CHAPTER 17

Charging and Starting Systems

Outcomes

After studying this chapter, you will be able to:

- ✓ Describe the construction and operation of an automotive battery.
- ✓ Explain the major parts and operating principles of a charging system.
- ✓ Explain the major parts and operating principles of a starter system.

This chapter will cover the fundamentals of vehicle charging and starting systems. The charging and starting systems are vital to the operation of almost every system on the vehicle. Without the electrical components discussed here, the ignition system, fuel injection, emission controls, electronic control module, air conditioner, lights, and radio would not be functional. Studying this chapter will give you an understanding of a vehicle's battery and the charging and starting systems. These systems are the foundation for all other electrical equipment in the vehicle.

Battery

An electric current can be produced by a ***lead-acid battery***. The battery stores this energy in chemical form until it is needed. The main purpose of the battery is to supply current for the ignition system and starter motor until the vehicle is running. The battery also acts as a source of extra power for the vehicle's electrical system. The various components of the battery are discussed here.

Battery Cells

A battery is constructed of separate elements, or ***cells***, **Figure 17-1**. Each cell is made up of two groups of plates. Each battery cell has an open circuit voltage of two volts. Total battery voltage is determined by the number of cells. One group of plates forms the positive group; the other forms the negative group. The number of plates does not affect open circuit voltage.

Battery Cell Plates

The ***positive plate*** is a grid (wire-like, skeletal framework, made of lead and antimony or of lead and calcium), filled with lead peroxide (PbO_2) in sponge form. The ***negative plate*** is filled with porous lead (Pb) and expanders to prevent the lead from returning to an inactive solid state. Both are sandwiched together so that a negative group is next to a positive group. The plates are arranged alternately: negative, positive, negative, positive, and so on.

Insulating ***separators*** of nonconducting plastic, rubber, glass, cellulose fiber, or other material are placed between each set of plates. The separators keep the plates from touching each other and short circuiting. **Figure 17-2** illustrates a battery cell's positive and negative plates with separators. Note how the elements are kept away from the bottom of the container. This allows room for shedding plate material to deposit in the form of sediment. If this sediment touches the plates, it will cause a short circuit.

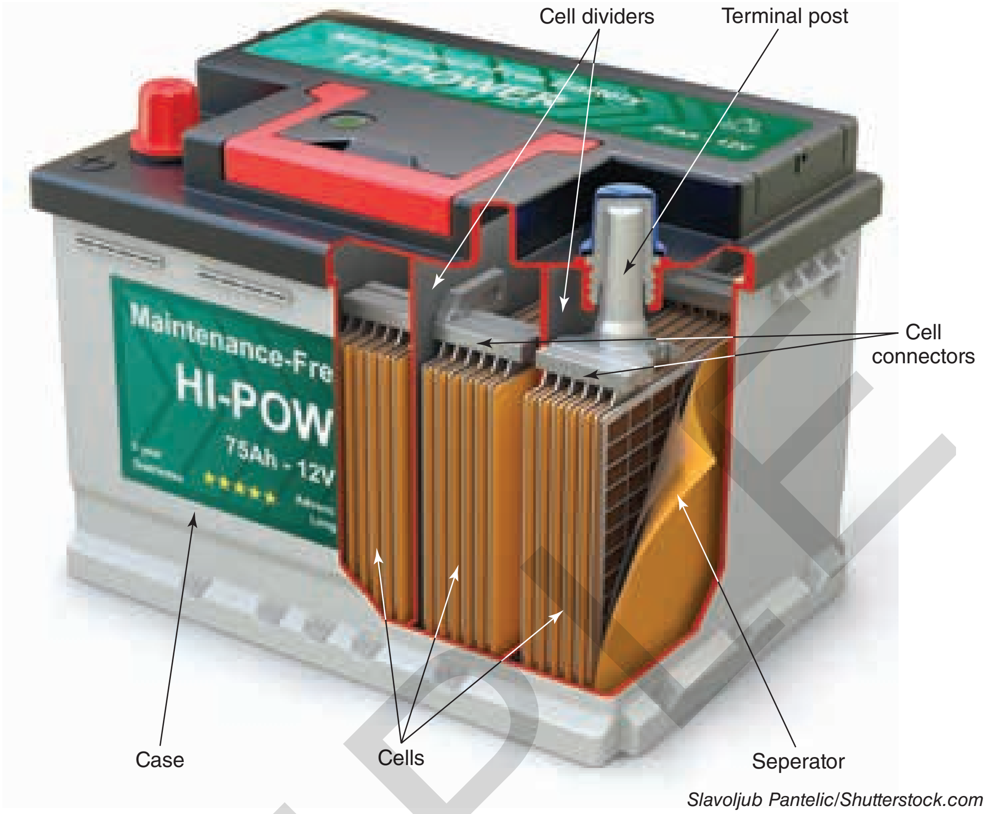

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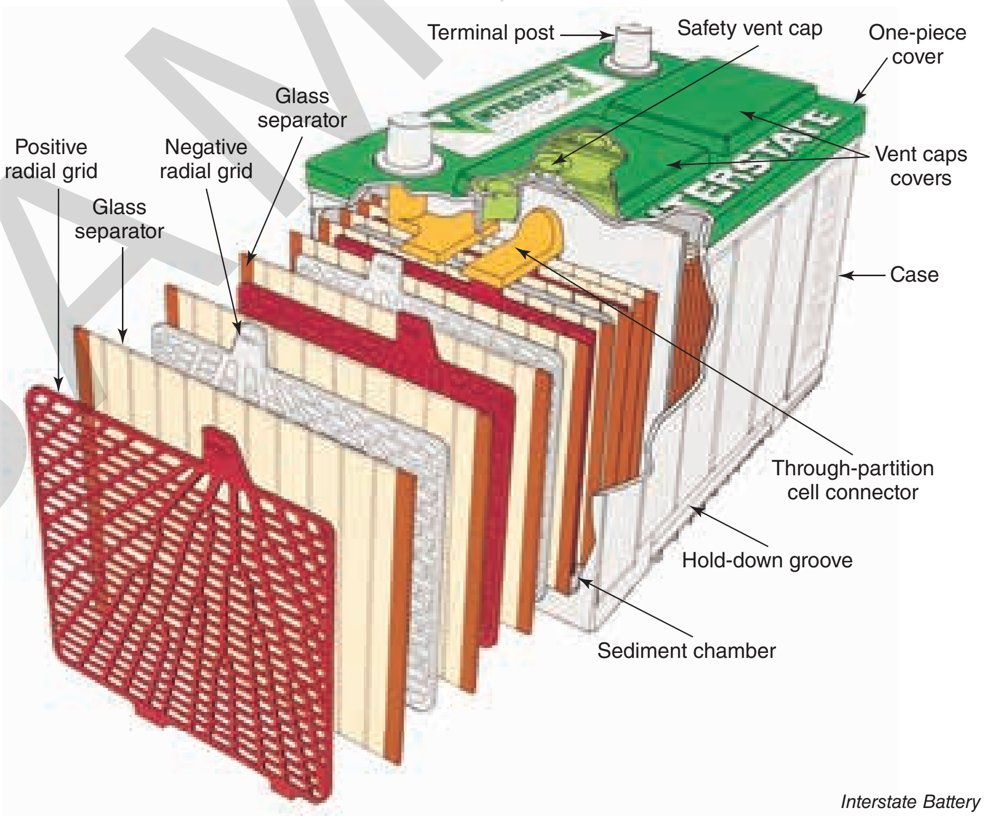
Figure 17-1. Cutaway of a 12-volt battery. Note the arrangement of cells (each one supplies approximately two volts), cell connectors, and seperators.

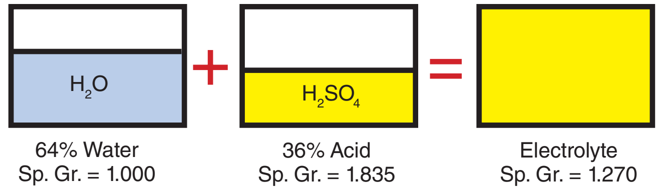


Interstate Battery

Figure 17-2. Typical 12-volt maintenance-free battery construction. Note the relative positions of the positive and negative grids and the separator plates.

Electrolyte

The cell components are assembled in a hard rubber or plastic (such as polypropylene) battery box or case. The case has partitions to divide it into six compartments or cells. The cells are filled with an ***electrolyte*** solution made up of about 64% distilled water (H_2O) and 36% sulfuric acid (H_2SO_4), **Figure 17-3**. The electrolyte will slightly cover the top of the plates. The sponge-form lead peroxide and porous lead allow the electrolyte to penetrate the positive and negative plates.



Deere & Co.

Figure 17-3. Chemical composition of battery electrolyte. Note the specific gravity of water compared to the sulfuric acid and the final electrolyte solution.

Absorbed Glass Mat Batteries

Many modern batteries use absorbed glass mat technology. An ***absorbed glass mat (AGM) battery*** does not have liquid electrolyte filling the battery cells. Instead, it uses fiberglass mats impregnated with liquid electrolyte. Absorbed glass mat batteries are sometimes called *AGM batteries*.

Spiral-Wound Absorbed Glass Mat Batteries

Like a conventional absorbed glass mat battery, a spiral-wound AGM battery has six cells that produce approximately two volts each. In each cell, the plates and glass mat separator containing the electrolyte are tightly wound into a tubular shape, **Figure 17-4**. Because the winding process tightly compresses the plates and mat, the chemical reaction can occur quickly to deliver more electrical power when needed. This battery design also allows brief high-current discharges for operation of power sliding door and tailgate motors, power windows, power locks, and other devices that are often used when the engine is not running.

Absorbed glass mat battery charging procedures may be different from those for conventional batteries. Consult the proper service information before charging or jump starting an absorbed glass mat battery.

Battery Construction

Figure 17-5 shows how each cell is fitted into the individual compartments. Because each element produces around two volts, 12 volts will be produced when they are connected

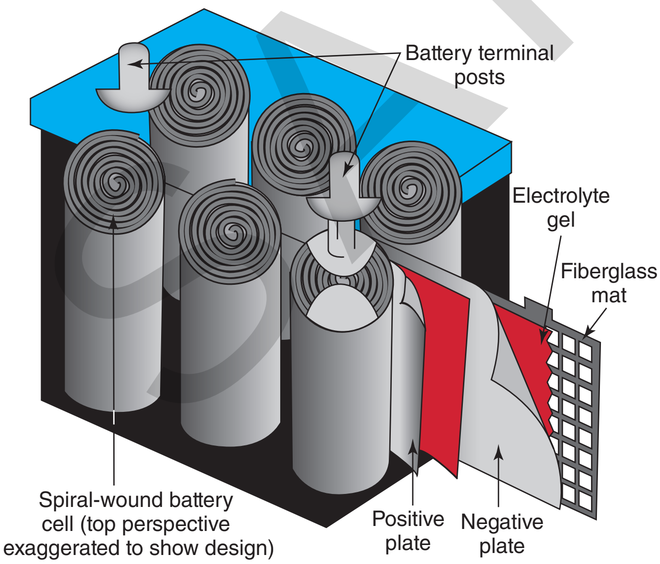


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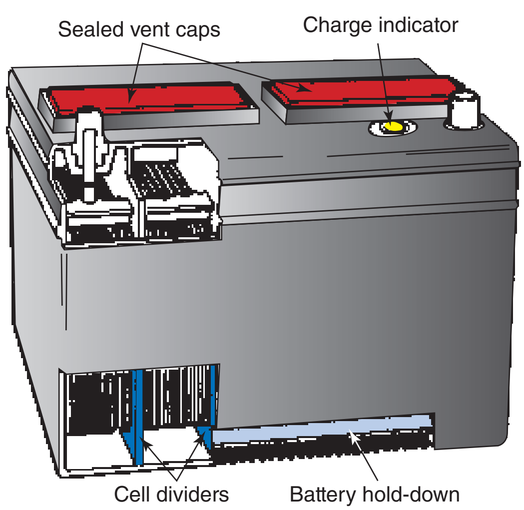
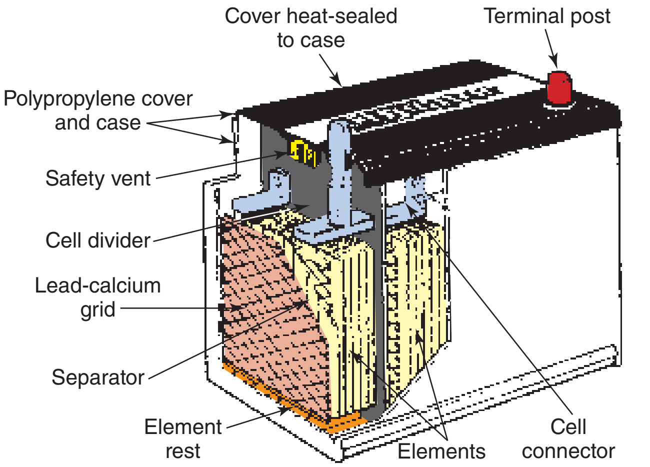
Figure 17-4. Like conventional batteries, spiral-wound batteries store chemical energy. The construction of a spiral-wound battery means that it can produce high rates of current when the engine is not running.



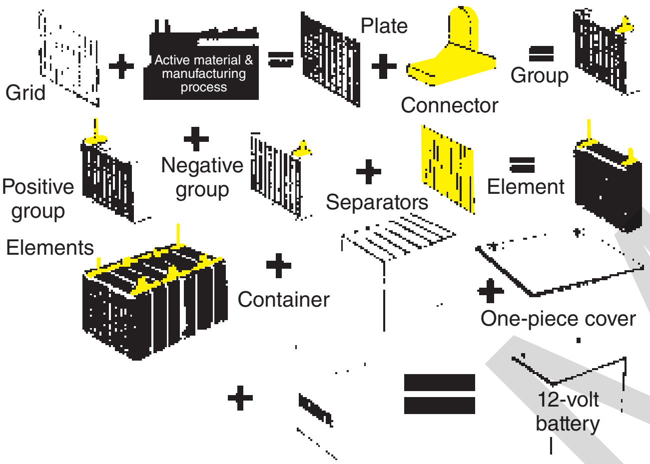
Chrysler

Figure 17-5. Battery container showing placement of cell dividers. Note the use of a built-in charge indicator.



Prestolite

Figure 17-6. Sectioned view of a complete 12-volt battery. Learn the names of all parts.



Firestone

Figure 17-7. Study the manufacturing sequence that occurs in a battery's construction. Note in the final battery that the plates are joined by cell connector straps.

in series. **Figure 17-6** shows the elements in place in the battery box. After installation, each cell is connected to its neighbor by a lead cell connector or strap. The end cells are connected to the ***battery terminals***.

Figure 17-7 illustrates all the various battery components and how they are joined together to produce the battery. Modern cars and light trucks have 12-volt batteries. Some older cars have 6-volt systems, while some agricultural vehicles have 8-volt systems. A few large trucks have 24-volt systems.

The electrolyte evaporated from older automotive batteries, which required water to be added every few weeks. Modern automotive batteries are sealed to reduce the amount of evaporation. Water cannot escape and condenses back into the electrolyte. These batteries are known as *maintenance-free batteries*. Some small non-automotive batteries may have removable caps for checking electrolyte level.

Warning

The sulfuric acid in electrolyte can cause severe burns. Avoid contact and wear protective clothing when working with batteries. A battery will sometimes release explosive hydrogen gas as part of its chemical action. Do not smoke or create any sparks or flame near a battery, **Figure 17-8**.

Battery Chemical Action

The battery does not actually store electricity. When charging, it converts electricity into chemical energy. Chemical action of electrolyte, working on active material in the plates, causes a transfer of electrons from the positive plates to the negative plates.

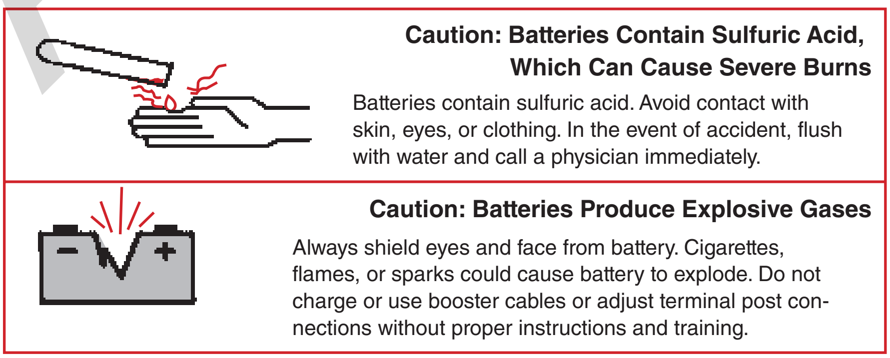


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Figure 17-8. Typical warning label placed on batteries. Use extreme care whenever you are handling batteries or working near batteries. Severe burns to skin and eyes, as well as battery explosions, are possible.

The amount of chemical energy in a battery is not inexhaustible. If the battery is not recharged, it will eventually be unable to operate. **Figure 17-9** shows the typical current load for some electrical systems used on modern vehicles. The charging system must produce sufficient current output to cover all possible electrical needs.

Battery Discharging

When the battery is placed in a closed circuit, such as when the starter is being operated, a surplus of electrons at the negative post will flow to the positive post. An electric current is produced by converting chemical energy into electricity, **Figure 17-10**.

As the current flows, the battery starts discharging. The sulfate ion (SO_4) in the sulfuric acid (H_2SO_4) combines with the lead (Pb) in the plate materials to form lead sulfate ($PbSO_4$). The hydrogen ion (H_2) combines with the oxygen in the lead peroxide to form water (H_2O). As the current continues flowing, the rate of current flow and the electrolyte become weaker and weaker, until the battery is completely discharged.

Battery Charging

The battery can be recharged by passing an electric current back into the battery (with a battery charger or the vehicle alternator) by raising the input voltage to a level above the battery voltage. The sulfate (SO_4) ions leave the plates and combine with the hydrogen (H_2) from the water to form sulfuric acid (H_2SO_4). The lead (Pb) in the positive plates combine with the free oxygen (O_2) ions to form lead peroxide (PbO_2). If the battery plates and electrolyte are in good condition, the battery will eventually become fully charged.

Battery Testing

Battery testing is done by checking voltage and performing load tests. A fully charged battery in good condition will indicate about 12.6 volts between the positive and negative terminals. When the battery is placed under a load, the battery should deliver the rated amperage without voltage dropping below approximately 9.5 volts. Special electrical system testers are needed to make these tests. Some newer testers can check battery internal resistance and determine battery condition without placing a load on the battery.

Battery Ratings

Electrical size has almost no relationship to battery physical size. Often, a small battery can have a high cranking amp rating. This varies because of different battery materials and construction standards. Newer batteries are often smaller than the older batteries that

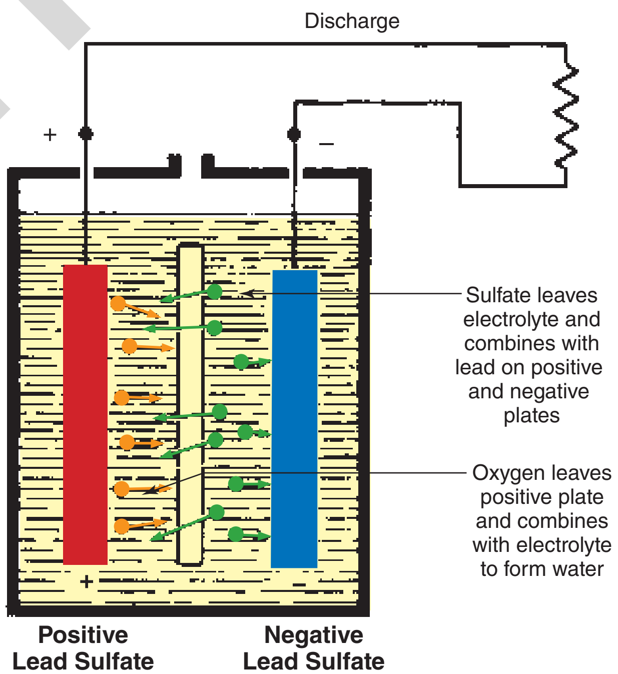
Typical Current Load of Modern Cars (in Amperes)

Switch	Accessory Switch Load	Max. Vehicle Operating Load
Parking	4 to 8	–
Low-Beam Headlamp	8 to 14	–
High-Beam (4) Headlamp	12 to 18	18
Heater	6 to 7	–
Windshield Wiper	2 to 3	3
Air Conditioner	10 to 15	15
Radio	0.4 to 1.8	1.8
Electronic Ignition	8 to 12	12
Alternator Field	3 to 5	5
Total		54.8
Summer Starting		100 - 400 Amperes*
Winter Starting		225 - 500 Amperes*

*Values vary with engine size, engine temperature, and oil viscosity.

Prestolite

Figure 17-9. Typical current load for various electrical units. The load will vary somewhat depending on the type of system and vehicle.



Ford

Figure 17-10. Normal chemical reaction during battery discharge. Note that the sulfate combines with the lead on the cell plates. This is why a battery is sometimes said to be sulfated.

they replace, but have higher electrical ratings. The list shown here explains the latest cold cranking and reserve capacity measurements:

- ***Cold cranking amps (CCA)***—The maximum amount of current that flows for 30 seconds without dropping below 7.2 volts and with the battery temperature at 0°F (–18°C). This measurement indicates how much current the battery can produce when cold, and is the standard measurement for modern batteries.
- ***Reserve capacity (RC)***—The number of minutes that the battery can produce 25 amps without dropping below 10.2 volts and with the battery temperature at 80°F (26.7°C). Reserve capacity indicates how long the battery can operate the vehicle electrical system in the event of a charging system failure.
- ***Cranking amps (CA)***—The maximum amount of current that flows for 30 seconds without dropping below 7.2 volts and with the battery temperature at 32°F (0°C). This measurement is also called *hot* or *marine cranking amps*.

Parasitic Battery Loads

The electrical and electronic components found on modern vehicles can cause a small, continuous drain on the battery after the ignition is turned off. This is called ***parasitic battery load***. Parasitic battery loads do not cause the battery to go dead, due to the small current draw (measured in milliamps), and should be considered normal. The chart in **Figure 17-11** shows some typical parasitic loads. An ammeter must be used to determine whether current flow is excessive.

Current Draw in Milliamperes (mA)

Component	Typical Parasitic Draw	Maximum Parasitic Draw
ABS-ECM	1.0	1.0
Alternator	1.5	1.5
Auto Door Locks	1.0	1.0
BCM	3.6	12.4
Chime	1.0	1.0
ECM	2.6	10.0
ELC	2.0	3.3
HVAC Power Module	1.0	1.0
Illuminated Entry	1.0	1.0
Keyless Entry	2.2	5.5
Radio	6.9	6.0
SRS	1.6	2.7
Theft Deterrent System	0.4	1.0

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Figure 17-11. Parasitic loads (mA), of various electronic components. (ABS-ECM–anti-lock brake system/electronic control module. BCM–body computer module. ECM–electronic control module. ELC–electronic level control. SRS–supplemental restraint system.)

Identifying Battery Terminals

The positive post of the battery, which is usually marked *POS* or (+), is somewhat larger than the negative post and its top is sometimes marked in red. The negative post is the smaller of the two, and is sometimes marked in green or black. It is usually marked *NEG* or (–), **Figure 17-12**.

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Figure 17-12. Typical top post battery. Note that positive and negative symbols are embossed on the case near their respective terminals.

On side terminal batteries, the positive connector is surrounded by a red plastic collar. On some side terminal batteries, the cables cannot be interchanged, as the positive connector is a different size than the negative.

The battery is usually located as close to the engine starter as possible to minimize voltage drop. The close location also reduces the length and cost of the wire necessary to connect the battery to the starter. An underhood location also makes the battery accessible for maintenance and replacement.

The negative terminal is grounded on all vehicles, except for very old cars and trucks with 6-volt electrical systems and a few other older vehicles. The ground wire is fastened to the engine or to some other suitable metal location.

Battery cables connect the battery to the rest of the electrical system. The negative cable is almost always connected to the engine block. The positive cable is usually connected to the starter solenoid. To conduct the heavy current needed to operate the starter, battery cables are constructed of a much heavier gage than other vehicle wiring. It is important to follow the manufacturer's service information when replacing any battery cables to ensure the correct gage cable is used. If too small of a cable gage is used, it can overheat during cranking and may cause the starter to operate too slowly to start the vehicle.

Dry-Charged Battery

Some batteries are shipped with the plates charged, but without electrolyte. This type of battery is called a ***dry-charged battery***. If this battery is kept in a cool, dry area, it will remain charged for a long time. Unlike the wet battery, dry-charged batteries do not utilize trickle charging (charging constantly at a very low rate). When the battery is delivered to the customer, the electrolyte is added. Dry-charged batteries are used in motorcycles, lawn equipment, and some cars.

Charging System

The charging system uses the rotation of the engine to create electricity. The electricity recharges the battery and provides power to operate the various vehicle electrical systems. The modern charging system consists of the alternator and regulator. On many vehicles, the regulator is built into the alternator. Alternator and regulator construction and operation are explained in this section.

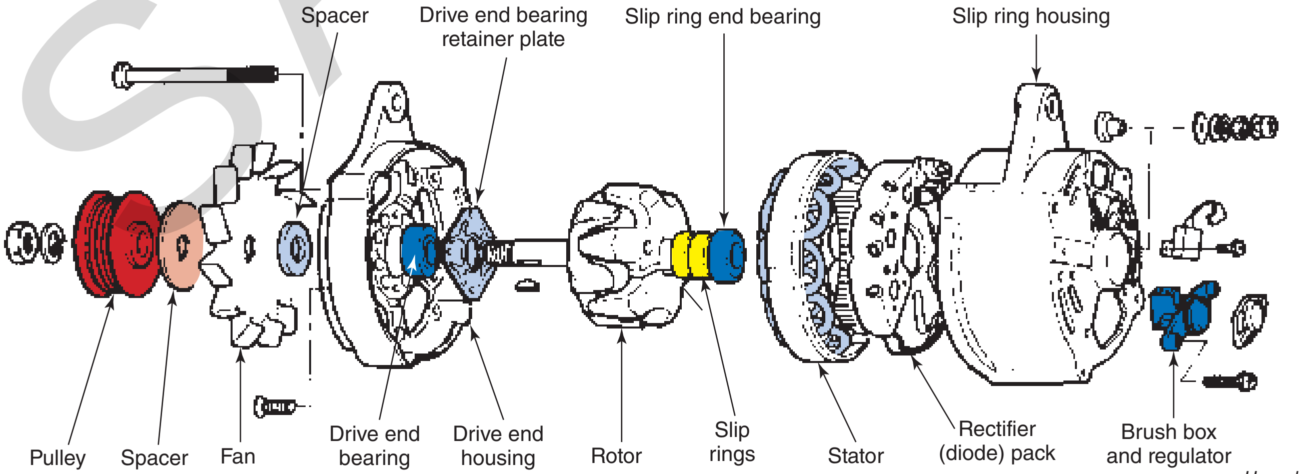
Alternator

The ***alternator*** uses magnetism to turn motion into electricity. It is usually turned by a belt from the engine crankshaft, or may be driven directly from the engine through gears.

Some older vehicles use the inertia starter drive, while on later vehicles the drive gear is engaged by the starter solenoid. The two types are described below. After the engine is started, the alternator produces electricity to meet the needs of the vehicle and to keep the battery charged. The modern vehicle contains many circuits that place a heavy load on the electrical system. Since many vehicles are used in stop-and-go city driving, this makes it difficult to maintain the battery in a fully-charged state. Therefore, the alternator must be extremely efficient at all speeds. A typical alternator used in one charging system is shown in **Figure 17-13**.

Using Magnetism to Produce Electricity

The alternator uses mechanical energy from the engine to create electricity. It can do this because of a basic fact of electricity and magnetism. You may want to review the section on



Hyundai

Figure 17-13. Typical parts of an alternator. The rotor turns within the stator to produce current. The action of other parts is explained in the text.

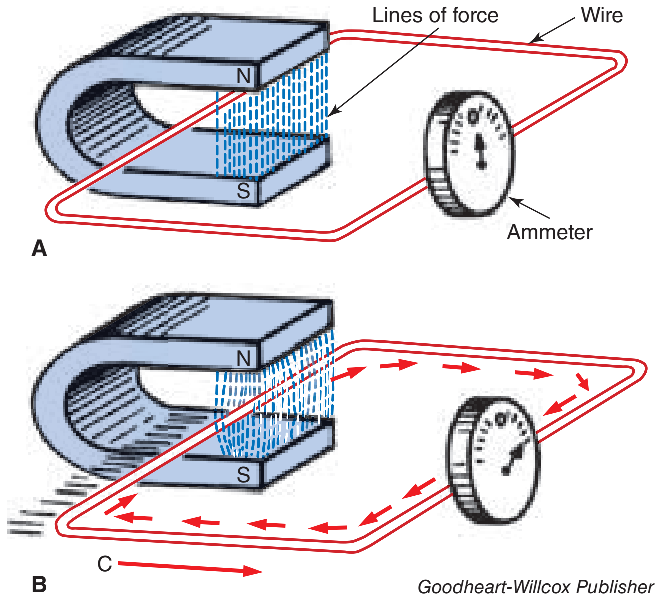


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Figure 17-14. Inducing voltage in a wire. A—The wire is stationary and no current is flowing. B—The wire is being drawn swiftly through magnetic lines of force in the direction of arrow *C*. As the wire passes through the magnetic field, it will have voltage induced in it. As it makes a complete circuit, current flows (see needle on ammeter).

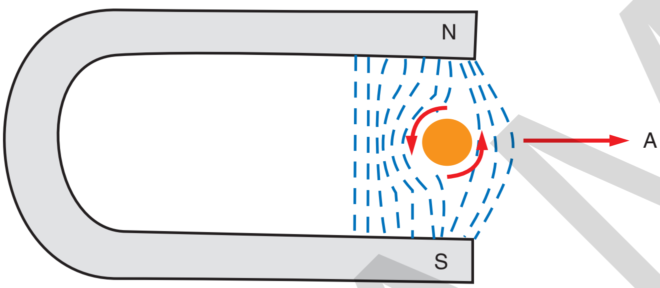

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Figure 17-15. Wire passing through a magnetic field. The wire is passing through the magnetic field in the direction of arrow *A*. Note how the lines of force are bent as the wire moves through the field. The two arrows around the wire indicate the direction in which the magnetic field moves around the wire.

magnetic fields and magnetism in Chapter 8, *Electrical System Fundamentals*.

When a magnetic field moves in relation to a wire, voltage is generated in the wire. The wire can be moved through a stationary magnetic field, or the magnetic field can be moved through a stationary wire. If the wire is part of a closed circuit, current will flow, **Figure 17-14**. If the wire is passed through the magnetic field in the opposite direction, the current flow in the wire will be reversed. The amount of current produced in the wire will depend on two factors:

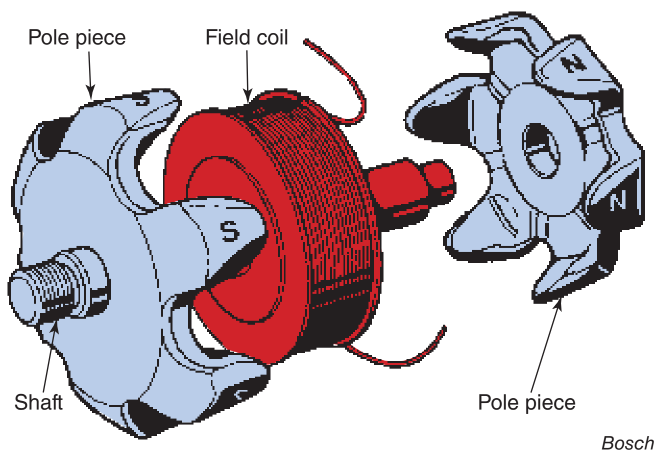
- The strength of the magnetic field.
- The difference in speed between the wire and field.

As the wire moves relative to the field, the lines of force are distorted or bent around the leading side. You will notice in **Figure 17-15** that the arrow around the wire indicates the direction in which the magnetic field moves around the wire. This excites the electrons in the wire, causing them to flow.

Inside an actual alternator, a field coil, or ***rotor***, with alternating (N) and (S) poles, spins inside a set of stationary ***stator*** windings. Current produced in the stator windings is delivered to the rest of the vehicle's electrical system. The alternator field coil is excited (current passed through it) by connecting it to the vehicle battery whenever the ignition switch is in the on position. The field current draw is relatively light, around 2 amps.

Alternator Construction

As mentioned earlier, the alternator spins a field coil with alternating (N) and (S) poles inside the stator windings. A round iron core is placed on a shaft, and the field winding is placed around the core. Two iron pole pieces are slid on the shaft. They cover the field winding and are arranged so the fingers are interspersed. The fingers on one pole piece all form (N) poles. The fingers on the other form (S) poles. As the fingers are interspersed, they form alternate N-S-N-S- poles. **Figure 17-16** shows the complete rotor assembly in exploded form.



Bosch

Figure 17-16. The pole pieces and field winding in this rotor assembly are pressed on the shaft.

As the rotor magnetic fields cut through the conductor, voltage is generated and current flows in the complete circuit. As the alternating (N) and (S) pole fields pass around the conductor, the current will alternate, first one direction and then the other. See **Figure 17-17**.

Rotor Drive

The rotor is attached to a pulley, which is driven by a belt from a pulley on the engine crankshaft. The crankshaft pulley is the drive pulley, and the rotor pulley is the driven pulley. The rotor pulley is much smaller than the crankshaft pulley, and therefore the rotor turns at a much faster speed than the engine crankshaft. Rotor speeds of over 10,000 rpm are common. Some alternators are gear-driven directly from a rotating part of the engine, usually the valve train.

Many modern alternators have a ***clutch pulley***. Clutch pulleys have an internal clutch to reduce vibration and increase belt and tensioner life. There are two kinds of clutch pulleys. An ***isolating alternator decoupler (IAD) pulley*** has a one-way clutch and rotates freely in one direction while driving the rotor in the other direction. An ***overrunning alternator decoupler (OAD) pulley*** will have free rotation in one direction and a springy feel when turned in the other direction. When an IAD- or OAD-equipped alternator is replaced, the technician must replace it with the same type. Using an incorrect pulley may cause vibration and damage the belt and tensioner.

Brushes and Slip Rings

Direct current from the battery is fed to the field coil by using ***brushes*** rubbing against ***slip rings***. One end of the field coil is fastened to the insulated brush, while the other end is attached to the grounded brush. As the pole fields pass through the conductor, voltage is imparted in the conductor, and current flows in one direction. When the rotor turns 180°, and the (N) pole and (S) pole are at opposite positions, current flows in the opposite direction.

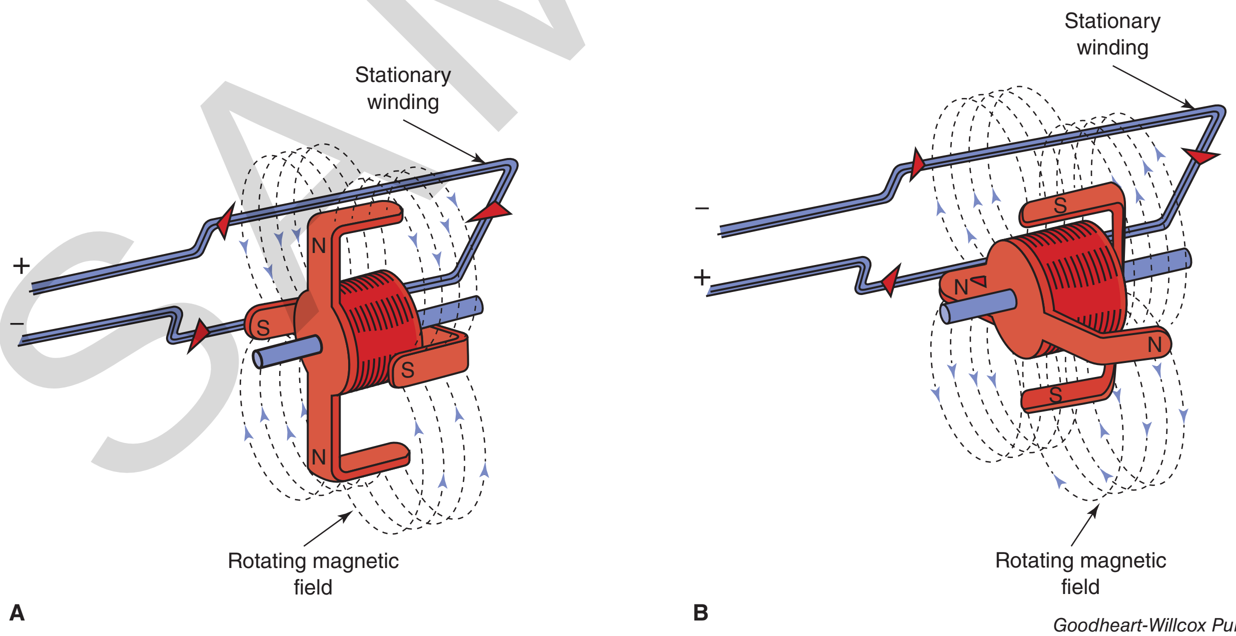


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Figure 17-17. A—The rotating magnetic field induces current flow in the stationary winding. B—Current flow reverses as the alternating magnetic fields of the north and south poles pass near the winding.

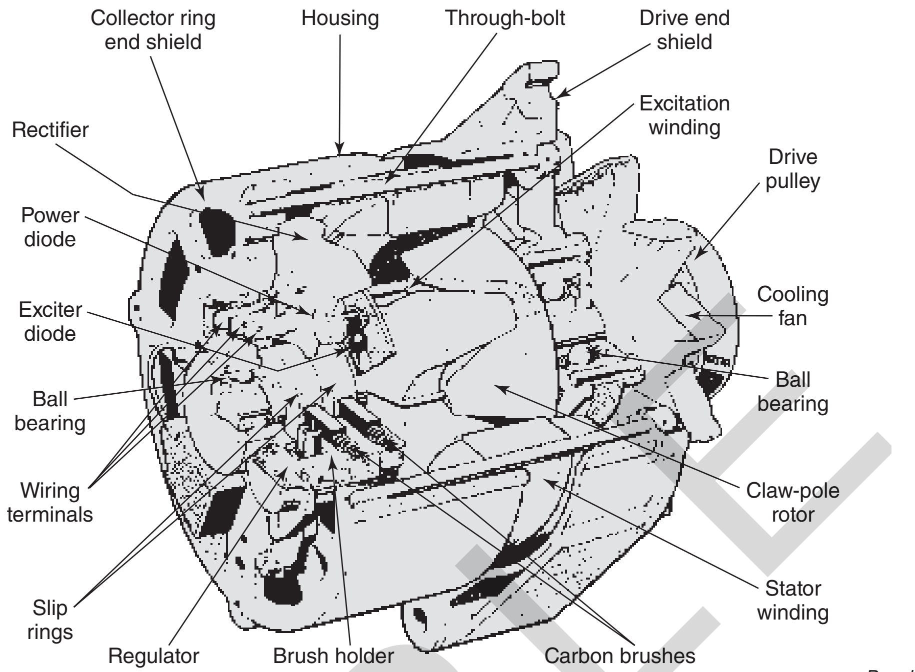

Figure 17-18. Cutaway view of an alternator showing the construction and layout of the various components.

A cutaway view of a typical alternator is shown in **Figure 17-18**. Study the relative locations of the parts already discussed. The use of diodes will be explained later in this chapter.

Alternator Output

The stator windings are made up of three separate windings. The windings produce what is known as *three-phase alternating current*. If only one winding is used, single-phase current results. A curve illustrating single-phase alternating current flow is shown in **Figure 17-19A**. **Figure 17-19B** illustrates three-phase alternating current.

Note that the distance between high points in the output is shorter. The important thing to remember is that the stator produces alternating current. The vehicle battery requires direct current. Before it can be used, alternating current must be ***rectified*** (changed) to direct current.

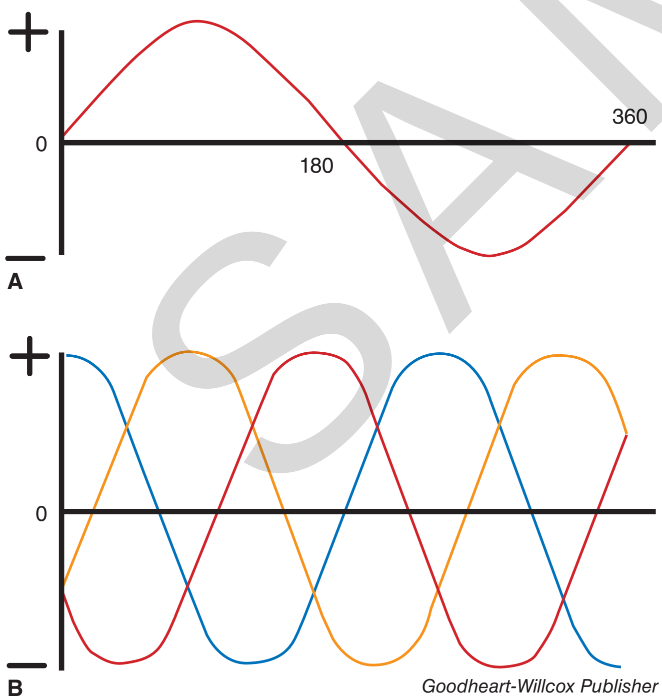

Figure 17-19. A—A single-phase alternating current wave. B—In three-phase alternating current, the phase outputs overlap, but do not coincide.

Diodes

Alternating current is rectified using diodes. Diodes have a peculiar ability to allow current to flow readily in one direction. When the current reverses and attempts to flow through in the other direction, current flow is stopped. Refer to Chapter 8, *Electrical System Fundamentals*, for more information about diodes.

The diodes are located in one end plate or shield. In the alternator illustrated in **Figure 17-20**, three negative polarity diodes are pressed into the aluminum end plate. These are on the ground side. Three positive polarity diodes are pressed into a heat sink, which is insulated from the end plate.

Remember that the stator has three windings. To rectify the current, each winding requires one negative and one positive diode. No matter which direction

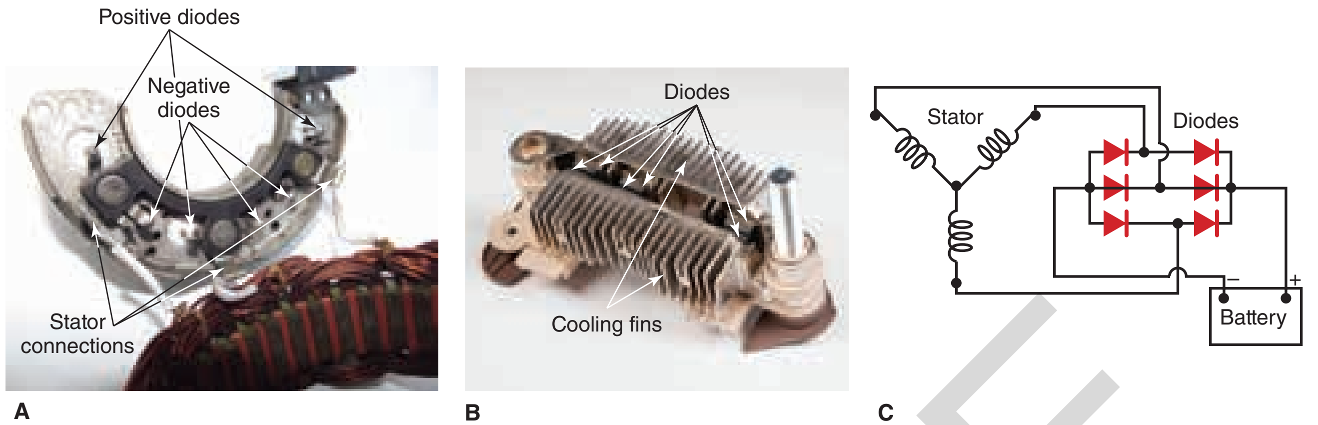

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Figure 17-20. A—A diode bridge containing six diodes. The three positive diodes are pressed into the top frame, which is connected through a heavy wire to the battery positive terminal. The leads for the three negative diodes pass through holes in the top frame and are pressed into the bottom frame, which is attached to the alternator body and therefore the battery negative. B—A type of diode bridge that has the positive and negative diodes installed in a compact assembly. The fins remove heat from the assembly as air flows through the alternator body. C—This schematic of a diode bridge shows how the stator ac output is connected through the diodes to provide dc current to the battery.

the current leaves any stator winding, the diodes are arranged to cause it to leave the alternator in the proper direction. The arrangement of the rectifiers will allow current to flow from the alternator to the battery, but will not allow current flow from the battery to the alternator. A cross-sectional view of a diode is given in **Figure 17-21**.

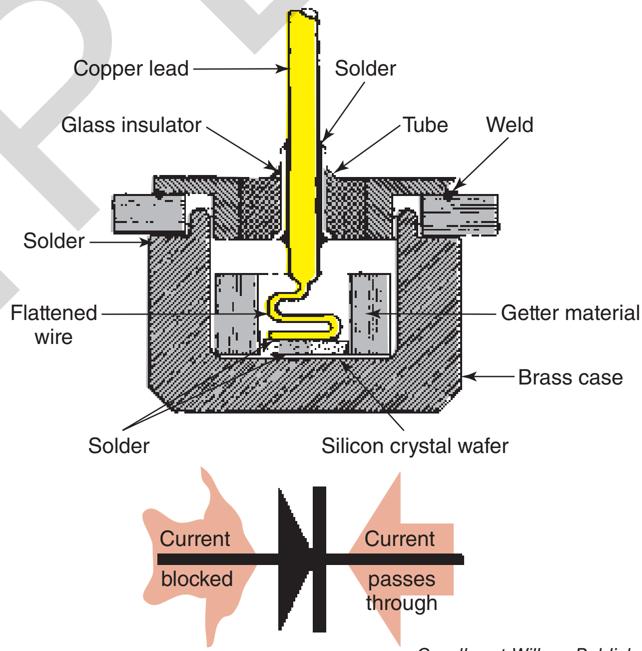

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Figure 17-21. Cross-section of a diode (rectifier). Current is free to pass one way only. A diode, like a transistor, is a semiconductor (conducts electricity under certain conditions, acts as an insulator under others).

Alternator Control

At idle, when the rotor is turning relatively slowly, the alternator can keep up with the demands of the vehicle electrical system. At normal vehicle speeds, the alternator can produce much more voltage and current than needed. To protect the alternator and the rest of the electrical system from damage, a means of reducing the output must be found.

As mentioned earlier in this chapter, there are two ways to control the amount of electricity produced in a wire: controlling the speed of rotor movement, or controlling the strength of the magnetic field. Since the rotor is driven directly by the engine crankshaft through belts and pulleys, controlling alternator speed would be difficult. The simplest way to control alternator output is to control the field strength.

To reduce alternator output, a ***voltage regulator*** is used. The voltage regulator controls the alternator output by adjusting the amount of current reaching the rotor. This controls the strength of the magnetic field passing through the stator windings. The regulator controls the field strength by reading voltage output from the alternator. If output voltage becomes too high, the regulator reduces field strength. If the output voltage drops, the regulator increases field strength.

The voltage regulator uses power transistors, integrated circuits, diodes, and other electronic parts to control alternator output. Some electronic regulators are remotely mounted. Modern regulators, however, are reliable, durable, and small enough to be incorporated into the alternator itself, as shown in **Figure 17-22**.

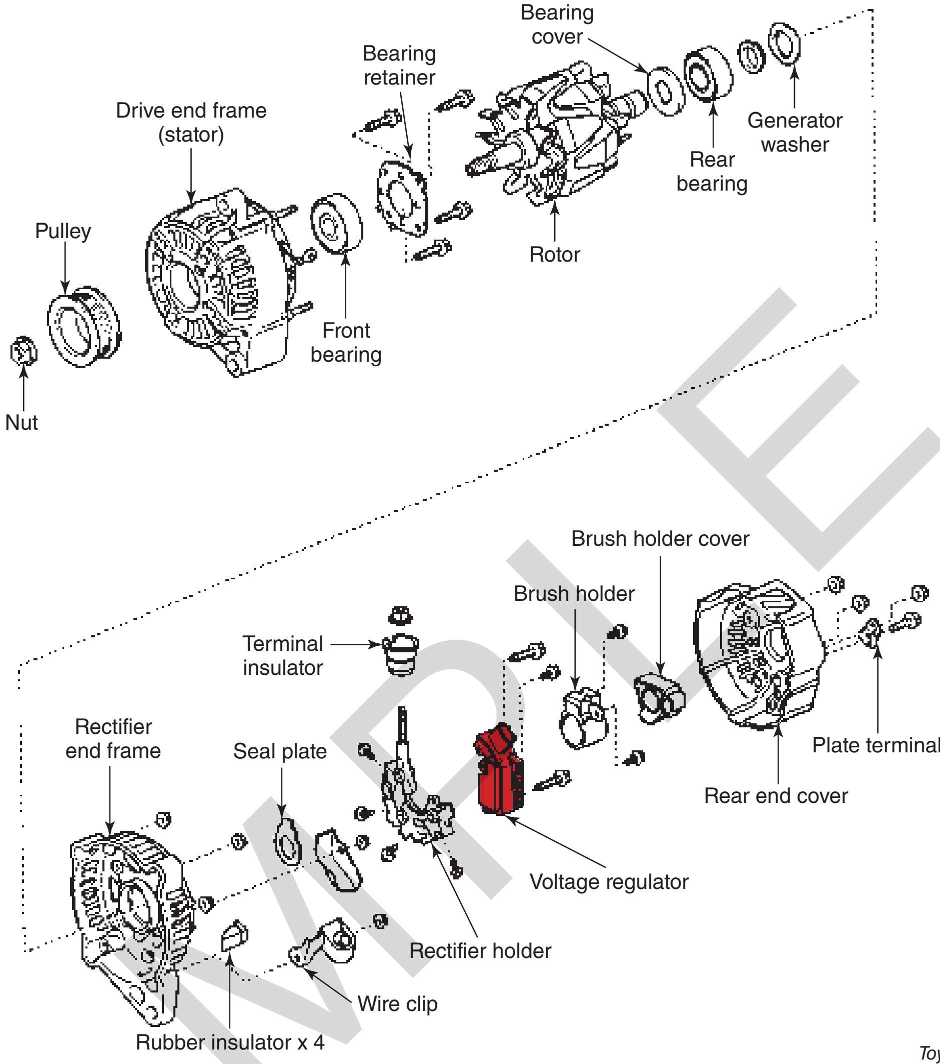


Figure 17-22. Exploded view of an alternator with a built-in-voltage regulator.

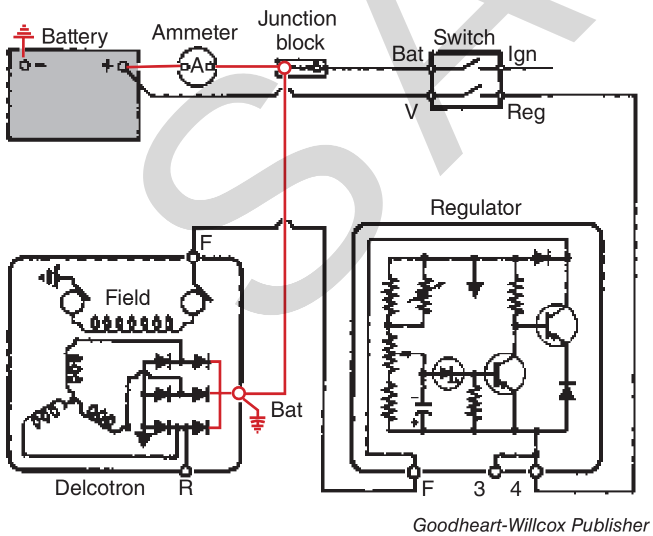


Figure 17-23. Schematic of a charging circuit employing a transistor regulator.

A charging circuit with alternator and regulator connections is shown in **Figure 17-23**. The most important part in the regulator is the Zener diode, discussed in Chapter 8, *Electrical System Fundamentals*. The breakdown point of the Zener diode is set at the maximum charging system voltage. The Zener diode is nonconducting until this voltage is reached. At this point, the diode breaks down and transmits electricity.

This current flow, acting through other transistors, turns the power transistor off and stops the flow of field current to the alternator. This causes the voltage output to fall below Zener diode breakdown voltage, at which time the diode once again becomes nonconductive. This stops the current flow to the transistors and allows resumption of field current flow. The cycle is repeated thousands of times per second.

Built-In Regulator Operation

A common charging system circuit with a built-in regulator is illustrated in **Figure 17-24**. A small amount of current passes from the stator through the diode trio to the regulator. This equalizes the voltage on either side of the indicator light, putting it out, and tries to ground through resistor R3.

When the stator voltage reaches a certain level, voltage going to ground through resistor R3 will increase to the point that it will cause Zener diode D1 to conduct. Forward-biased (voltage applied in direction causing current flow) transistor TR2 conducts and transistor TR3 is reverse-biased off. This turns transistor TR1 off. The field current and system voltage immediately decrease with TR1 off.

When system voltage decreases, voltage through R3 decreases and D1 stops conducting. This causes transistor TR2 to become reverse-biased off and transistors TR1 and TR3 forward-biased on. Output voltage and field current will increase. This cycle is repeated thousands of times per second, holding alternator voltage output to a preset level.

Sudden voltage change across R3 is prevented by capacitor C1, and excessive back current through TR1 at high temperature is prevented by R4. TR1 is protected by D2 that prevents a high induced voltage in the field winding when TR1 is off. Voltage control temperature correction is provided by a thermistor (resistance decreases as temperature increases).

Computer-Controlled Voltage Regulation

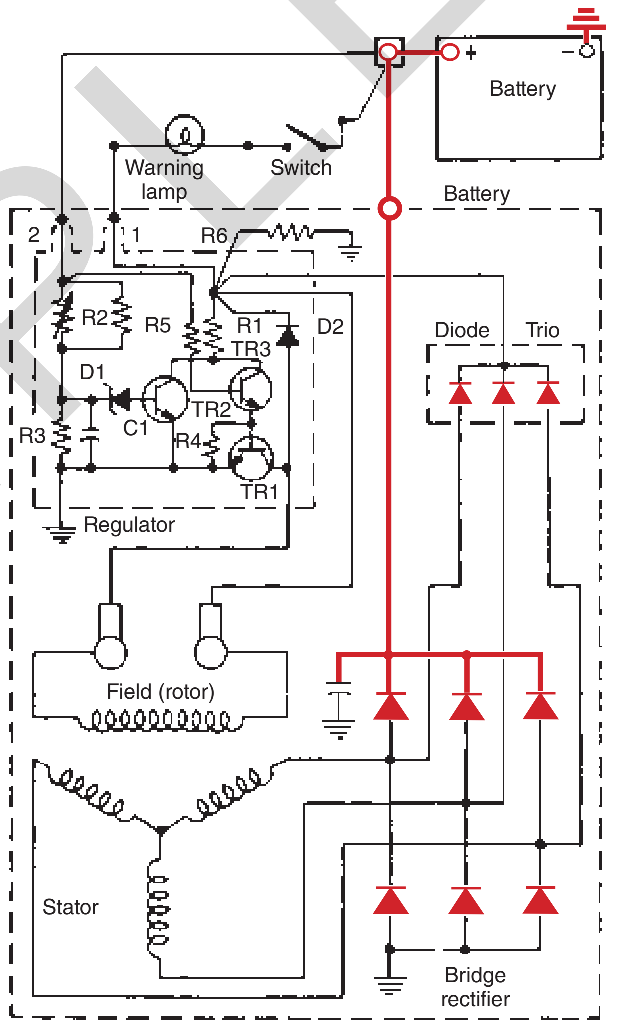
The vehicle ECM is sometimes used to control voltage to the field winding, which eliminates the need for a separate regulator. The logic module tells the power module what to do in this charging system. The disadvantage of this system is if the portion of the ECM that controls voltage regulation becomes defective, the entire ECM must be replaced.

Alternator Operation

When the ignition key is turned on or the start button is pressed, the battery is connected to the field terminal through the voltage regulator. When the engine is started, it will drive the alternator rotor. As the turning rotor pole force fields cut through the stator windings, alternating current voltage is generated. The diodes rectify the alternating current into direct current. The alternator output leaves the positive terminal and travels to the battery. The return circuit is completed through the engine block and vehicle frame.

Brushless Alternator

Some heavy-duty truck alternators do not have slip rings and brushes. All conductors carrying current are stationary (do not move). These are regulator circuit components, field winding, stator windings, and rectifier diodes. The field coil does not turn. Instead, permanent magnets are turned by the shaft and create the magnetic field.



Chrysler

Figure 17-24. Charging system schematic showing a transistor voltage regulator. Note the diode trio. This unit rectifies current flow from ground through TR1 and the field windings to the stator windings. The rectifier diode bridge changes stator ac voltage to dc output.

Charge Indicator

The *charge indicator* is usually a light installed in the instrument panel and warns of charging system problems. The charge indicator is operated directly by system voltage. It is wired so that voltages are equal on both sides of the bulb when the system is charging. When voltages are equal, no current flows and the bulb does not light. If the system stops charging, one side of the circuit is grounded and current flows through the bulb, illuminating it. Trace the warning light circuit shown in **Figure 17-24**.

Starter System

To start an internal combustion engine, it must be cranked (rotated by an outside source). Small two-stroke engines are often cranked by pulling a rope, which causes the internal engine parts to revolve. The first automobiles used a hand crank rod for starting. However, this method was dangerous and impractical. A method was soon developed to start the engine by using a high-torque electric starting motor, or ***starter***.

The starter is mounted on the transmission housing and operates a small gear that can be meshed with a large ring gear attached to the flywheel. To energize the starter, the driver turns the ignition switch to start, which completes an electrical circuit to the starter. Most newer vehicles use a separate starter button to energize the starter. When the starter motor armature begins to turn, the starter gear moves out and engages the ring gear, which spins the crankshaft. When the engine starts, the driver breaks the starter electrical circuit by releasing the ignition key switch or starter button. This causes the starter gear to move out of mesh with the ring gear.

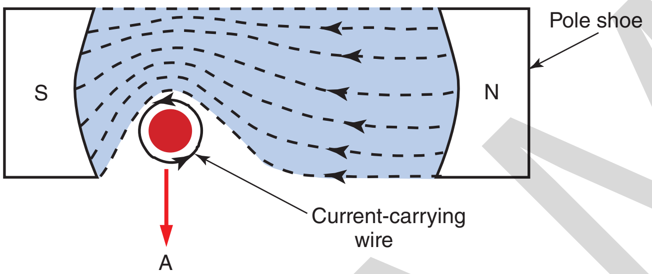


Figure 17-25. Current-carrying conductor in a magnetic field. The magnetic field around the wire (see small arrows) will oppose the magnetic field from the poles. This will cause the wire to be forced out in direction of arrow *A*.

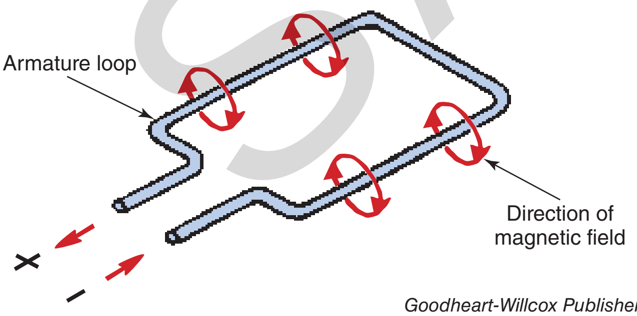


Figure 17-26. Note the direction of the magnetic field on each side of this armature loop.

Starter Motor Principles

All electric motors operate on the same fundamental principles. If a current-carrying wire is placed in a magnetic field, the field set up around the wire by the moving current will oppose that of the magnetic field, **Figure 17-25**. If the wire is free to move, it will move out of the field.

Armature Loop

If the conductor is bent in the form of a loop, each side of the loop will set up a magnetic field. Since the current is traveling in opposite directions, the two sides will have opposing fields, **Figure 17-26**. This is called an ***armature loop***. When the armature loop is placed in a magnetic field, both sides of the loop will oppose the magnetic field, but in opposite directions. This will cause the loop to rotate out of the field, **Figure 17-27**.

Commutator Segments

In order to pass an electrical current into the revolving loop, the loop ends must be fastened to ***commutator segments***. Copper brushes rub against the turning segments, **Figure 17-28**. One loop would not give the starter motor sufficient power, so many loops are used. The ends of each loop are connected to a copper commutator segment, **Figure 17-29**.

The loops are insulated and formed over a laminated iron core. The ends of all loops are connected to the copper commutator segments. The segments are insulated from the shaft and from each other. The core is supported on a steel shaft that, in turn, is supported in bronze bushings.

When current is fed into two of the four brushes, it flows through all the loops and out the other brushes. This creates a magnetic field around each loop. As the armature turns, the loop will move to a position where the current flow reverses. If this were not done, the magnetic field around the loops would push them out of one side of the field. As a result, they would be repelled when they entered the other side of the pole field. This constant reversal of current flow is accomplished by the commutator segments moving under the brushes. Two brushes are insulated and two are grounded.

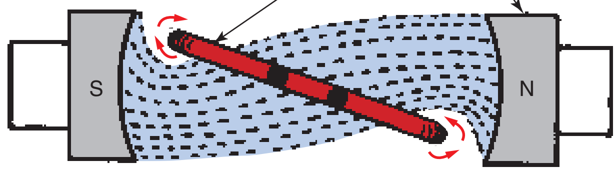


Figure 17-27. Each side of the armature loop has a field moving in opposite directions. These fields will oppose the pole shoe field, causing the loop to rotate.

Field Pole Shoes

Field pole shoes, usually called *poles*, are placed inside a steel cylinder (field frame). There may be four or more pole shoes. Two or more of the shoes are wound with heavy copper strips. Then, when current is passed through the coils, the pole shoes become powerful magnets. The field frame provides a low reluctance magnetic path, further strengthening the magnetic field.

Starter Electrical Circuits

The copper loops and field windings are heavy enough to carry a large amount of current with minimum resistance. Since they draw heavy amounts of current, they must not be operated on a continuous basis for longer than 15 seconds. After operating a starter for 15 seconds, wait a couple of minutes to let the starter motor dissipate some of its heat. A starter heats quickly, so prolonged use can cause serious damage.

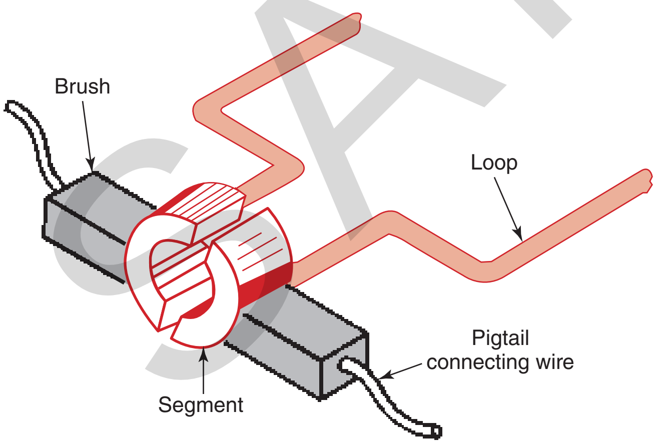


Figure 17-28. In an actual starter motor, many loops and commutator segments are used. Each commutator segment is insulated from the shaft and other segments.

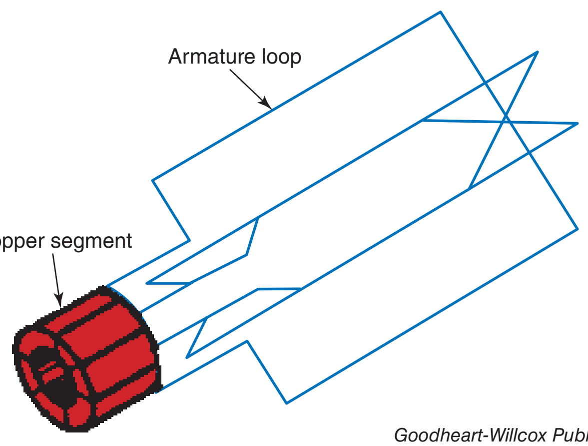


Figure 17-29. Many loops are required in a starter motor. Additional loops will increase the starter motor's torque.

Various wiring arrangements are used in starter construction. **Figure 17-30A** illustrates a four-pole, two-field winding. By wiring the field coil in parallel, resistance is lowered, and the field coils produce stronger magnetic fields. The other two poles have no windings, but serve to strengthen the field. **Figure 17-30B** shows a four-pole, four-winding armature wired series-parallel.

Figure 17-30C illustrates a four-pole, three-winding setup. Two of the windings are in series with themselves and the armature. One winding does not pass through the armature, but goes directly to ground. This ***shunt winding*** aids with additional starting torque. As starter speed increases, the shunt draws a heavy current and tends to keep starter speed within acceptable limits.

Figure 17-30D shows a four-pole, four-winding setup. Three windings are in series, and one is a shunt winding. **Figure 17-30E** is a four-pole, four-winding setup with all windings in series. There are other setups. However, the circuits illustrated in **Figure 17-30** are the most commonly used.

Starter Motor Construction

Figure 17-31 shows an exploded view of the various parts of a typical starter motor. This particular starter has a four-pole, three-winding circuit. One of the windings is a shunt winding. **Figure 17-32** shows a cutaway view of a typical starter using an overrunning clutch starter drive. Note how the armature shaft is supported at both ends by a bronze bushing.

Starter Drive System

To provide a means for the starting motor to turn the engine, a drive system is used. It consists of a ***ring gear*** and a ***starter pinion gear***. These are explained in the following sections.

Ring Gear

The ring gear is attached to the flywheel of vehicles with manual transmissions. The ring gear is either welded or shrink-fit to the flywheel. In shrink-fitting, the ring gear is expanded by heat and fitted on the flywheel while hot. As it cools, the metal contracts and

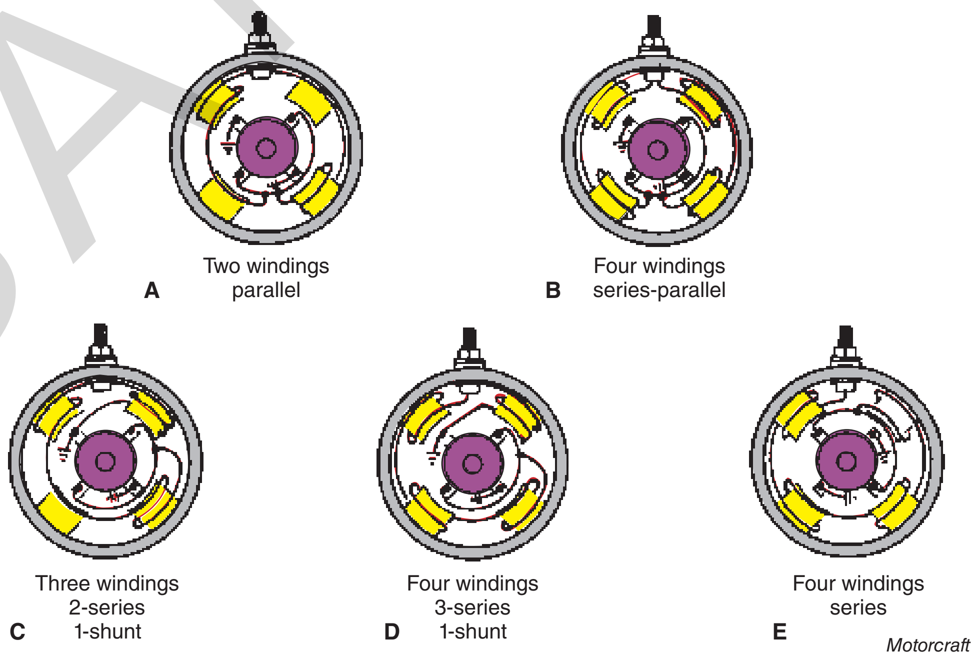


Figure 17-30. Various starter wiring circuits. The different wiring circuits provide different amounts of starting and running torque.

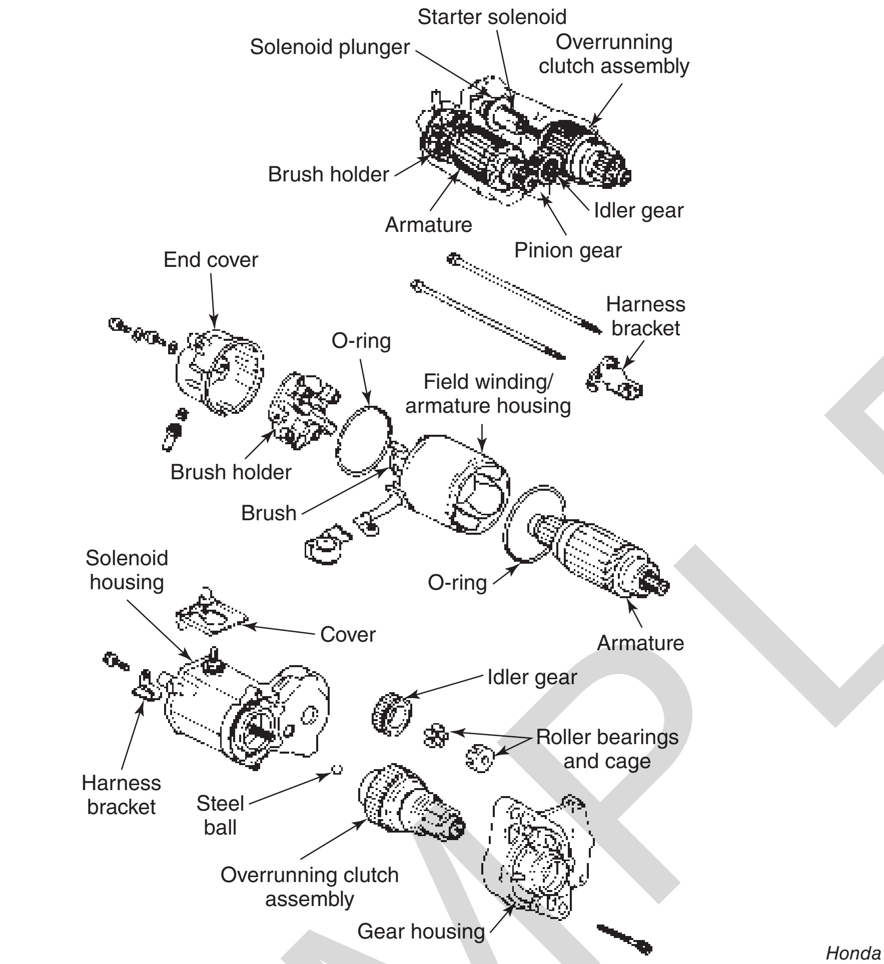


Figure 17-31. Exploded view of a typical starter motor. Learn the names and locations of all the parts.

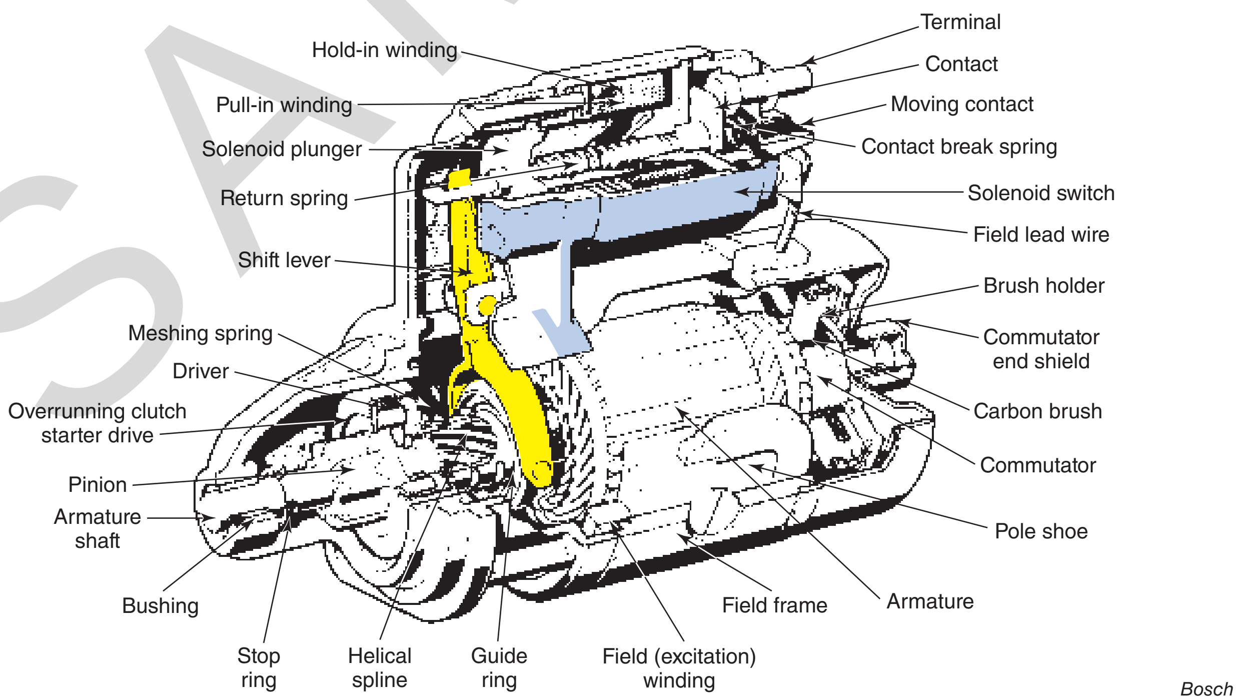


Figure 17-32. Cutaway of a starter motor using an overrunning clutch starter drive. Note the shift lever and solenoid.

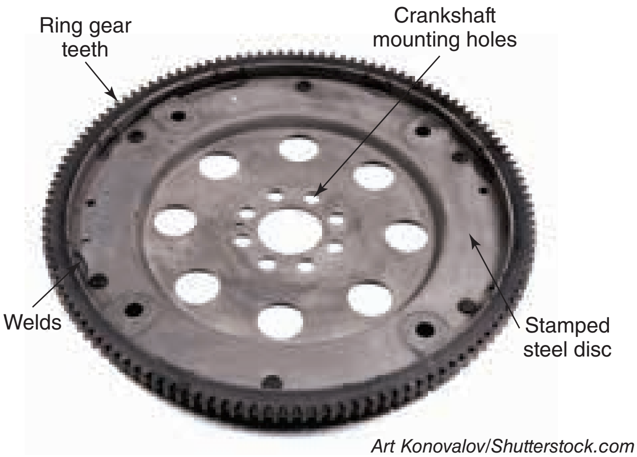


Figure 17-33. The flex plate is usually stamped from heavy sheet steel. It is bolted to the end of the crankshaft and is fastened to the torque converter housing by bolts or threaded studs and nuts.

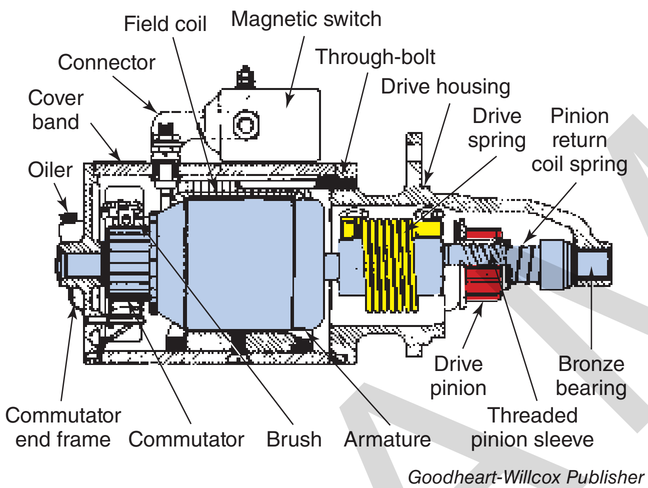


Figure 17-34. Cutaway of a starter motor with a Bendix drive.

the ring grasps the flywheel securely. The ring gear usually has 150–200 teeth. Some ring gears are welded to the torque converter.

Vehicles with automatic transmissions and transaxles use a lightweight disc to connect the crankshaft and torque converter. The ring gear is welded to the disc. These discs are called *flex plates* or simply *ring gears*, **Figure 17-33**.

Starter Pinion Gear

A small gear, called a *starter pinion gear*, is attached to the starter armature shaft. The pinion gear is much smaller than the ring gear (about 10–15 teeth) and must turn 15–30 revolutions in order to crank the flywheel one revolution.

Pinion Engagement Devices

It is necessary to mesh the pinion gear for cranking and demesh (disengage) the pinion when the engine has started. The two basic types of pinion engagement devices are the inertia type and the overrunning clutch type. There are several designs of each basic type.

Inertia Starter Drive

With the ***inertia starter drive***, sometimes called the ***Bendix drive*** or ***self-engaging drive***, the armature shaft spins and the drive pinion stands still while the threaded sleeve spins inside the pinion. As the sleeve spins, the drive pinion slides out and meshes with the ring gear. As soon as the drive pinion reaches its stop, the turning sleeve causes the drive pinion to turn with it to crank the engine.

The pinion sleeve fits loosely on the armature shaft and is connected to a large drive spring that is fastened to the armature shaft. The spring absorbs the sudden shock of drive pinion engagement. When the engine starts, the drive pinion spins faster than the pinion sleeve. This causes the drive pinion to move backward along the threaded pinion sleeve until it is free of the ring gear. A small pinion return coil spring prevents the drive pinion from working back into mesh with the ring gear.

An inertia drive, in place on a starter motor, is shown in **Figure 17-34**. Note the threaded pinion sleeve and the drive pinion. The drive pinion is weighted on one side, so it will tend to resist being turned until it has slid into mesh with the ring gear.

Overrunning Clutch

The one-way drive, or ***overrunning clutch drive***, is engaged with the ring gear by an electric solenoid that actuates the shift linkage. In operation, the pinion is turned by the overrunning clutch. When the pinion is slid into mesh with the ring, the shifting mechanism completes the starter circuit and the overrunning clutch drives the pinion.

When the engine starts, the ring will spin the pinion faster than the starter armature is turning. The pinion is free to run faster because the overrunning clutch engages the pinion only when the armature is driving it.

Figure 17-35 shows a typical overrunning clutch starter drive. Note the pinion, drive shell and sleeve assembly, coil spring, and shift collar. The coil spring comes into use when the pinion teeth mesh against the ring teeth. The actuating lever, or shift lever, will continue to move the shift collar, compressing the spring. When the lever has moved far enough to close the starter switch, the pinion will turn and the compressed spring will force it into mesh with the ring gear.

Figure 17-35 provides an end view showing the spring-loaded clutch rollers. When the drive sleeve turns faster than the pinion and collar assembly, the rollers are wedged against the pinion, causing it to turn. When pinion speed exceeds that of the sleeve, the rollers retract and the pinion is free of the shell and sleeve assembly.

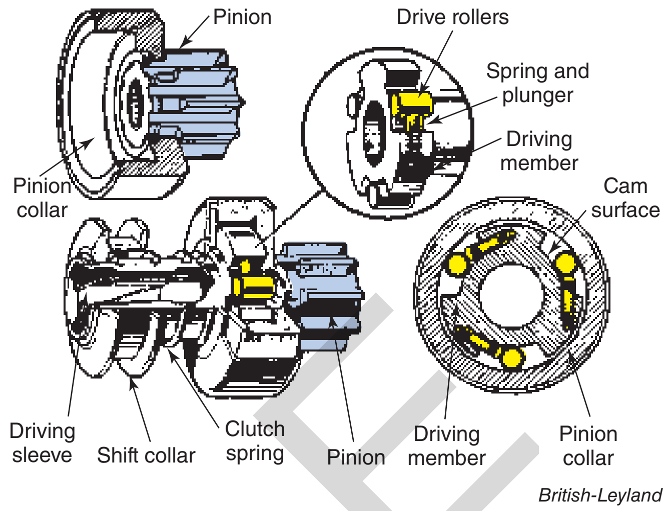


Figure 17-35. In this overrunning clutch starter drive, the rollers lock the pinion and collar assembly to the drive member when the armature shaft is spinning the drive member faster than the pinion.

Starter Solenoid

If an iron core is placed inside a coil of wire and an electric current is passed through the coil, the iron core will be drawn into the coil. Such a unit is called a solenoid. The primary job of the solenoid is to make the electrical contact between the battery and starter motor.

Figure 17-36 shows how a solenoid can be used to pull on a starter shift lever. The solenoid is energized from the start position on the ignition switch. You will note that the solenoid not only moves the starter shift linkage, but also closes the starter switch as the starter drive gear meshes with the ring gear. Making electrical contact is the solenoid's only function when an inertia starter drive is used.

Starter Solenoid Operation

In the disengaged position, the drive gear is demeshed. The solenoid plunger is released and no current is flowing. When the ignition switch is turned to the start position, current from the ignition switch flows through the solenoid coils. The coils draw the plunger inward, causing it to move the linkage. The starter drive pinion gear begins to mesh with the ring gear.

As the pinion gear fully meshes with the ring gear, the solenoid plunger closes the starter switch. Current flows from the battery through the starter switch to the starter.

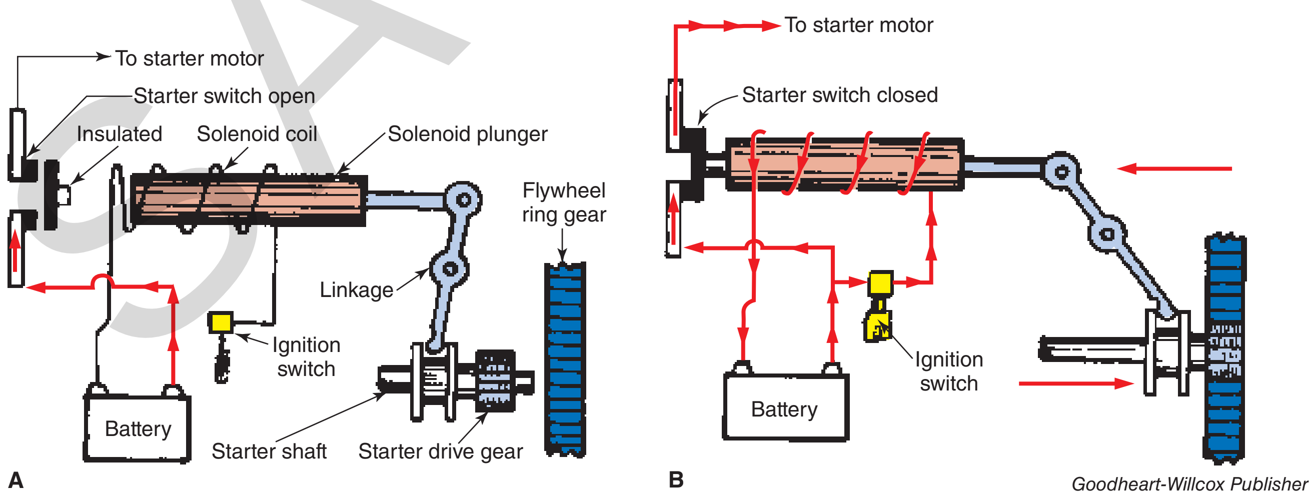


Figure 17-36. Starter drive solenoid operation. A—The solenoid plunger has moved to the right, opening the starter switch and retracting the starter drive gear. The ignition switch is off. B—The ignition switch is on, energizing the solenoid, which draws the plunger into the coil. The plunger has engaged the drive gear and closed the starter switch. The starter will now crank the engine.

The starter pinion gear turns the ring gear and engine. When the engine has started, the solenoid coil will cut out and the plunger will move out, retracting the pinion and opening the starter switch.

Most solenoids have two windings: a pull-in winding and a hold-in winding. Both windings are energized to move the plunger and engage the pinion gear with the flywheel. Once the pinion is engaged, the pull-in winding is de-energized so more current can flow to the starter motor.

Reduction Gear Starters

To increase starter torque, some starter drives are driven through a ***reduction gear***. The reduction gear is used in high-speed starter motors. The reduction gear reduces speed to increase starter torque. A common reduction gear starter is shown in **Figure 17-37**.

Planetary Gear Reduction Starter

For many years, ***planetary gears*** have been used in automatic transmissions to obtain desired gear reduction. Planetary gearsets are also used for reduction in some starter motors, **Figure 17-38**. This design decreases the overall size and weight of the starter by approximately 35% while maintaining the needed starter torque.

The planetary gears, located on the shaft, mesh with the teeth of the internal or ring gear. Most reduction gear starters use permanent magnets, which eliminate the field coil windings. There are six permanent magnets mounted inside the armature housing that reduce current draw while starting, **Figure 17-38**. The magnets are aligned according to polarity and cannot be removed from the housing. The magnets are permanently affixed to the housing.

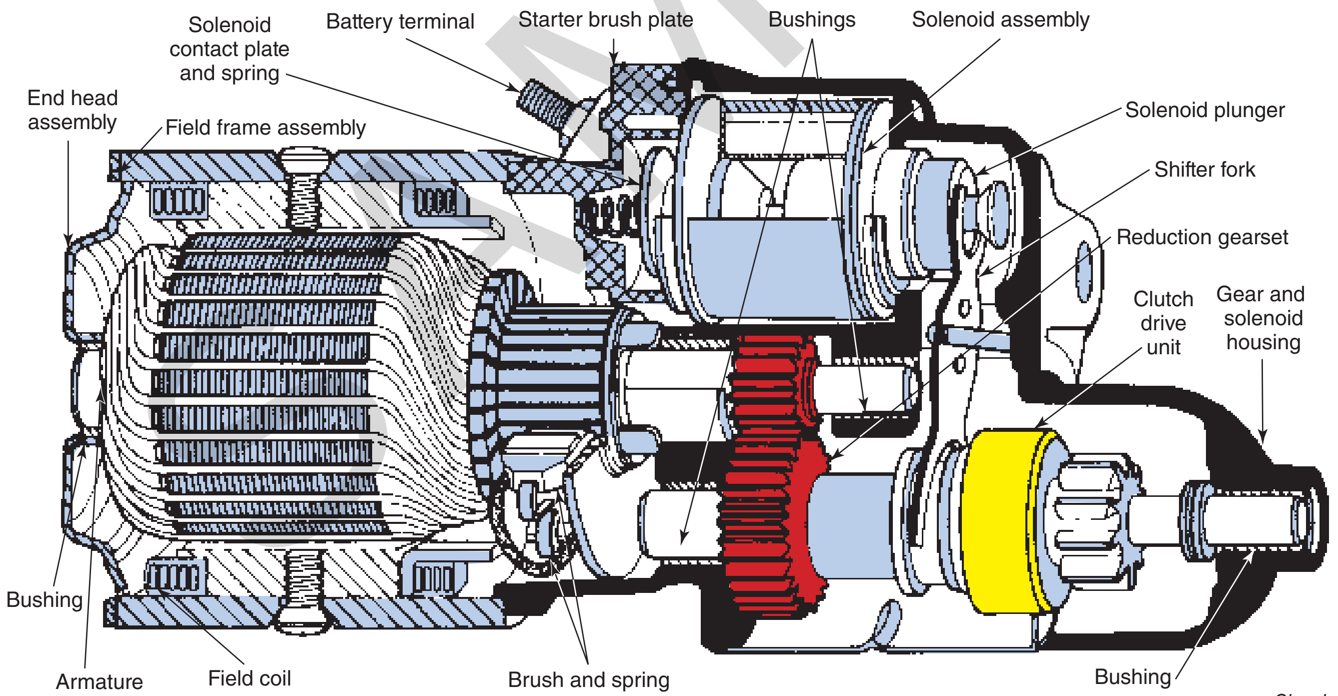


Figure 17-37. Cutaway of a starter motor using reduction gears. The starter motor drives the smaller gear, which turns the larger gear and the pinion gear. The difference in gear sizes causes the pinion gear to turn more slowly than the motor, but with more torque.

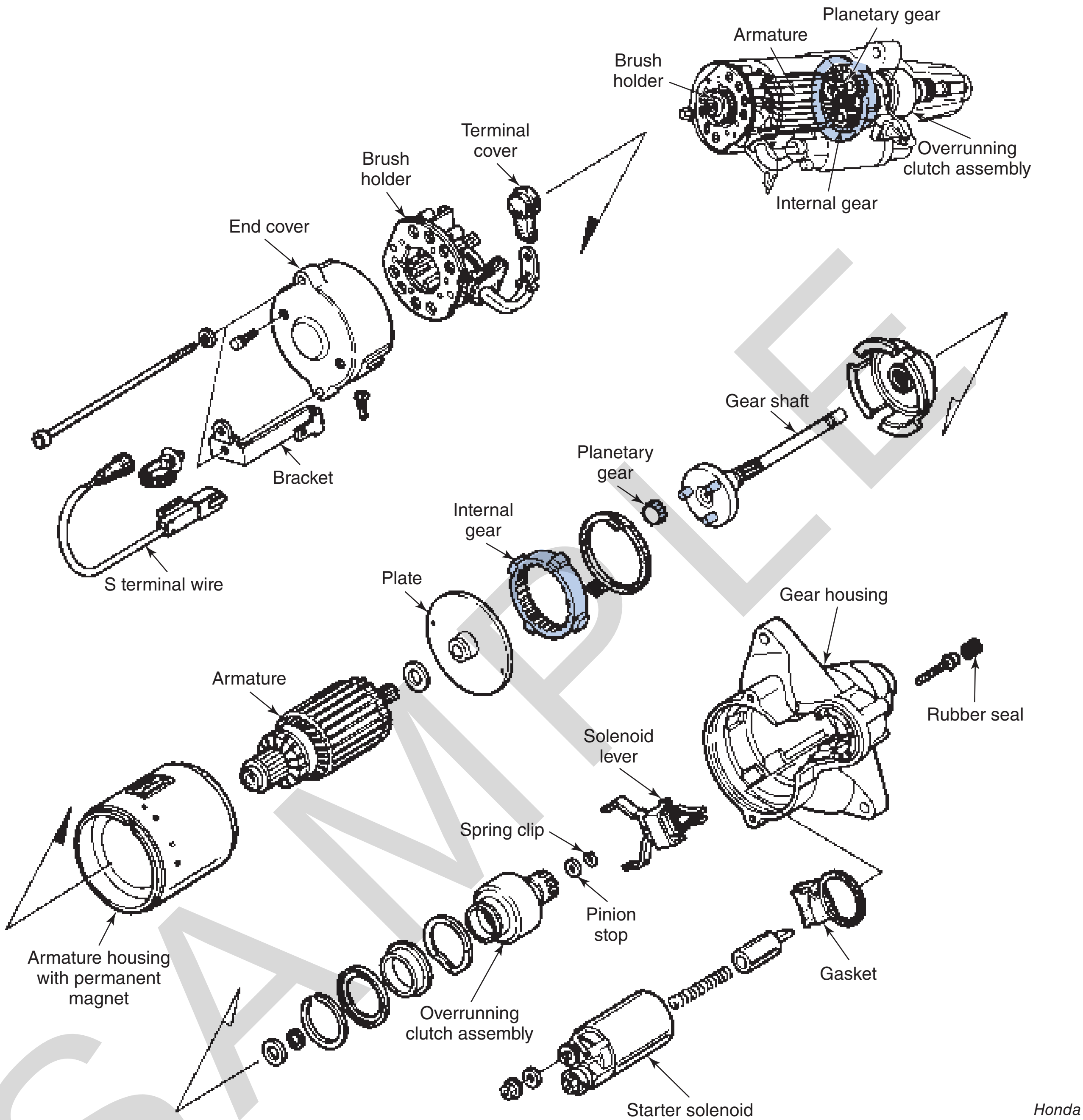


Figure 17-38. Exploded view of a planetary gear reduction starter motor assembly. Note the use of an overrunning clutch.

Starter Actuating Switches

In addition to the solenoid-operated switch that directs battery current to the starter, it is necessary to furnish current to the solenoid. On most vehicles, turning the key to the fullest travel closes a switch to the solenoid. However, current must first pass through a ***neutral safety switch***, **Figure 17-39**, before energizing the solenoid.

On some vehicles equipped with manual transmissions, the clutch must be depressed to close the neutral safety switch. On vehicles equipped with automatic transmissions, the gear selector must be placed in *Park* or *Neutral* for current to flow through the neutral

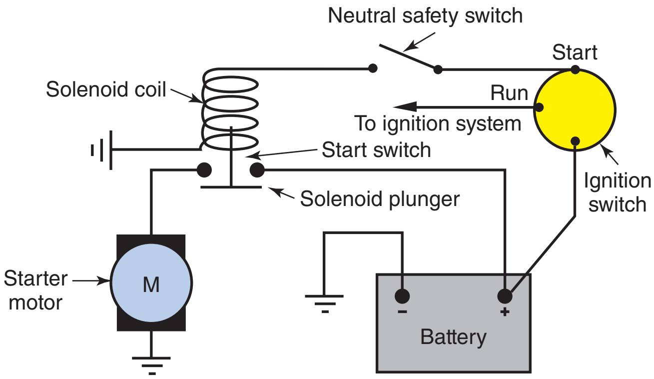


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Figure 17-39. Starting circuit including neutral safety or clutch start switch. If the switch remains open, the vehicle will not start.

Tom Wang/Shutterstock.com

Figure 17-40. The start button on this vehicle is located on the instrument panel to the right of the steering wheel. On some vehicles, the button can be removed to uncover a standard ignition switch for starting the vehicle if the push button system fails.

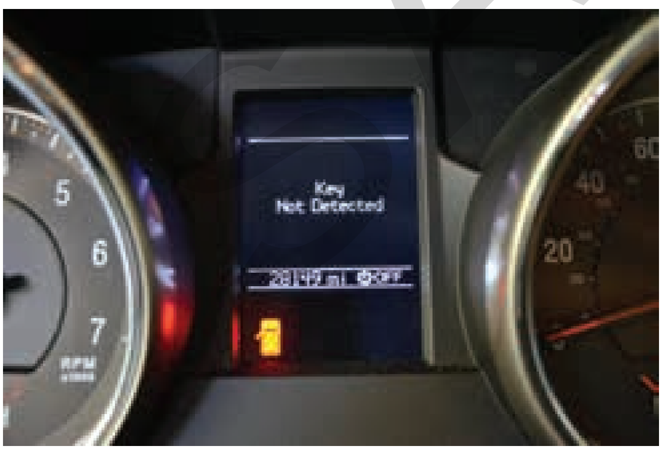

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Figure 17-41. The key fob must be nearby before the engine will crank. This is an anti-theft measure. If the start button is pressed without the fob in the specified vicinity, a message similar to the one shown here will display.

safety switch to the solenoid. This prevents the vehicle from being started when the transmission is in gear. Some vehicles do not use a neutral safety switch. Instead, these vehicles have a mechanical interlock that prevents the key from being turned unless the shifter is in neutral and park.

Many newer vehicles are equipped with a start button instead of a keyed ignition lock cylinder, **Figure 17-40**. Pushing the start button cranks the engine. Most vehicles with a start button must sense the presence of the vehicle key fob near the vehicle before the starter will crank. The key fob sends a signal that communicates with the vehicle electrical system through a start control module. If the module does not sense the key fob, it may display a message as shown in **Figure 17-41**. Some key fobs have a remote start feature that allows the vehicle to be cranked from nearby.

Note

Some hybrid vehicles do not use a conventional starter. Instead, the motor-generator is used to crank the engine during starting.

Workplace Skills

A knowledge of automotive technology will make you a better employee in any automotive field. As you study automotive technology, research other automotive-related professions. You may discover other areas of interest. For example, you might enjoy selling cars more than working on them. Consider the following questions.

1. How would knowledge of basic automotive technology help you get a job in an auto repair and maintenance shop?
2. What type of personal and work skills might help you advance from a porter to a sales position in an auto dealership?

Summary

- A battery is an electrochemical device used to supply current for starting the vehicle.
- A 12-volt battery contains positive and negative plates that are connected in such a way as to produce six groups of cells, which each have a 2-volt charge.
- Automotive batteries are usually 12 volts, though other battery sizes are used by trucks and commercial vehicles.
- Battery plates are covered with an electrolyte solution.
- A charged battery will gather a surplus of electrons at the negative post.
- When a charged battery is connected to a complete circuit, the electrons at its negative post will flow from the negative post, through the circuit, and on to the battery's positive post, which discharges the battery.
- The battery is recharged when electrons flow from the positive to the negative post.
- Batteries are commonly tested with electrical testers.
- Batteries can explode and should never be exposed to sparks or open flame. Battery electrolyte can cause burns. Proper personal protective equipment should be worn when working with batteries.
- The primary job of an alternator is to supply the necessary current for the electrical needs of the vehicle and to keep the battery charged after the engine is started.
- An alternator operates by using magnetism to change mechanical energy (rotation) into electricity.
- A voltage regulator controls the maximum voltage and current output developed by the alternator.
- Modern voltage regulators are often located inside of the alternator.
- The battery, alternator, and voltage regulator work together and the function of any one unit is dependent upon the action of the other two.
- Battery condition and vehicle electrical load determine the current and voltage requirements from the alternator.
- The alternator produces the required voltage and current, and the voltage regulator controls the alternator output on a level consistent with system needs.
- A high-torque electric starting motor called a starter is used to crank the engine for starting purposes.
- The starter motor utilizes a current-carrying series of armature loops placed in a strong magnetic field produced by field coils.
- As the armature loops are repelled by the magnetic field, the armature is forced to spin.
- By arranging a sufficient number of armature loops and connecting them to commutator bars or segments, current in the loops keeps reversing so the repelling force will remain constant.
- A starter uses large copper conductors in both the field and armature circuits.
- The field and armature are connected in series via four brushes.
- Starters draw heavy current loads and therefore heat quite rapidly.
- Starters must not be operated continuously for longer than 15 seconds without a brief rest to dissipate the heat.
- The starter pinion that engages the flywheel ring gear uses one of two different designs.
- A Bendix drive spins a pinion sleeve that causes the pinion to slide out on the sleeve until it engages the ring.

- An overrunning clutch moves the starter pinion into mesh by using a shift lever actuated by a solenoid. The clutch allows the drive pinion to freewheel when the engine starts, until it is drawn out of mesh.
- A starter is energized by a solenoid.
- The starter solenoid is energized by operating the ignition switch through a neutral safety switch.
- Newer vehicles have a start button or can be started from outside of the vehicle with a key fob.

Technical Terms

absorbed glass mat (AGM) battery
alternator
armature loop
battery terminals
Bendix drive
brushes
cells
clutch pulley
cold cranking amps (CCA)
commutator segments
cranking amps (CA)
dry-charged battery
electrolyte
field pole shoes
inertia starter drive
isolating alternator decoupler (IAD) pulley
lead-acid battery
negative plate
neutral safety switch
overrunning alternator decoupler (OAD) pulley
overrunning clutch drive
parasitic battery load
planetary gears
positive plate
rectified
reduction gear
reserve capacity (RC)
ring gear
rotor
self-engaging drive
separators
shunt winding
slip rings
starter
starter pinion gear
stator
voltage regulator

Review Questions

Answer the following questions using the information provided in this chapter.

1. All of the following statements about batteries are true, *except*:
   A. an automotive battery contains positive and negative plates.
   B. a 12-volt battery will contain three cells.
   C. the battery electrolyte contains water.
   D. a battery stores chemical energy.
2. What two liquids make up the electrolyte of a conventional automotive battery?
   A. Water and sulfuric acid.
   B. Nitric acid and sulfuric acid.
   C. Water and hydrochloric acid.
   D. Nitrogen and acetic acid.
3. An absorbed glass mat (AGM) battery contains _____ impregnated with liquid electrolyte.
   A. glass plates
   B. fiberglass mats
   C. pleated paper filters
   D. hollow metal columns
4. *True or False?* A battery stores electricity.
5. *True or False?* When an automotive battery is discharging, sulfate ions in the electrolyte combine with lead on the positive and negative battery plates.
6. All of the following are battery rating measurements, *except*:
   A. reserve capacity.
   B. cold cranking amps.
   C. maximum parasitic load draw.
   D. cranking amps.

7. Positive battery post polarity is indicated by all of the following methods, *except*:
   A. red paint or red plastic terminals.
   B. a plus (+) sign.
   C. the letters POS.
   D. slightly smaller post diameter.
8. A dry-charged battery is shipped without _____.
   A. plates
   B. terminals
   C. individual cells
   D. electrolyte
9. Which of the following alternator parts rotates?
   A. Rotor.
   B. Stator.
   C. Diodes.
   D. Brushes.
10. *True or False?* Alternator pulleys are equipped with an internal clutch to reduce vibration and increase belt and tensioner life.
11. The alternator slip rings are used with _____ to transfer direct current from the battery to the field coil.
    A. diodes
    B. solenoid
    C. brushes
    D. commutator bars
12. Which of the following alternator parts change alternating current into direct current?
    A. Rotor.
    B. Stator.
    C. Diodes.
    D. Pulley.
13. *True or False?* If alternator output voltage becomes too high, the voltage regulator increases the strength of the magnetic field passing through the stator windings.
14. A Zener diode inside an alternator's voltage regulator allows electricity to flow when the _____ of the charging system passes a certain point.
    A. temperature
    B. amperage
    C. voltage
    D. phase shift
15. *True or False?* An internal combustion engine must be cranked (rotated by an external source) before it will start.
16. If a magnetic field surrounds a current-carrying wire, in what direction will the wire try to move?
    A. Out of the field.
    B. Toward the center of the field.
    C. Toward the magnet's north pole.
    D. It does not move.
17. Which of the following starter parts does *not* rotate during starter operation?
    A. Armature windings.
    B. Commutator segments.
    C. Drive pinion.
    D. Field pole shoes.
18. *True or False?* For greatest efficiency, continuously operate the starter motor for 1–2 minutes to start the vehicle's engine.
19. What is the function of the shunt winding in a starter?
    A. Decrease starter current flow.
    B. Produce additional starting torque.
    C. Cool the starter armature.
    D. Increase starter speed.
20. The two general classes of starter pinion engagement devices are the overrunning clutch type and the _____ type.
    A. inertia
    B. regulator
    C. slip ring
    D. distributor
21. The overrunning clutch engages the pinion only when the _____ is driving it.
    A. starter motor armature
    B. engine ring gear
    C. starter solenoid
    D. shunt winding
22. The primary job of the starter solenoid is to provide an electrical connection between the battery and the _____.
    A. ignition switch
    B. starter motor
    C. alternator
    D. drive mechanism

23. Some starters have a movable pole shoe to _____.
   A. increase starter torque
   B. reduce starter speed
   C. engage the starter drive
   D. prevent starter overheating
24. A vehicle equipped with an automatic transmission must have the gear selector shifted into *Park* or *Neutral* for battery current to flow through the _____ to the starter solenoid.
   A. pinion drive switch
   B. neutral safety switch
   C. field coil
   D. armature loop
25. Hybrid vehicles use a _____ instead of a conventional starter to crank the engine.
   A. surge-generator
   B. motor-generator
   C. air pressure starter
   D. hydraulic starter

Critical Thinking Questions

1. Research the chemical reaction that takes place in a lead-acid automotive battery during charging and discharging. Draw two illustrations—one showing discharging and the other charging—and be prepared to describe the chemical process occurring in each.
2. Research a late-model hybrid or full-electric vehicle's starting and charging systems. In what ways are they similar and in what ways are they different from the systems equipped in a vehicle with only an internal combustion engine? What components are used in both systems in a hybrid or full-electric vehicle? How do the starting and charging systems in a hybrid or full-electric vehicle operate?