection. ● **SEE FIGURE 7-12** for a brush riding on an armature commutator.



**FIGURE 7-13** A set of brusher leads.



**FIGURE 7-14** Current flow through a series wound motor (Halderman, *Automotive Technology*, 5th ed., Fig. 52-11).

The motor's brushes are held in contact with the commutator bars by spring pressure. The brushes will eventually wear down and not make proper contact. They are made of a hard conductive combination of carbon and copper material and will constantly transfer current to and from the armature commutator. This current is the full current flow that the starting motor will see whenever it is energized by the starter solenoid. This could be as much as 3000 amps when the motor is first engaged. ● **SEE FIGURE 7-13** for a starter motor set of brush leads. The brush holder assembly is held in place by the end housing of the starter. The brushes have a flexible lead that attaches to a terminal on the brush holder assembly. One brush will supply voltage to the armature from the field coil while the brush opposite will be connected to ground. Most heavy-duty starters will have two or three sets of brushes to energize more armature windings at the same time. This will in theory double or triple the motor's output.

When a series wound electric motor is first energized and the armature is stationary, the motor will make its maximum torque. This is because there should be very little resistance in the motor components that have current flowing through them. ● **SEE FIGURE 7-14** for the current flow through a series wound starter motor assembly. As it is shown, if you think of current flowing in the conventional direction, it starts at the

battery positive, goes to the first set of field windings, and then goes through the rest. A series wound starter could have two, four, or six field coils. This current flow path will change if the starter is a shunt wound or compound (combination shunt and series). Different field winding arrangements will give a starter motor different characteristics such as good low speed torque or good speed limiting.

Heavy-duty starters will sometimes have an external ground cable to ensure a good connection to ground. Light-duty starters will be internally grounded. This means they rely on their mounting fasteners to make a good connection to the flywheel housing, which in turn should get a good connection through the engine block to battery ground. This, however, is sometimes a source of problems and some repairs include putting an external ground cable on to the starter housing.

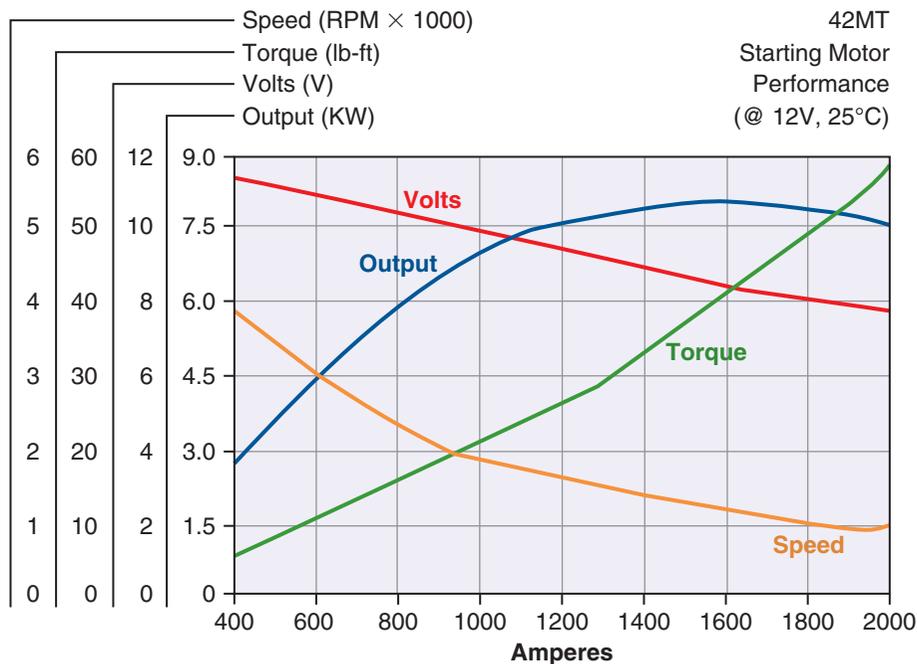
In theory, if energized, an electric motor should keep increasing in speed until it self-destructs. A self-limiting phenomenon called counter-electromotive force (CEMF) will not allow an electric motor to keep increasing in speed. Another outcome between magnetism and conductors happens when a conductor is moved through a magnetic field. Current flow is generated because of something called induction. This is the basic principle behind generators and alternators. As the armature windings move past the field coils, there is a voltage induced in the armature. This voltage opposes the voltage that is flowing into the winding from the brushes. The two opposing voltages reduce the overall size of the magnetic field around the armature windings. The higher the speed that the armature

spins, the greater the CEMF produced. Therefore, the motor self-governs its speed as the speed increases.

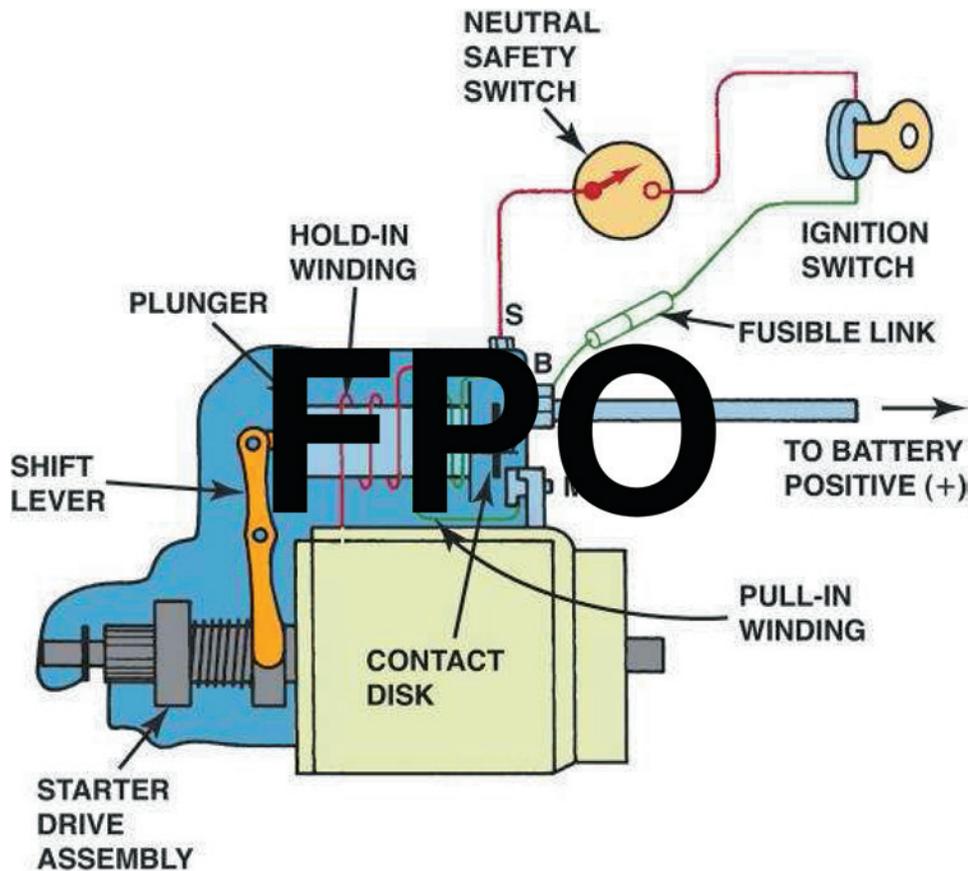
Remember that it was stated earlier that the motor makes its maximum torque at 1 rpm and the torque reduces as the speed increases. This is exactly how you would want a starter motor working. In other words, when the engine is stationary, it will take the most power to start it cranking, and then as the cranking rpm increases, it should take less torque and this is how the starter motor delivers its torque and speed. The CEMF reduces current flow by opposing the current flowing into the armature and this in turn reduces torque as speed increases. This is a proportionate reaction. ● SEE FIGURE 7-15 for the graph showing the speed, torque, and horsepower output of a heavy-duty electric starter.

**STARTER MOTOR SOLENOID** All heavy-duty electric starter motors will use a solenoid assembly to do two things. They will pull a plunger in to move the drive pinion out and will close a heavy-duty contact switch. There are typically four terminals on a heavy-duty starter solenoid. The two smaller ones are the “S” terminal, which is energized by a key switch or **starter relay**, and the “G” terminal, which supplies the ground to the solenoid. The two larger terminals are “B+” for the main battery positive cable and a motor terminal that sends current from the solenoid to the motor. Sometimes the ground wire isn’t needed as the solenoid may be grounded internally.

A starter solenoid will have two sets of wire windings in it. The pull-in and the hold-in windings get energized to pull



**FIGURE 7-15** A graph showing the speed, torque, and horsepower output of a heavy-duty electric starter.



**FIGURE 7-16** Current flow through the hold-in and pull-in windings in a typical solenoid (Halderman, *Automotive Technology*, 5th ed., Fig. 52-25).

the solenoid plunger in against return spring pressure. The pull-in winding will use a lower-resistance, bigger gauge wire to let more current flow through it. Current flow through typical solenoid pull-in windings is from 30 to 60 amps. This will create a strong magnetic field that is needed to overcome the initial spring pressure. If the pull-in winding stayed energized, it would overheat because of the higher current flow.

When the plunger is pulled in, it will also connect two contacts with a heavy copper contact plate. This will allow current to flow from the main battery cable into the starter motor where it starts heading to ground through the field coils, brushes, and armature.

The hold-in winding will have its own ground and stay energized as long as the “S” terminal gets power from a key switch or start relay. The hold-in coil has a higher resistance and will typically only have about 5–10 amps flowing through it.

The pull-in coil is also energized from the S terminal, but it gets its ground ultimately from the starter motor ground. Once the solenoid contact plate starts allowing current flow to the starter motor, the pull-in coil’s ground turns into a positive part of the circuit. As the pull-in coil has a positive voltage on each end of its winding, there is no potential difference

and, therefore, current stops flowing through the coil. ● **SEE FIGURE 7-16** for how current flows through the two windings of a solenoid.

**SOFT START STARTERS** You may hear the term *soft start* when a type of starter is being discussed. The term refers to a different way of connecting the solenoid to the motor with the purpose of sending some current flow to the motor as the pinion is being pushed out. This will help to ease the engagement of pinion and ring gear.

**THERMAL OVER-CRANK PROTECTION** To protect a starter motor from excessive heat damage caused by extended cranking periods, the motor may incorporate a thermally sensitive switch. These switches are commonly called over-crank protection (OCP) switches. The switch will open when the temperature gets too high. This switch will be part of the starter control circuit so when it opens, the starter solenoid will not be energized and, therefore, the starter cannot operate until it cools down. When the starter cools down, the switch closes and starter operation goes back to normal. ● **SEE FIGURE 7-17** for a starter with a thermal OCP switch.



**FIGURE 7-17** A starter with an OCP switch.

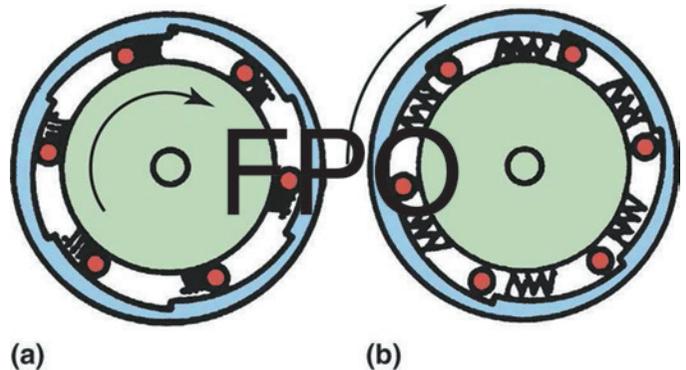
**STARTER DRIVES** The business part of the starter is the pinion gear, which is driven by the starter drive. For a direct drive starter, the drive is turned directly from the armature shaft by splines. Gear reduction starters will have one or more gears between the armature shaft and the starter drive. The drive pinion will have between 7 and 11 teeth that must be of the same pitch as the ring gear teeth they are engaging with. A typical ratio between the starter's pinion and the flywheel ring gear is 15:1. This would equate to a pinion speed of 2250 rpm if the engine is turning at 150 rpm.

The drive mechanism must provide a means of not allowing the starter's armature to be driven by the engine's flywheel. If we take the ratio of 15:1 and calculate potential pinion speed if the engine is running at low idle of 700 rpm, we would see the pinion would spin at 10,500 rpm. This would surely damage a starter motor that is designed to operate at a maximum speed of 5000 rpm. To prevent this from happening, an overrunning or one-way clutch will be between the pinion gear and the armature shaft.

● **FIGURE 7-18** shows an overrunning clutch for a starter drive.

An overrunning clutch works like a ratchet in that it provides a positive drive action in one direction but allows slippage in the reverse direction. Overrunning clutches can get worn and allow slippage in both directions.

The drive mechanism also engages the pinion before full motor torque is starting to turn the pinion. This will reduce damage to the pinion and the ring gear. To engage the pinion with the ring gear, a mechanism will shift the pinion out along the pinion drive shaft. Most drive shafts will have a helix or very coarse thread shaped machined on them with which the pinion drive engages. Its purpose is to slightly rotate the pinion as it is pushed into the ring gear so that it will engage easier. The pinion gear teeth will usually have a taper machined into the leading edge of the tooth that will assist with engagement. These features are to prevent the pinion from trying to be a



**FIGURE 7-18** An overrunning clutch for a starter drive. (A) A starter shaft driving pinion gear. (B) A pinion gear is allowed to rotate separately from starter shaft (Halderman, *Automotive Technology*, 5th ed., Fig. 52-23).

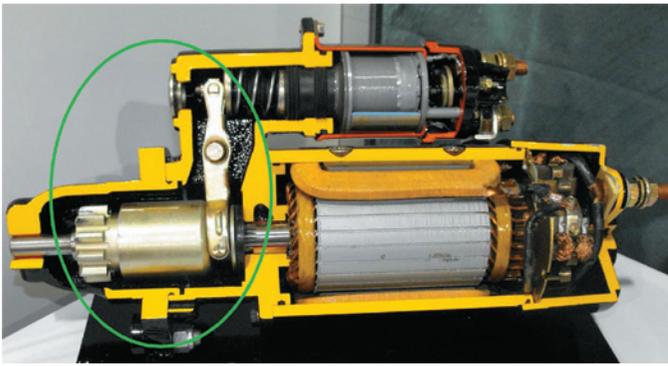
milling machine and take material off the ring gear teeth. If you hear someone mention that a ring gear has been milled, you now know what this means.

Direct drive and planetary drive starters will use a shift lever to move the pinion drive out toward the ring gear. The shift lever is actuated by the solenoid plunger and pivots on a cross pin. The bottom part of the shift lever has a fork with wear buttons that ride in a slotted part of the drive. This allows the drive to rotate and still be allowed to be pushed out by the shift lever.

● **SEE FIGURE 7-19** for how a shift lever and drive assembly work together.

### Progress Check

1. If an electric starter is run for 15 seconds, it should be cool down for how many seconds before running again:
  - a. 15
  - b. 30
  - c. 90
  - d. 120
2. An electric direct drive starter will drive the pinion gear with:
  - a. the solenoid plunger
  - b. the armature shaft



**FIGURE 7-19** A shift lever and drive assembly.

- c. the brush drive
  - d. the vane motor shaft
3. A hydraulic starting system will use this component as the equivalent to a battery in an electric starting system:
    - a. accumulator
    - b. control valve
    - c. pump
    - d. nitrogen tank
  4. If current flowing through a wire creates a magnetic field around the wire, then to increase the strength of the magnetic field, you would:
    - a. increase the length of the wire
    - b. increase the diameter of the wire
    - c. decrease the diameter of the wire
    - d. increase the amount of current flowing through the wire
  5. An electric drive starter motor will make maximum torque:
    - a. before the solenoid plunger moves
    - b. at maximum speed
    - c. when the engine is running
    - d. just as it starts to rotate
  6. The S terminal on an electric starter solenoid is for:
    - a. receiving current from a relay or switch
    - b. sending current to the motor
    - c. special applications and not normally used
    - d. sensing when the starter is turning
  7. The solenoids hold-in coil will have less current flowing through it than the pull-in coil because:
    - a. it gets energized after the pull-in coil
    - b. it only gets half system voltage
    - c. it has a separate resistor
    - d. its wire is a smaller gauge
  8. Some starters will have an OCP switch. This stands for:
    - a. only crank positive
    - b. over-center pinion
    - c. overdrive clockwise pinion
    - d. over-crank protection

9. If the ratio of starter pinion teeth to ring gear teeth was 20:1 and the engine was turning at 180 rpm, then the pinion must be turning at:
  - a. 900 rpm
  - b. 2000 rpm
  - c. 3600 rpm
  - d. 4800 rpm
10. The starter's overrunning clutch will allow:
  - a. the starter pinion to spin with the flywheel but not drive the starter motor
  - b. the armature to increase output torque
  - c. the pinion to be pushed back away from the ring gear
  - d. the armature to increase speed output

### **ELECTRIC STARTER MOTOR REMOVAL, DISASSEMBLY, COMPONENT TESTING, AND INSTALLATION**

One of the last things to be done when diagnosing a starting system problem is to remove the starter. However, if a proper troubleshooting procedure has been followed and there appears to be a problem with the starter motor, then it must be removed. Electric starting system troubleshooting procedures are discussed later in this chapter.

The following are key points to remember when replacing a starter:

- Always disconnect the battery cables from the battery first.
- Clean the area around the starter because the flywheel housing may be wet (be part of a drivetrain fluid system) and any dirt that drops into the housing will now be circulating through drivetrain components.
- Always mark the wires as they are removed.
- Starters can be awkward and heavy to remove so call for help or attach a lifting device before the last bolt is taken out.
- Put the old and new starter side by side to make sure that you have the right one (all terminals are the same) and the nose piece is oriented correctly.
- Make sure that you have the right mounting gasket if required.
- Support the main battery stud with a wrench when tightening the battery cable terminal nut.
- Clean any dirty terminal before installing and put protective covers back over terminals.

The ring gear should always be inspected when a starter is removed to look for excessive wear. Although the ring gear will likely be in its normal resting position, the engine should be rotated by a helper while the whole ring gear is inspected.

**BENCH TESTING AN ELECTRIC STARTER** A starter bench test should be done after any starter is removed. This will require the starter to be put in a vice to hold it securely. First, check the drive mechanism to see if it turns free in one direction and locks in the other. The gear should also be inspected for excessive wear. A power source is then connected to the starter B+ terminal and a ground to the starter housing and the S terminal is energized. The pinion should be pushed out firmly. When the pinion is turning, a tachometer can be used to measure no load speed and an ammeter can measure current draw. A typical no load current draw is 75–150 amps and a maximum speed could be as high as 5000 rpm depending on the starter. These two measurements can then be compared to specifications. If the measurements are out of spec, then consider the following causes:

#### Diagnose No-Load Test

Fails to Operate—Low Current Draw (approximately 25 amps)

- Open series field circuit
- Open armature windings
- Defective brush contact with commutator

Fails to Operate—High Current Draw

- Grounded terminal or fields
- Seized bearings

Low Speed—Low Current Draw

- High internal resistance
- Defective brush contact with commutator

Low Speed—High Current Draw

- Excessive friction
- Shorted armature
- Grounded armature or fields

High Speed—Low Current Draw

- Open shunt field circuit

High Speed—High Current Draw

- Shorted series field coils

If the measurements are within spec and the drive appears good, then you should think twice before installing a new starter.

Once a starter is removed and found to be defective, it will most likely be replaced with a new or exchange unit. However, sometimes a situation may call for a starter to be reconditioned by the HDET who removes it.

The following is a list of starter components that should be tested and the kind of test done. You should always consult the starter manufacturer's service information for the particular starter you are working on.

- Field coils: Check for opens and shorts.
- Armature windings: Check for opens and shorts (growler tool is used).
- Armature commutator: Check for shorts, insulation depth, and bar appearance. If necessary, clean up with crocus cloth or fine sandpaper (do not use emery cloth).
- Armature condition: Check for shaft straightness and bearing mount surface.
- Solenoid: Check for opens and shorts, energize, and check that it pulls in plunger.
- Drive shift mechanism: Check for positive movement both ways.
- Brushes: Measure length.
- Brush holder: Check for brush to base ground.
- Brush springs: Check tension.

After reconditioning the starter, perform a no-load test to confirm that the starter is okay to install on the machine.

Starter motor installation requires all fasteners to be torqued to specification and wires to be secured to prevent insulation wear through.

**BATTERY CABLES—SIZING, REPAIR** Due to the fact that the starting circuit is the highest current drawing part of a machine's electrical system, it is critical that the battery cables and connections that run between the battery system and the starter are sized right and are in good condition. Any less than ideal sizing or connection condition will create excessive resistance, which will translate into a voltage drop and slow cranking. Battery cables are purposely large to give very little resistance to current flow. Usually, this resistance is less than 1 milliohm. ● **SEE FIGURE 7-20** for a chart that indicates minimum cable size for a given length and system voltage.

Ideally batteries should be located as close as possible to the machine's starter. This is not always the case though and some machines will have cables over 20 ft long. These cables will be subject to vibration and damaged from other machine parts. Part of an HDET's duties will at some point include repairing or replacing battery cable assemblies. Care should be taken relating to the following points:

- Proper cable sizing (diameter) to avoid unnecessary resistance. It is better to oversize cables if you are unsure.

## Determining Starting Circuit Cable System Cable Size

		Total Cranking Circuit Length in Inches									
System Voltage and Type	Maximum Circuit Voltage Drop Per 100 Amps	100		200		300		400		500	
		12-Volt High-Output Heavy-Duty (4.5–7.8 kW)	w/Single Path** to-and-from Starter 0.075 Volts	00	000	In Parallel					
w/Dual Path* to-and-from Starter 0.075 Volts (0.150 per LEG)	00		000		In Parallel						
12-Volt Super Heavy-Duty (7.9–8.5 kW)	Single Path** 0.060 Volts	00	000	0000 or 2-0	2-00	2-000	2-0000	2-0000 Positive Cables 2-0000 Negative Cables			
	Dual Path** 0.120 per LEG	00		000		0000		In Parallel			
24-Volt Heavy-Duty (7.5–9.0 kW)	0.20 Volts	6	4	2	1	0	00	000	In Parallel		
								0000 or 2-0	2-0		

\* See Fig. 1: Dual Path Circuit  
\*\* See Fig. 2: Single Path Circuit

**Note:** Cable Should meet or exceed SAE J1127.

**FIGURE 7-20** Minimum cable size for length and system voltage.

- Proper terminal to cable installation to ensure longevity and corrosion protection.
- Proper cable security. Battery cables should be secured every 18–24 in. to prevent insulation being worn off from other parts rubbing on it. ● **SEE FIGURE 7-21** for how a battery cable should be secured.
- Seal all connections to prevent corrosion. There are many types of electrical connection sealants. Be sure to use one after installing battery cable terminals or connections.

Some tools and equipment required to make battery cable repairs are as follows:

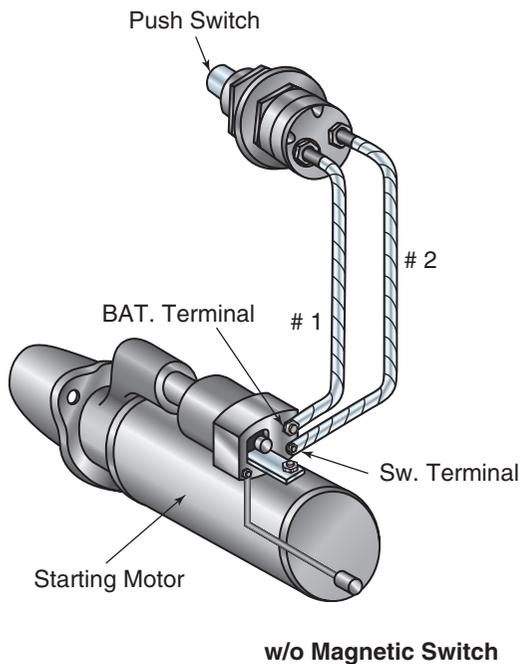
- Heavy-duty cable cutter
- Heavy-duty insulation stripper
- Heavy-duty terminal crimper
- Propane torch
- Solder
- Shrink tube
- Terminals

**STARTER CONTROL CIRCUIT** The starting control circuit can be a very simple series circuit with a key or push button switch in the cab that is fed power from a fuse. It will



**FIGURE 7-21** A properly secured battery cable.

then send power to the starter solenoid when the key or push button switch is closed. ● **SEE FIGURE 7-22** for a simple starter control circuit. Most starting circuits will use a relay between the control switch and the starter solenoid. This will be the case on all but the smallest machines. The relay will be used to handle higher current flow that needs to go to the starter solenoids on larger starter motors. Some very large starters could even have two relays between the switch and the solenoid.



**FIGURE 7-22** A simple starter control circuit.



**FIGURE 7-23** A keypad used to start a machine.

Control circuits can also be very complicated and include several switches, relays, sensors, and ECMs. Many machines today that use electronic controls will use keypad buttons to control the starter control circuit. This could incorporate a security system where the operator has to key in a password before the machine will start. ● **SEE FIGURE 7-23** for a keypad used to start a machine.

Other starting circuit features that could be part of an electronic system are as follows:

- If the ECM sees that the engine is turning more than 300 rpm, it won't allow the starter to engage.

- If the starter has been running longer than 30 seconds at a time, it will stop the starter cranking the engine and not allow it to engage for 60 seconds to allow it to cool down.
- Fault codes can be generated such as when the control circuit sends a signal to the starter relay, but there is no engine rpm sensed at the engine speed sensor.

The starter control circuit could tie into other machine electrical circuits such as hydraulic, drivetrain, and lighting. Some examples of what this interaction might do are as follows:

- The hydraulic pump could be electrically de-stroked to decrease the load on the starter.
- The work light circuit could be de-energized to provide more current for the starter.
- The transmission neutralizer circuit could be actuated to ensure that the transmission doesn't try to drive the machine.
- The HVAC circuit could be de-energized to provide more current flow for the starter.

Different engine applications could call for an alternative starting system to the electrical one just discussed. The environment the machine is working in could be flammable and require a spark-proof machine or the cost of replacing batteries in extremely cold environments is seen to be excessive. One alternative is to use a dedicated air supply to spin an air-powered starter motor assembly.

There are some advantages to having an air driven starter. They are much lighter and, therefore, have a higher power to weight ratio than a comparable output electric starter. There is no chance of an air starter overheating from over-cranking. Because of their simple design, there is very little that goes wrong with them. The most problematic area that can cause trouble with an air starter assembly is excessive moisture in the air system that can freeze in cold weather.

One disadvantage is how fast the air supply is depleted when the starter is engaged. Most starting tanks will empty within 20 seconds. If the air tank does deplete before the engine starts, this means charging the tank with an external air source from a shop air line, other machine, or service truck.

An air starter will generate high cranking speed and torque so that under normal conditions the engine should start before the starter air tank runs out.

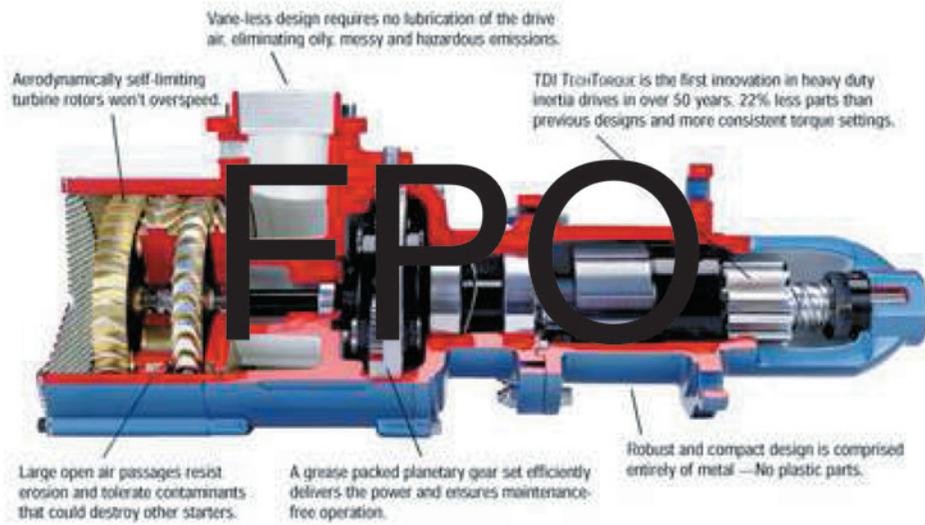
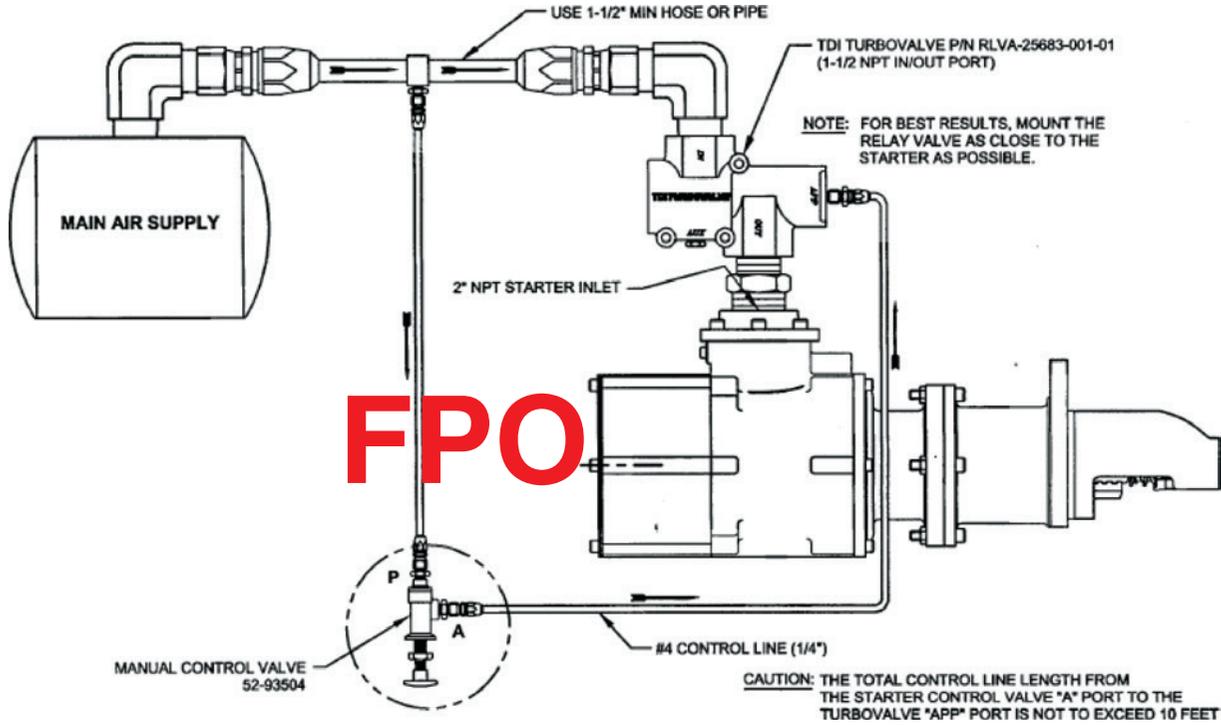
There are two main types of air starter motors. One is a vane type that uses sliding vanes in a rotor to convert air flow into mechanical movement. The other type is called turbine, and its rotation is created by air flow pushing on the blades of one or more turbine wheels.

If you look back to the chart comparing air, hydraulic, and electrical starting systems, the main differences are the energy supply, type of motor, air lines, and system control.

The machine will most likely have an air compressor to provide air for other pneumatic systems and to keep

the starter air tank charged up. Once the engine starts, it is then up to the machine's air compressor to recharge the starting tank and the machine's other supply tanks. The air starting tank will be charged to between 110 and 150 psi.

To send air to the starter, a relay valve will be controlled by an electric solenoid valve that is activated by the key switch or there could be a floor-mounted air relay valve to send air to the main relay valve. ● **SEE FIGURE 7-24** to see the arrangement of components for an air starting system. When the solenoid



**FIGURE 7-24** Components of an air starting system.

valve is energized, it will send air to the relay valve that will open to allow tank air into the starter motor. There are two main types of starter motors: vane and turbine. The motors create shaft rotation that usually has its speed reduced and torque increased through a gear reduction. The torque is then sent out through a drive pinion to engage with the flywheel. Vane-type motors will need lubrication and will usually have diesel fuel drawn into the motor inlet during starter engagement.

It is important to have clean dry air entering air starters and their control circuit. Problems with moist air are magnified in the winter with relay valves freezing and sticking. Air leaks and air restrictions are the only other concern with air starter systems. The motors will last a long time, and if they are found to be worn out, repair kits can be installed to renew the starter assembly.

Another nonelectric starting system is one that uses hydraulic fluid to rotate a hydraulic starter motor. The motor will then rotate a drive gear in the same manner as typical electric starters. Hydraulic start systems have an accumulator that keep

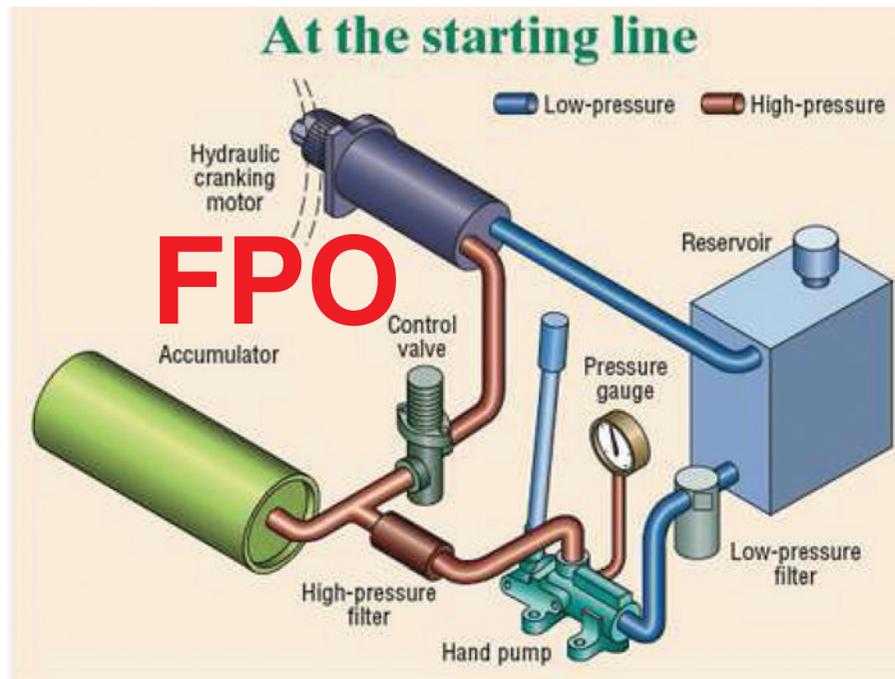
hydraulic fluid stored under pressure until needed. A control valve is actuated to send pressurized fluid to the motor to get the motor turning. The motor is a fixed displacement axial piston unit, and its shaft drives the pinion gear directly. ● **SEE FIGURE 7-25** for a hydraulic starting system. The control valve could be floor mounted, cable operated, or controlled electrically through an LCD screen touch pad called a human-machine interface (HMI).

The accumulator for this system has a pre-charge of 1500 psi of nitrogen, and when the oil is pumped into it, the pressure builds to 3000 psi.

This system will have a backup hand pump that could be used to charge the accumulator.

If the system doesn't operate, then just like an electric or air system, perform a good visual inspection. Then check the accumulator pre-charge pressure and the oil pressure after the accumulator has been charged. If these pressures are good, then look for restrictions or leaks past the accumulator toward the control valve. Make sure that the valve is moving as it should, and if there is still a problem, you may have to install pressure gauges throughout the system to see if there is oil pressure getting past the control valve.

As with any fluid power system, cleanliness is crucial so check for fluid contamination. For information on accumulator service and repair, refer to Chapter 16.



**Simplified representation of the components in the Hydrotor starting system.**

**FIGURE 7-25** A hydraulic starting system (Courtesy of Kocsis Technologies Inc.).

# STARTING CONTROL CIRCUIT INTERLOCK SYSTEMS

Most machines will have some kind of safety-related or damage-preventing system that will not allow the engine to either crank over or start under certain circumstances. There could be one or more conditions that have to be met before the operator's input to try and start the machine will result in a signal going to the starter solenoid. This could be done with a simple two-position switch or with several switches and one or more ECMs. The interlock system will likely be part of the starter control ground side but could be on the positive side. It will complete that part of the circuit by closing switches or changing sensor values.

Here are a few examples of things that may need to be satisfied:

- Seat belt fastened
- Safety bar lowered
- Door closed
- Operator in seat
- Gear selector in neutral
- Hydraulic controls in neutral
- Parking brake engaged
- Password entered

All these conditions can be verified with switches, sensors, or a keypad. There may also be certain active fault codes that won't let the starter engage. One example might be that the engine oil level switch or sensor may indicate low oil level and be setting an active fault code. Until the oil is topped up or the sensor repaired, the machine will not start.

The starting system's interlock system must be satisfied before it will let the starter engage.

If you are unfamiliar with a machine, you should read the operator's manual to see what switches or sensors need to change state to let the starter solenoid be energized.

To know if the interlock system is letting the starter solenoid get energized, you could confirm the solenoid is receiving power to the S terminal. To do this, connect a multimeter positive lead to it with the meter's lead going to a good ground and have someone try to start the machine.

To troubleshoot a problem with a machine's **starter interlock** system, you should be referring to the machine's electrical schematic. The schematic will tell you all the sensors, switches, and wire numbers that are part of the system.

Relays were looked at in Chapter 5 but a quick review here is beneficial. A relay will be part of two different circuits. One part will be a control circuit that gets energized by the operator's starter control circuit. This is the low current flow part of the relay and is simply a coil of light gauge wire that will create a magnetic field when energized. The second part of the relay is the high current section that will have a constant power feed that will get sent out of the relay depending on the state of the relay's control circuit.

When the control coil is energized, the magnetic field created will close the switch or contacts on the high current side.

The most common relay will have terminal numbers that indicate the part of the relay they are connected to. ● **FIGURE 7-26** shows the terminal numbers for this common relay.

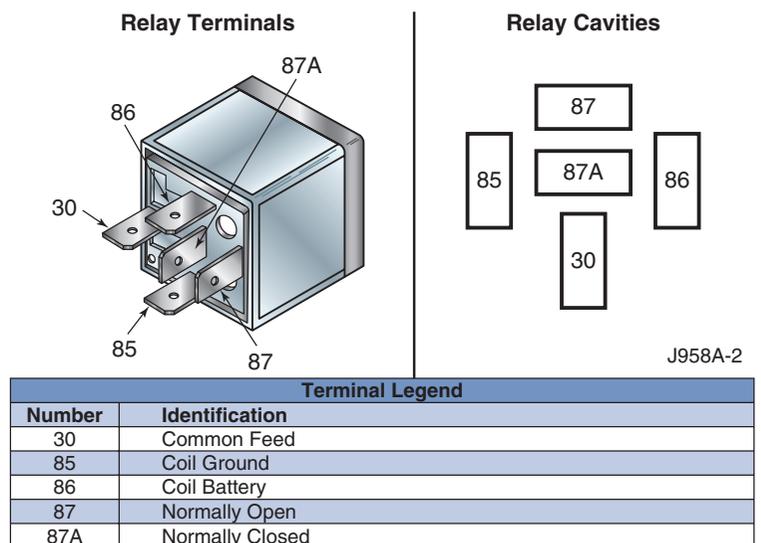
Some large starters will need a heavy-duty relay like the one shown in ● **FIGURE 7-27**.

Some relays are internally grounded, meaning the control coil has one end of it connected to the housing of the relay. This means the relay body must be grounded.

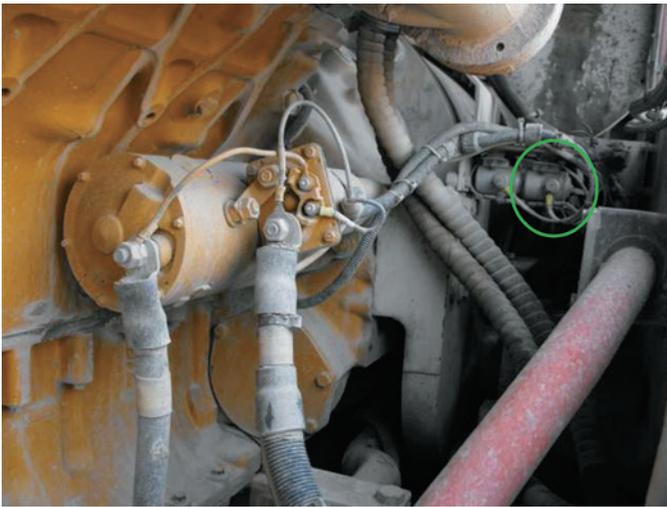
Some starters will have a relay mounted directly on them, and these are usually called integrated magnetic switches (IMS).

Starter relays are sometimes overlooked as a problem part of the starting circuit. They are fairly easy to troubleshoot once you understand how they work. Sometimes the hardest part is finding them!

A simple check is to have someone try to start the machine while you listen and feel for a "click." This will tell you that



**FIGURE 7-26** Terminal numbers for a common relay.



**FIGURE 7-27** A heavy-duty starter relay.

at least the relay is getting energized and the control coil has a good ground. If you hear a click, then check the voltage at the high current supply. If this is good, then check the high current output for voltage while someone tries to start the machine again. You could check for an excessive voltage drop across the high current terminals of the relay. If this checks okay, then the starter solenoid should be getting voltage if there are no wiring issues.

The basic steps of troubleshooting should be followed here and as always start with the following.

**VERIFY THE COMPLAINT** The two most common problems you will hear about with a starting system are no cranking and slow cranking. To some operators, not starting means not cranking, and in any case, where there's a starting complaint, you need to see for yourself what is happening. If the problem is happening now, then get the operator to show you. If the problem is intermittent, then ask when and under what conditions the problem is occurring. You can try to recreate it or you may have to return at another time.

Always check to see if the problem isn't simply part of the starting interlock system or that there is extra resistance to cranking the engine being caused by other factors (wrong engine oil viscosity, hydraulic system load, drivetrain load).

Once you have verified there is a starting system problem, then you can move on to diagnose it.



#### TECH TIP

For any type of starting system, when diagnosing a no crank problem and you try to engage the starter, you should listen and feel for the starter solenoid actuating. If you hear and feel a heavy clunk, this should tell you the control circuit is good, the solenoid is working, and the starter may be trying to turn over a seized engine. To confirm this, closely watch the crankshaft vibration damper when the solenoid is actuated. This will require some extra help. If the damper moves slightly, there's a good chance the engine has some serious issues.

You should also turn on some work lights to see if they dim while trying to crank the engine. If they dim, this should tell you the starter motor is drawing current.

**CHECK THE SIMPLE STUFF FIRST** There are many checks you can make before getting any tools out. A good HDET sensory check (look, listen, smell, feel) may detect the problem. Visually look for loose or corroded cable and wire connections, battery defects (cracked case, missing vent cap, dirty top, loose/broken/missing hold down), loose starter mounting fasteners, loose switches or relays, and loose or broken control switches. With electrical systems your nose may tell you that the starter has been overheated or some wiring has melted. Carefully feel for hot wires and components. Air and hydraulic systems should be carefully checked for leaks. Never use your bare hands to check for air or hydraulic leaks. Use a piece of cardboard or wood. Check to see if there are other electrical system problems by turning on lights, wipers, or fans.

**CHECK THE BATTERY SYSTEMS** The battery condition and charge state should always be confirmed when looking into any starting problem. After a thorough visual inspection (checking electrolyte level if possible), check open circuit voltage (OCV) of the battery systems. This should be a minimum of 12.4V for a 12V system and 24.8 for a 24V system. See Chapter 5 for more details on battery testing. If OCV is good, perform a load test or electronic battery condition test. If the battery condition indicates it needs a charge, then hook up a charger and start the charging process (see Chapter 5 for details).

Once a good battery condition has been confirmed and a visual inspection of the rest of the system hasn't uncovered any defects, then you can move on to determining whether the problem is in the starter control circuit or the main power circuit. This will be done with available voltage checks.

Checking voltage at the starter solenoid is a good place to start. Have an assistant try to start the engine while you are checking for voltage at the S terminal on the starter solenoid. If there is battery voltage at the S terminal, then you need to focus on the starter assembly and battery cables. If there is

less than battery voltage, you will need to focus on the starter control circuit.

Once you have decided which part of the system is defective, you should be checking for available voltage and good ground through the system. Voltage should be very close to battery voltage, but if you find voltage and it is less than it should be, then you should start performing voltage drop testing throughout the control circuit. This will be done with the circuit energized. You are looking for excessive voltage loss that will indicate high resistance. The likely places for this are connection points such as wiring harness connectors and switch or relay terminal. ● **SEE FIGURE 7-28** for how to check for voltage drops through the starter control circuit.

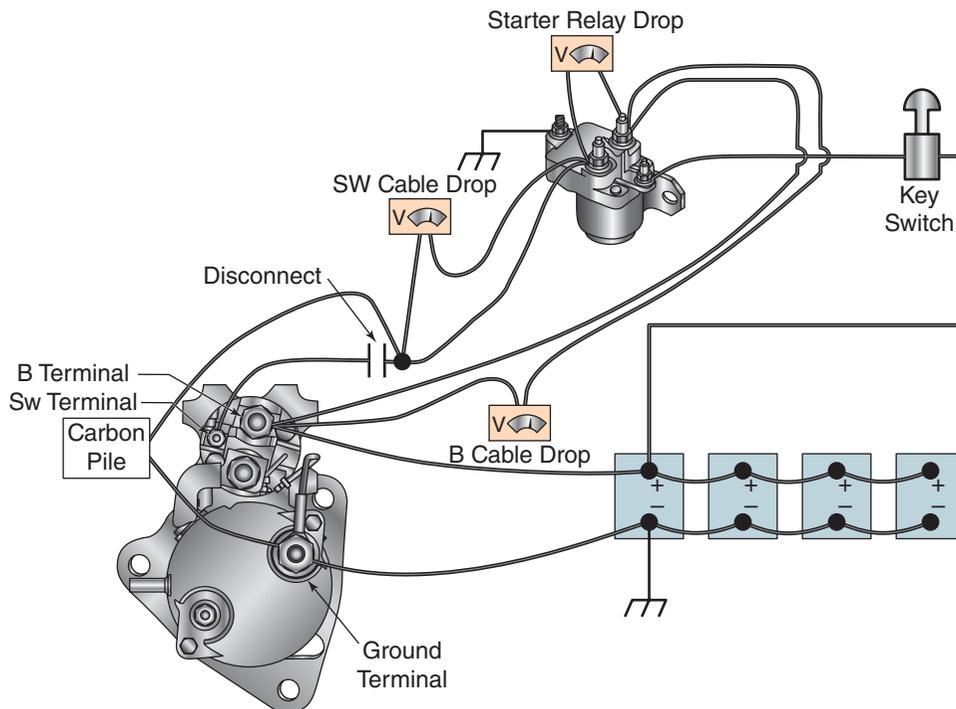
The control side is all about sending power to the S terminal but relays will need a good ground to operate. Some likely problems in the control side are the following:

- Faulty key switch
- Faulty interlock switches/sensors
- Faulty relay(s)
- Loose, corroded, broken, or dirty wires
- Open circuit protection device

If you find the problem is past the S terminal, then keep in mind that the starter motor needs voltage from the solenoid and a good ground back to the battery. A quick way to determine if battery cables, the master switch, or any connections

### SAFETY TIP

At this point in the diagnosis it will be tempting to "jump the starter." This means using a jumper wire to energize the S terminal from the B+ terminal on the solenoid. This is how many people have been injured or killed over the years. Try to avoid this at all cost. If you insist on doing this, you must ensure that the fuel system won't inject fuel and that the drivetrain and hydraulic system are neutralized if the engine is cranked over by jumping it. There's also the possibility of causing electronic component damage when jumping circuits.



**FIGURE 7-28** How to check for voltage drops through the starter control circuit.



## TECH TIP

Most heavy equipment machines will have a battery **disconnect switch** (sometimes called master switch). It is usually on the ground side but is occasionally on the positive side of the system. These heavy-duty switches take a lot of current flow and are often overlooked when diagnosing a starting problem. A simple voltage drop test across the switch terminals will detect a problem. There should be no more than a 0.2V drop for a 24V system and no more than a 0.1V drop for a 12V system.

are a problem is to bypass all this with a good set of booster cables. Take care not to cause sparks near the battery when doing this. You will be going from the battery system's positive to the starter B+ terminal and from the battery system's negative to the starter ground post or starter housing. If this temporary battery cable arrangement gets the engine cranking, then you will have a better idea where the problem lies. You could then take one cable off at a time and try it again. Remember to disconnect at the starter first and be careful with the live cables.

If all cables, connections, and the master switch check out fine and the starter still won't engage when the S terminal is energized, then you should take the starter off and bench test it.

Some problems that you may find with the starter assembly and battery cables are as follows:

- Loose, broken, corroded, dirty battery cable connections
- Faulty starter drive

- Loose starter mounting fasteners
- Worn ring gear teeth
- Faulty motor components

For a no crank problem with either an air or a hydraulic starting system, the same general diagnostic procedure applies. Determine if the problem is in the starter control or the starter motor energy supply circuit. Pressure checks may need to be done with gauges to see how far pressure is getting.

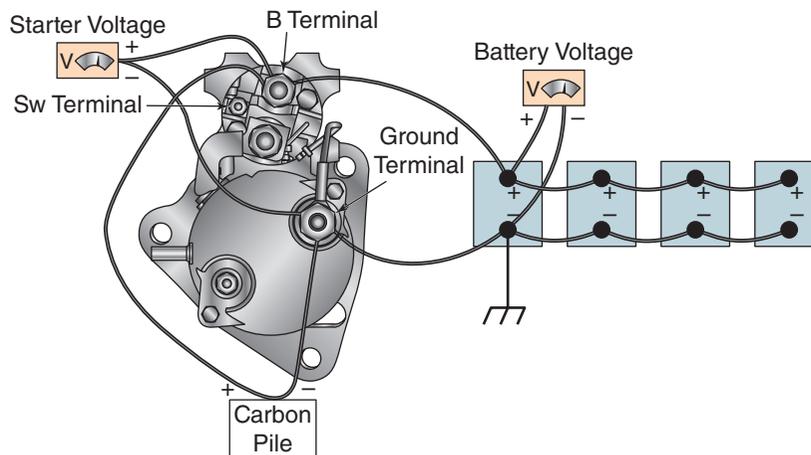
**CHECK FOR SLOW CRANKING** To verify a slow cranking problem, you may need to measure engine speed with a tachometer or it may be obvious enough that you don't need to. You should be able to find a spec for minimum cranking speed at a certain ambient temperature.

If the cranking speed measures slow, then you must determine if the problem is because of too much resistance against the crankshaft.

Don't forget the simple stuff first and battery testing before moving into instrument testing.

Because the starter is getting engaged, you can assume the control circuit is working properly. The main test you will perform is a voltage drop test. This will be the best way to confirm wire and connection condition because you will perform it with the wire's conducting current.

● **FIGURE 7-29** shows where to connect your voltmeter to perform a voltage drop test. This test is to see how much resistance there is in the battery cables and their connection points. A carbon pile-type load tester is used to create current flow. This is preferable to using the starter for a couple of reasons. First, safety wise there is always the possibility of injury if you are near rotating



**FIGURE 7-29** Where to connect a voltmeter to perform voltage drop testing on the high current part of the starting system.

parts if the engine is cranking. Second, the carbon pile is an adjustable steady load that will give a more accurate result when using the starter for putting a load on the high current circuit.

● **SEE FIGURE 7-30** for the maximum allowable voltage drops for different locations in a 12V and 24V system.

If you find one part of the circuit to have an excessive voltage drop, you should be able to isolate the part of the circuit to see exactly where the high resistance is.

Once the problem is found and you make the necessary repairs, then try to start the engine and see if the cranking speed is normal.

LOCATION	12V	24V
Negative battery post to the starting motor negative	0.5 volts	1.0 volts
Drop across the disconnect switch terminals	0.5 volts	1.0 volts
Positive battery post to the positive terminal of the starting motor	0.5 volts	1.0 volts
Solenoid "Bat" to the solenoid "Mtr" terminal	0.2 volts	0.4 volts
Across starter relay load terminals	0.3 volts	0.6 volts

**FIGURE 7-30**

Maximum allowable voltage drops for different parts of the circuit.



## CASE STUDY

Fred was sent out to a machine for a starting complaint issue. When he arrived at the machine, it was working so he asked the operator what the problem was. The operator told Fred that lately he has had to work the key on and off several times to get the machine to start. Once the starter engages, it starts fine. Fred asks the operator if he can try it, and when Fred tries to start the machine several times, it starts without hesitation. Fred asks the operator when the problem occurs, and the operator says it can happen anytime he tries to start the machine. Fred performs a quick visual inspection of the machine's batteries, wiring, relay, and starter and finds everything looking normal. He then takes a few minutes to look at the electrical system service information and schematics related to the start circuits. He finds information on the starter interlock system and reads through the troubleshooting tree to be prepared for when the machine won't start again.

Fred has the operator call him the next time it won't start and asks that the operator not try to get the machine going before he gets to it. A couple of days later Fred gets a call and gets to the machine as soon as he can. He verifies that the machine won't start and begin his diagnostic procedure. He has a quick look around for anything obvious and checks to see if any other electrical circuits are not operating by trying lights, HVAC fan, wipers, and horn. This will also take any surface charge off the battery. Everything seems to be working as it should except for the

starter. He checks battery OCV and finds it to be 12.5V, which indicates a good charge.

Fred then asks the operator to get ready to start the engine. Fred attaches the positive lead of his voltmeter to the S terminal and the negative to a good frame ground and gives the operator the signal to start the machine. The display on the meter reads 0V. Fred then begins to work back through the circuit to see where the problem is.

He finds the starter relay and checks for available voltage at the high current terminal and reads 12.3V. He again asks the operator to try start the engine and finds that there is 12.3V at the relay low current in terminal and doesn't hear it click.

He then checks for continuity to ground from the relay low current ground terminal with the meter set to ohms. The display reads OL (overloaded) but changes to 0 ohms when the wire is jiggled. When Fred pulls on the wire, it separates from the wire end terminal. When a temporary jumper is installed to give the relay a good ground, the machine starts fine.

Fred makes a new wire, installs it, and seals the terminals with an electrical sealer. When the operator tries to start the machine several times, the starter engages each time.

This is an example of a starting system problem diagnostic procedure that shows a typical diagnostic and repair procedure.

## Progress Check

11. These are two values measured during a starter bench test:
  - a. no load torque and speed
  - b. no load speed and voltage
  - c. no load speed and current draw
  - d. full load speed and current draw
12. This is the largest battery cable size:
  - a. 0
  - b. 00
  - c. 1
  - d. 2
13. The purpose of the starter interlock system is to:
  - a. stop the engine from cranking until one or more safety-related conditions are met
  - b. lock the starting pinion out for a minimum of 15 seconds
  - c. lock the flywheel in place for security reasons
  - d. prevent the machine from starting if the operator has been drinking
14. A machine that has a starter relay will use it to:
  - a. shift the drive pinion out
  - b. send current to the S terminal on the starter solenoid
  - c. increase current flow to the starter motor
  - d. switch the G terminal at the starter solenoid
15. This is the first step in troubleshooting a starting system complaint:
  - a. check battery voltage
  - b. listen for the solenoid clicking
  - c. check starter current draw
  - d. verify the complaint
16. This testing tool will verify a slow cranking problem:
  - a. voltmeter
  - b. tachometer
  - c. ammeter
  - d. ohmmeter
17. The faster a starter motor turns:
  - a. the less CEMF that is generated
  - b. the more torque that is generated
  - c. the less current that is drawn from the battery
  - d. the more current that is drawn from the battery
18. A starter's brushes will transfer current between:
  - a. the solenoid and the motor
  - b. the individual field coils
  - c. the field coils and the armature windings
  - d. the hold-in and pull-in coils
19. If a voltage drop test is done and the result is outside of specification, this means:
  - a. the battery needs to be charged
  - b. there is a bad ground
  - c. there is a short
  - d. there is excessive resistance in the circuit
20. When diagnosing a no crank problem and you find sufficient voltage being supplied to the S terminal but the starter doesn't turn, you can safely say:
  - a. the control circuit is operating fine
  - b. the brushes are worn out
  - c. the armature is grounded
  - d. the battery terminals are loose



### SHOP ACTIVITY

Go to a machine with an electric starting system and list the main components of the system. Draw an electrical schematic showing the main components of the starting system. Describe a step-by-step procedure to replace the starter. Inspect the battery cables leading to the starter and record any defects. Are there any safety interlock devices to prevent the starter from engaging? If yes, test these devices to ensure that they are working properly.

## SUMMARY

1. Some safety concerns related to starting systems are battery explosion risks, burns from overheated wires, strains from lifting heavy components, and injuries related to sudden release of stored energy.
2. Diesel engine starting systems need to produce torque that will turn the engine's crankshaft fast enough to start the combustion process. This is usually between 150 and 250 rpm.
3. Some older engines used a "pup" engine to crank the diesel engine. They were a small gasoline engine that drove the flywheel pinion through a transmission.
4. Most starting systems use DC electric motors to drive a pinion gear to rotate the engine's flywheel.
5. They can be 12V or 24V motors, and all starter motor output torque gets increased because of the gear ratio between the pinion and the flywheel. Usually, this is 20:1.
6. For larger diesel engines, they will need more powerful starter motors to crank them. Some engines will use two starter motors.
7. Other factors that necessitate larger starter motors are cold engine oil, engine driven accessories, and electronically controlled engines.
8. Overheating electric starter motors is the leading cause of failure. *Do not* engage a starter for longer than 15 seconds straight. Wait two minutes to allow the starter to cool.
9. Electric starter motors are the most common type used on heavy equipment. Other types are hydraulic and pneumatic.
10. Electric starter assemblies convert electric DC into rotational torque output at the starter pinion gear. The gear engages with the engine's flywheel ring gear.
11. Two types of electric starter motors are direct drive and gear reduction.
12. DC brush-type motors use current flow to create opposing magnetic fields, which in turn rotate the motor shaft.
13. The motor housing has field coils and pole shoes that create one field. Arranged in pairs on opposite sides of housing.
14. Armature rotates in center of housing and has many separate loops of heavy copper wire laid into grooves of laminated steel core.
15. Armature is fed current through brushes to commutator bars.
16. Each loop on the armature creates the second magnetic field when current flows through it.
17. Starter motors are designed to make maximum torque at low rpm and are self-limiting speed wise by CEMF (counter-electromotive force).
18. Starter solenoids will move the starter pinion into the flywheel and close a set of contacts to send current to the starter motor.
19. Solenoids have two windings: **pull in** and **hold in**.
20. Some starters feature an OCP (over-crank protection) switch that disengages the starter if it overheats.
21. Most starter pinions incorporate an overrunning clutch that prevents the engine's flywheel from driving the starter pinion.
22. Starter replacement requires cleaning area, marking wires, carefully removing wires, using a lifting device if necessary, cleaning gasket area, and torqueing all fasteners to spec.
23. Bench testing starters requires a power source and connecting starter. Operate starter and measure pinion rpm and current draw.
24. Many problems can be traced to bench test results that aren't in specification.
25. Further diagnostics can reveal starter component problems. Reconditioning starters is mostly left to specialty shops.
26. Starter/battery cable sizing is critical to proper operation of starting system. When replacing existing or installing new cable, *do not* undersize cable. Make sure that cables are secure.
27. Starter control circuit will allow operator to send current to starter solenoid.
28. Pneumatic starting systems use compressed air as an energy source and an air-powered motor to provide pinion drive torque. Provides plenty of torque but will deplete air supply quickly and can freeze up.
29. Hydraulic starting systems use pressurized hydraulic fluid that is stored in an accumulator to rotate a hydraulic motor. The motor output then turns a pinion gear.
30. Starting circuit interlock systems prevent engine cranking unless certain conditions are met such as seat belt is latched, doors are closed, and transmission is in neutral. They will keep the solenoid circuit open.
31. Relays are a common part of starter control circuits.
32. Starting system troubleshooting starts with verifying the complaint. If there is an interlock circuit, make sure that it is not open.
33. Voltage drop testing is done with current flowing through circuits and will determine if there is excessive resistance.