PRINCIPLES OF ALTERNATOR OPERATION

TERMINOLOGY It is the purpose and function of the charging system to keep the battery fully charged. The Society of Automotive Engineers (SAE) term for the unit that generates electricity is *generator.* The term **alternator** is most commonly used in the trade and will be used in this title.

PRINCIPLES All electrical alternators use the principle of electromagnetic induction to generate electrical power from mechanical power. Electromagnetic induction involves the generation of an electrical current in a conductor when the conductor is moved through a magnetic field. The amount of current generated can be increased by the following factors.

1. Increasing the *speed* of the conductors through the magnetic field
2. Increasing the *number* of conductors passing through the magnetic field
3. Increasing the *strength* of the magnetic field

CHANGING AC TO DC An alternator generates an alternating current (AC) because the current changes polarity during the alternator's rotation. However, a battery cannot "store" alternating current; therefore, this alternating current is changed to direct current (DC) by diodes inside the alternator. Diodes are one-way electrical check valves that permit current to flow in only one direction.

ALTERNATOR CONSTRUCTION

HOUSING An alternator is constructed using a two-piece cast aluminum housing. Aluminum is used because of its lightweight, nonmagnetic properties and heat transfer properties needed to help keep the alternator cool. A front ball bearing is pressed into the front housing, called the **drive-end (DE) housing,** to provide the support and friction reduction necessary for the belt-driven rotor assembly. The rear housing, or the **slip-ring-end (SRE) housing,** usually contains either a roller bearing or ball bearing support for the rotor and mounting for the brushes, diodes, and internal voltage regulator (if so equipped). ● **SEE FIGURES 54–1 AND 54–2.**

FIGURE 54–1 A typical alternator on a Chevrolet V-8 engine.

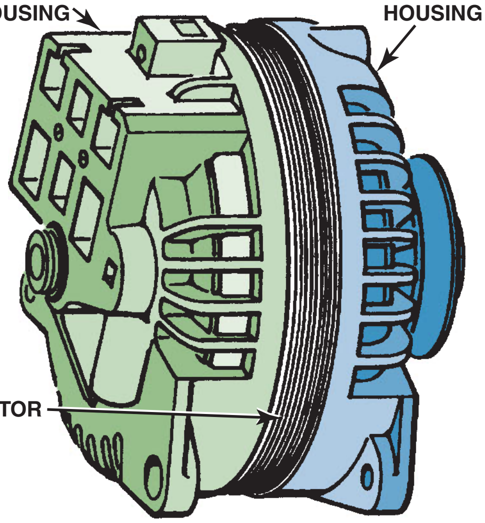

FIGURE 54–2 The end frame toward the drive belt is called the drive-end housing and the rear section is called the slip-ring-end housing.

ALTERNATOR OVERRUNNING PULLEYS

PURPOSE AND FUNCTION Many alternators are equipped with an **overrunning alternator pulley (OAP),** also called an *overrunning clutch pulley* or an *alternator clutch pulley*. The purpose of this pulley is to help eliminate noise and vibration in the accessory drive belt system, especially when the engine is at idle speed. At idle, engine impulses are transmitted to the alternator through the accessory drive belt. The mass of the rotor of the alternator tends to want to keep spinning, but the engine crankshaft speeds up and slows down slightly due to the power impulses. Using a one-way clutch in the alternator pulley allows the belt to apply power to the alternator in only one direction, thereby reducing fluctuations in the belt. ● **SEE FIGURES 54–3 AND 54–4.**

A conventional drive pulley attaches to the alternator (rotor) shaft with a nut and lock washer. In the overrunning clutch pulley, the inner race of the clutch acts as the nut as it screws on to the shaft. Special tools are required to remove and install this type of pulley.

Another type of alternator pulley uses a dampener spring inside, plus a one-way clutch. These units have the following names.

- **Isolating Decoupler Pulley (IDP)**
- Active Alternator Pulley (AAP)
- Alternator Decoupler Pulley (ADP)
- Alternator Overrunning Decoupler Pulley
- **Overrunning Alternator Dampener (OAD)** (most common term)

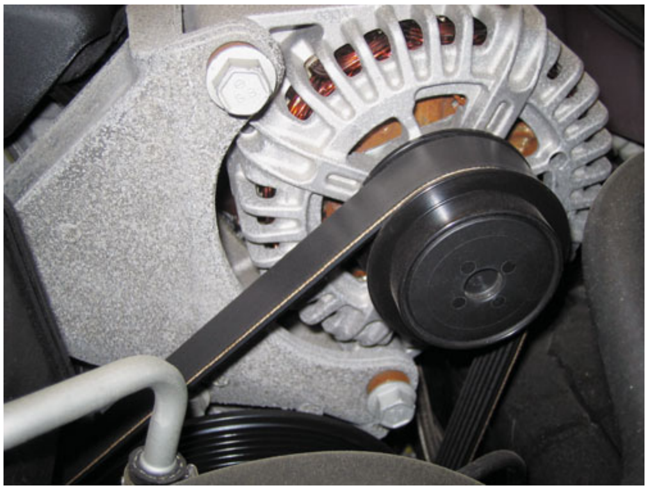

FIGURE 54–3 An OAP on a Chevrolet Corvette alternator.

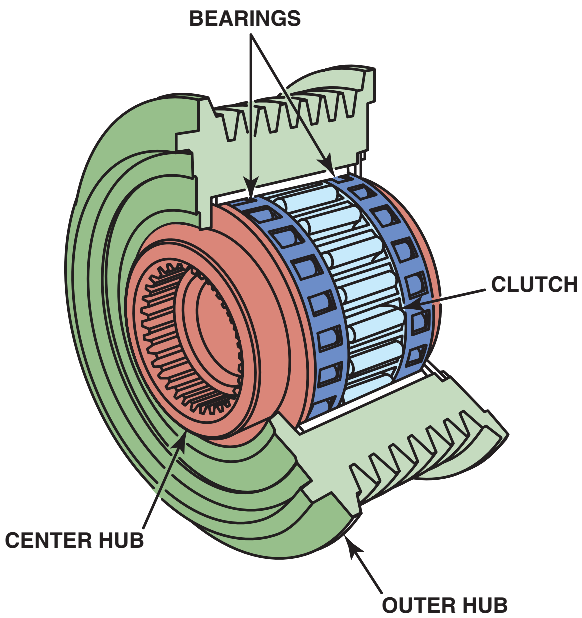

FIGURE 54–4 An exploded view of an overrunning alternator pulley showing all of the internal parts.

OAP or OAD pulleys are primarily used on vehicles equipped with diesel engines or on luxury vehicles where noise and vibration need to be kept at a minimum. Both are designed to:

- Reduce accessory drive belt noise
- Improve the life of the accessory drive belt
- Improve fuel economy by allowing the engine to be operated at a low idle speed

ALTERNATOR COMPONENTS AND OPERATION

ROTOR CONSTRUCTION The **rotor** is the rotating part of the alternator and is driven by the accessory drive belt. The rotor creates the magnetic field of the alternator and produces a current by

TECH TIP

Alternator Horsepower and Engine Operation

Many technicians are asked how much power certain accessories require. A 100 ampere alternator requires about 2 horsepower from the engine. One horsepower is equal to 746 watts. Watts are calculated by multiplying amperes times volts.

Power in watts = 100 A × 14.5 V = 1,450 W
1 hp = 746 W

Therefore, 1,450 watts is about 2 horsepower.

Allowing about 20% for mechanical and electrical losses adds another 0.4 horsepower. Therefore, when someone asks how much power it takes to produce 100 amperes from an alternator, the answer is 2.4 horsepower.

Many alternators delay the electrical load to prevent the engine from stumbling when a heavy electrical load is applied. The voltage regulator or vehicle computer is capable of gradually increasing the output of the alternator over a period of several minutes. Even though 2 horsepower does not sound like much, a sudden demand for 2 horsepower from an idling engine can cause the engine to run rough or stall. The difference in part numbers of various alternators is often an indication of the time interval over which the load is applied. Therefore, using the wrong replacement alternator could cause the engine to stall!

FREQUENTLY ASKED QUESTION

Can I Install an OAP or an OAD to My Alternator?

Usually, no. An alternator needs to be equipped with the proper shaft to allow the installation of an OAP or OAD. This also means that a conventional pulley often cannot be used to replace a defective overrunning alternator pulley or dampener with a conventional pulley. Check service information for the exact procedure to follow.

TECH TIP

Always Check the OAP or OAD First

Overrunning alternator pulleys and overrunning alternator dampeners can fail. The most common factor is the one-way clutch. If it fails, it can freewheel and not power the alternator or it can lock up and not provide the dampening as designed. If the charging system is not working, the OAP or OAD could be the cause, rather than a fault in the alternator itself.

In most cases, the entire alternator assembly will be replaced because each OAP or OAD is unique for each application and both require special tools to remove and replace.

● **SEE FIGURE 54–5.**

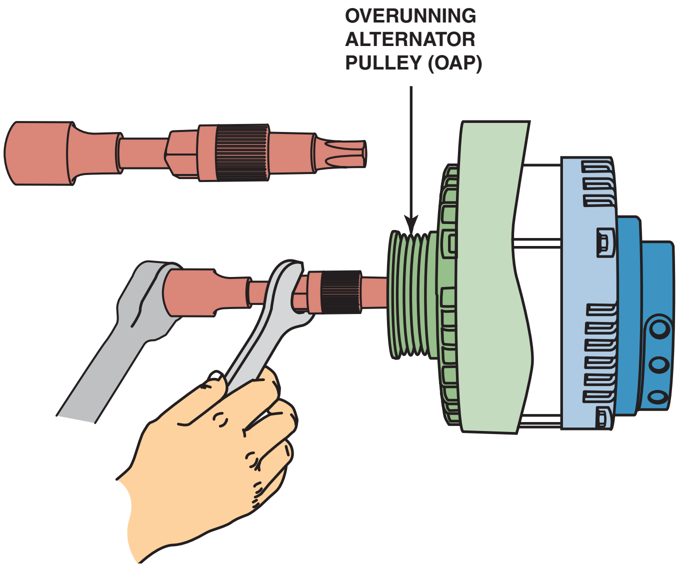

FIGURE 54–5 A special tool is needed to remove and install overrunning alternator pulleys or dampeners.

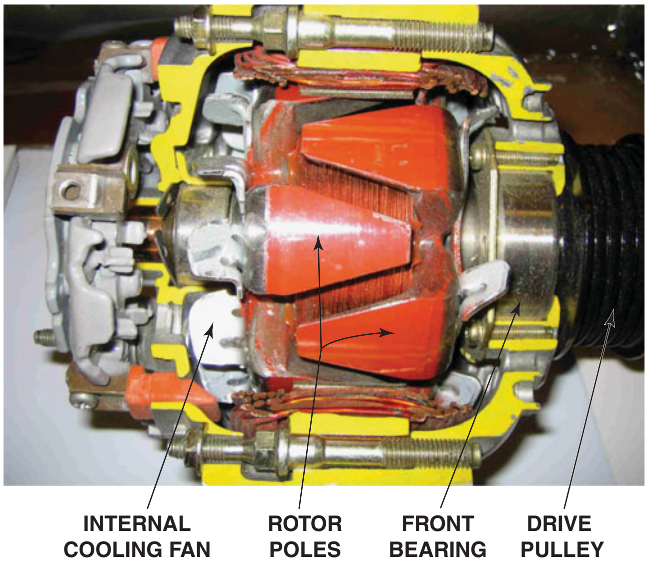

FIGURE 54–6 A cutaway of an alternator, showing the rotor and cooling fan that is used to force air through the unit to remove the heat created when it is charging the battery and supplying electrical power for the vehicle.

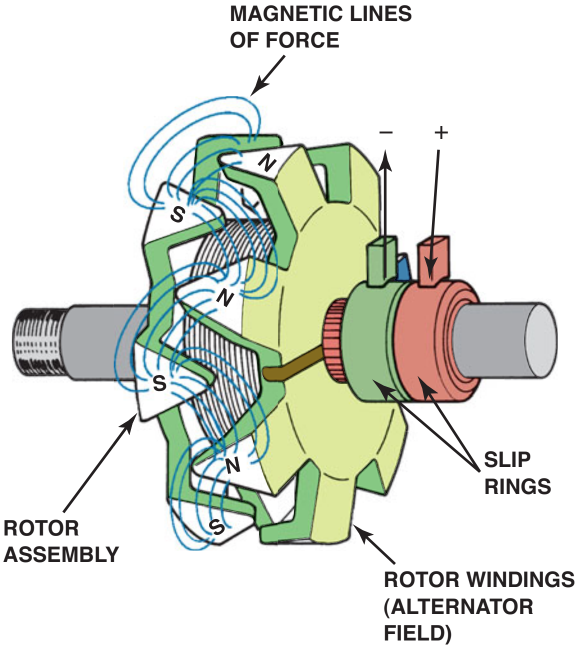

FIGURE 54–7 Rotor assembly of a typical alternator. Current through the slip rings causes the "fingers" of the rotor to become alternating north and south magnetic poles. As the rotor revolves, these magnetic lines of force induce a current in the stator windings.

electromagnetic induction in the stationary stator windings. The rotor is constructed of many turns of copper wire coated with a varnish insulation wound over an iron core. The iron core is attached to the rotor shaft.

At both ends of the rotor windings are heavy-gauge metal plates bent over the windings with triangular fingers called **claw poles.** These pole fingers do not touch, but alternate or interlace, as shown in ● **FIGURE 54–6.**

HOW ROTORS CREATE MAGNETIC FIELDS The two ends of the rotor winding are connected to the rotor's slip rings. Current for the rotor flows from the battery into one brush that rides on one of the slip rings, then flows through the rotor winding, then exits the rotor through the other slip ring and brush. One alternator brush is considered to be the "positive" brush and one is considered to be the "negative" or "ground" brush. The voltage regulator is connected to either the positive or the negative brush and controls the field current through the rotor that controls the output of the alternator.

If current flows through the rotor windings, the metal pole pieces at each end of the rotor become electromagnets. Whether a north or a south pole magnet is created depends on the *direction* in which the wire coil is wound. Because the pole pieces are attached to each end of the rotor, one pole piece will be a north pole magnet. The other pole piece is on the opposite end of the rotor and therefore is viewed as being wound in the opposite direction, creating a south pole. Therefore, the rotor fingers are alternating north and south magnetic poles. The magnetic fields are created between the alternating pole piece fingers. These individual magnetic fields produce a current by electromagnetic induction in the stationary stator windings. ● **SEE FIGURE 54–7.**

ROTOR CURRENT The current necessary for the field (rotor) windings is conducted through slip rings with carbon brushes. The maximum rated alternator output in amperes depends on the number and gauge of the rotor windings. Substituting rotors from one alternator to another can greatly affect maximum output. Many commercially rebuilt alternators are tested and then display a sticker to indicate their tested output. The original rating stamped on the housing is then ground off.

The current for the field is controlled by the voltage regulator and is conducted to the slip rings through carbon brushes. The brushes conduct only the field current which is usually between 2 and 5 amperes.

STATOR CONSTRUCTION The **stator** consists of the stationary coil windings inside the alternator. The stator is supported between the two halves of the alternator housing, with three copper wire windings that are wound on a laminated metal core.

As the rotor revolves, its moving magnetic field induces a current in the stator windings. ● **SEE FIGURE 54–8.**

DIODES **Diodes** are constructed of a semiconductor material (usually silicon) and operate as a one-way electrical check valve that permits the current to flow in only one direction. Alternators often

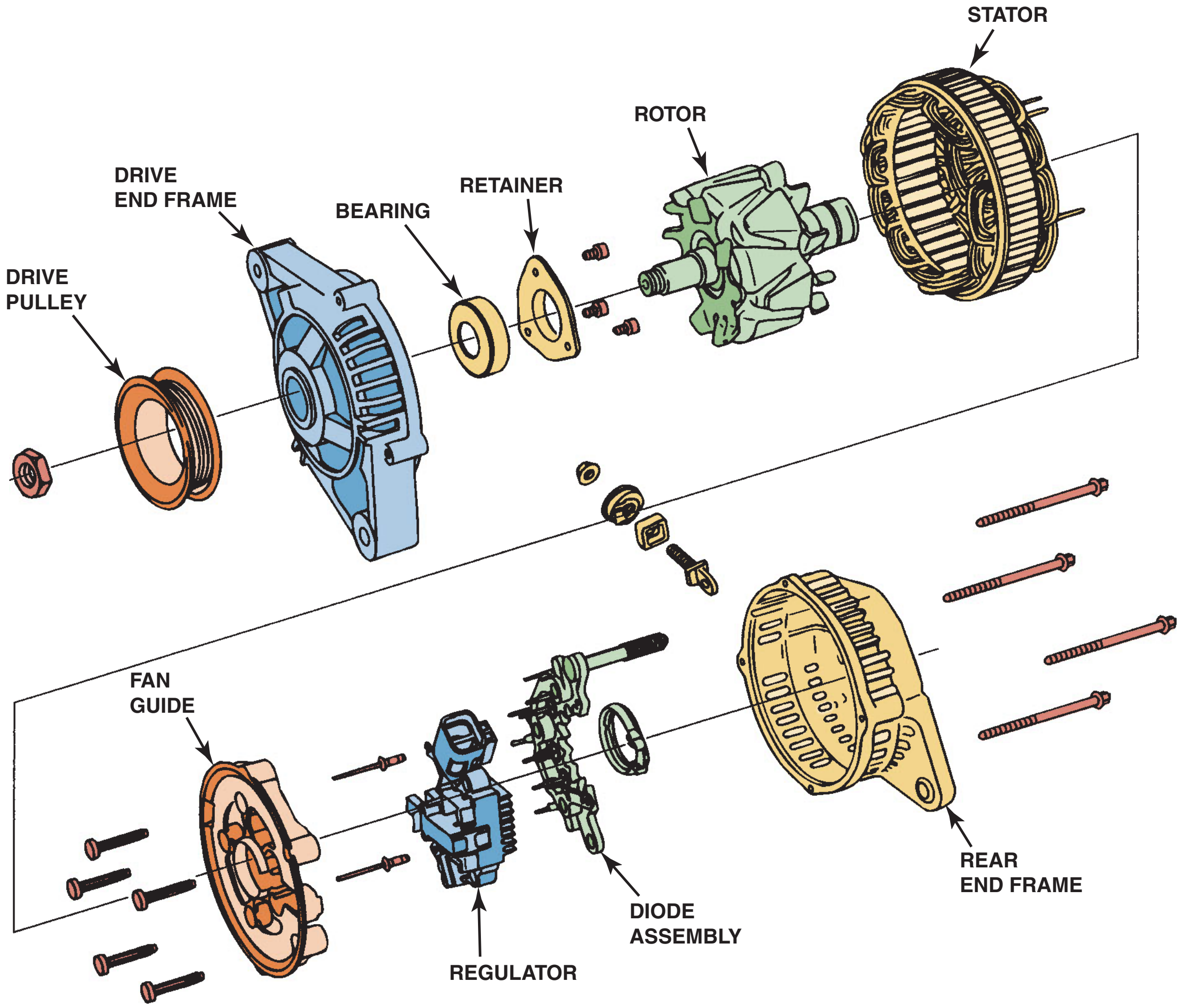

FIGURE 54–8 An exploded view of a typical alternator showing all of its internal parts including the stator windings.

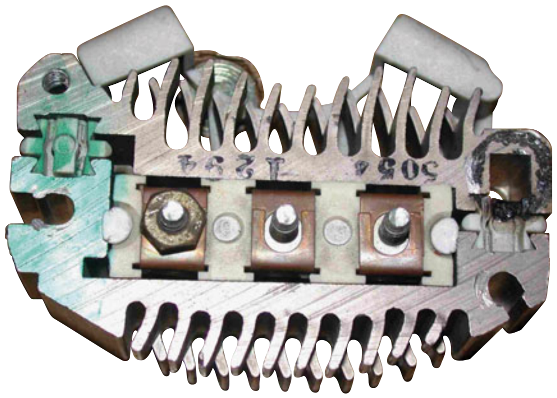

FIGURE 54–9 A rectifier usually includes six diodes in one assembly and is used to rectify AC voltage from the stator windings into DC voltage suitable for use by the battery and electrical devices in the vehicle.

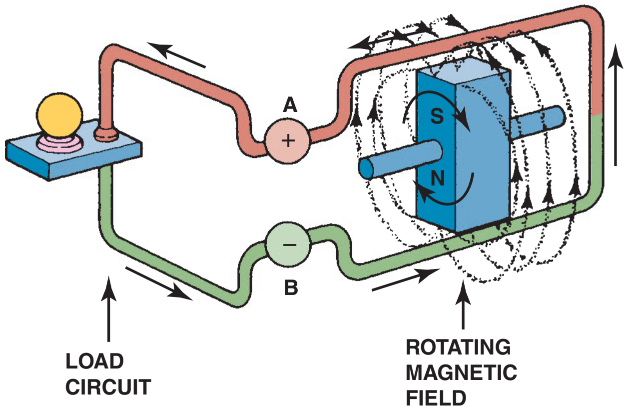

FIGURE 54–10 Magnetic lines of force cutting across a conductor induce a voltage and current in the conductor.

use six diodes (one positive and one negative set for each of the three stator windings) to convert alternating current to direct current.

Diodes used in alternators are included in a single part called a **rectifier,** or *rectifier bridge*. A rectifier not only includes the diodes (usually six), but also the cooling fins and connections for the stator windings and the voltage regulator. ● **SEE FIGURE 54–9.**

DIODE TRIO Some alternators are equipped with a diode trio that supplies current to the brushes from the stator windings. A diode trio uses three diodes, in one housing, with one diode for each of the three stator windings and then one output terminal.

HOW AN ALTERNATOR WORKS

FIELD CURRENT IS PRODUCED A rotor inside an alternator is turned by a belt and drive pulley which are turned by the engine. The magnetic field of the rotor generates a current in the stator windings by electromagnetic induction. ● **SEE FIGURE 54–10.**

Field current flowing through the slip rings to the rotor creates an alternating north and south pole on the rotor, with a magnetic field between each finger of the rotor.

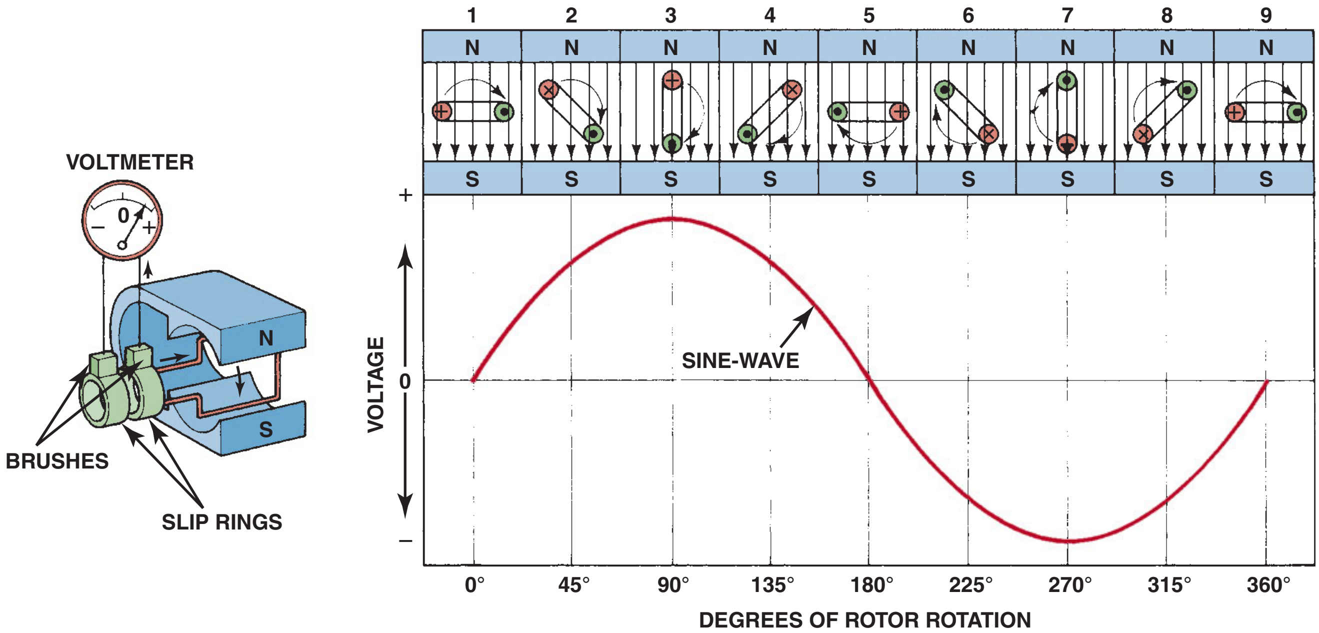

FIGURE 54–11 A sine wave (shaped like the letter *S* on its side) voltage curve is created by one revolution of a winding as it rotates in a magnetic field.

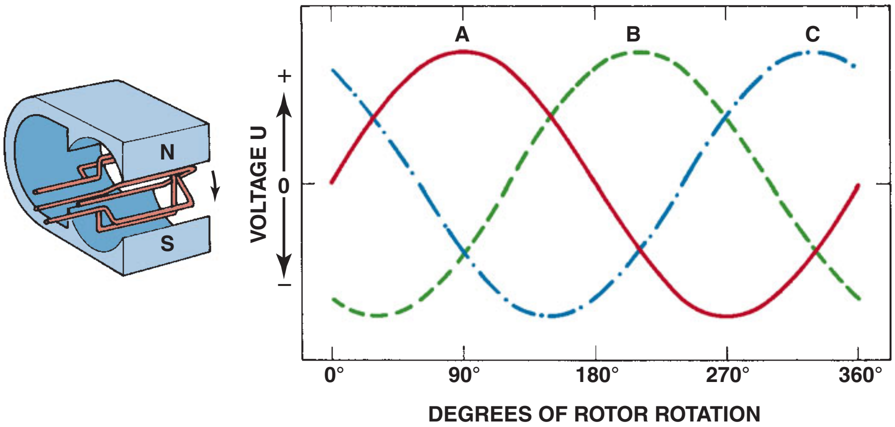

FIGURE 54–12 When three windings (A, B, and C) are present in a stator, the resulting current generation is represented by the three sine waves. The voltages are 120 degrees out of phase. The connection of the individual phases produces a three-phase alternating voltage.

CURRENT IS INDUCED IN THE STATOR The induced current in the stator windings is an alternating current because of the alternating magnetic field of the rotor. The induced current starts to increase as the magnetic field starts to induce current in each winding of the stator. The current then peaks when the magnetic field is the strongest and starts to decrease as the magnetic field moves away from the stator winding. Therefore, the current generated is described as being of a sine wave or alternating current pattern. ● **SEE FIGURE 54–11.**

As the rotor continues to rotate, this sine wave current is induced in each of the three windings of the stator.

Because each of the three windings generates a sine wave current, as shown in ● **FIGURE 54–12,** the resulting currents combine to form a three-phase voltage output.

The current induced in the stator windings connects to diodes (one-way electrical check valves) that permit the alternator output current to flow in only one direction. All alternators contain six diodes, one pair (a positive and a negative diode) for each of the three stator windings. Some alternators contain eight diodes with another pair connected to the center connection of a wye-type stator.

WYE-CONNECTED STATORS The Y (pronounced "wye" and generally so written) type or star pattern is the most commonly used alternator stator winding connection. ● **SEE FIGURE 54–13.**

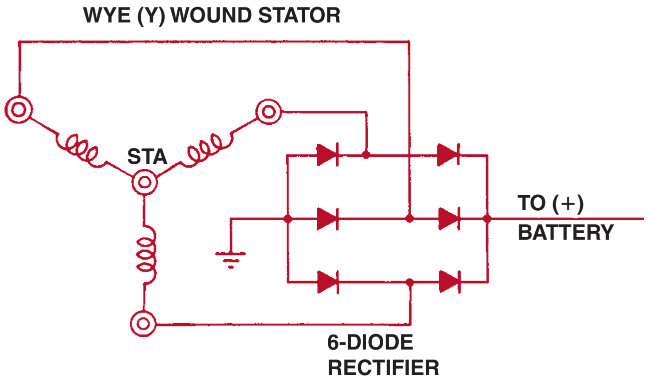

FIGURE 54–13 Wye-connected stator winding.

The output current with a wye-type stator connection is constant over a broad alternator speed range.

Current is induced in each winding by electromagnetic induction from the rotating magnetic fields of the rotor. In a wye-type stator connection, the currents must combine because two windings are always connected in series. ● **SEE FIGURE 54–14.**

The current produced in each winding is added to the other windings' current and then flows through the diodes to the alternator output terminal. One-half of the current produced is available at the

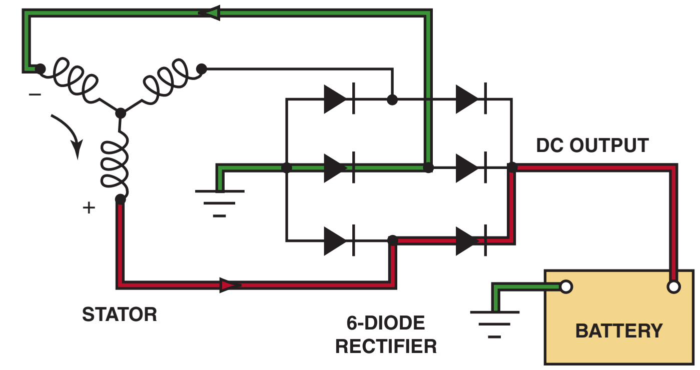

FIGURE 54–14 As the magnetic field, created in the rotor, cuts across the windings of the stator, a current is induced. Notice that the current path includes passing through one positive (+) diode on the way to the battery and one negative (−) diode as a complete circuit is completed through the rectifier and stator.

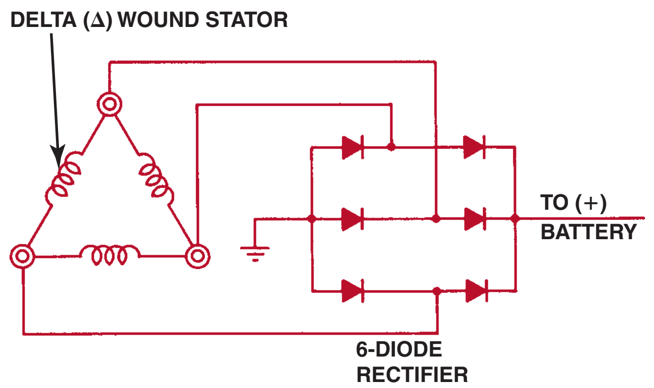

FIGURE 54–15 Delta-connected stator winding.

neutral junction (usually labeled "STA" for stator). The voltage at this center point is used by some alternator manufacturers (especially Ford) to control the charge indicator light or is used by the voltage regulator to control the rotor field current.

DELTA-CONNECTED STATORS The **delta winding** is connected in a triangular shape. Delta is a Greek letter shaped like a triangle. ● **SEE FIGURE 54–15.**

Current induced in each winding flows to the diodes in a parallel circuit. More current can flow through two parallel circuits than can flow through a series circuit (as in a wye-type stator connection).

Delta-connected stators are used on alternators where high output at high-alternator RPM is required. The delta-connected alternator can produce 73% more current than the same alternator with wye-type stator connections. For example, if an alternator with a wye-connected stator can produce 55 A, the *same* alternator with delta-connected stator windings can produce 73% more current, or 95 A ($55 \times 1.73 = 95$). The delta-connected alternator, however, produces lower current at low speed and must be operated at high speed to produce its maximum output.

ALTERNATOR OUTPUT FACTORS

The output voltage and current of an alternator depend on the following factors.

1. **Speed of rotation.** Alternator output is increased with alternator rotational speed up to the alternator's maximum possible ampere output. Alternators normally rotate at a speed two to three times faster than engine speed, depending on the relative pulley sizes used for the belt drive. For example, if an engine is operating at 5000 RPM, the alternator will be rotating at about 15,000 RPM.

FIGURE 54–16 A stator assembly with six, rather than the normal three, windings.

2. **Number of conductors.** A high-output alternator contains more turns of wire in the stator windings. Stator winding connections (whether wye or delta) also affect the maximum alternator output. ● **SEE FIGURE 54–16** for an example of a stator that has six rather than three windings, which greatly increases the amperage output of the alternator.
3. **Strength of the magnetic field.** If the magnetic field is strong, a high output is possible because the current generated by electromagnetic induction is dependent on the number of magnetic lines of force that are cut.
   a. The strength of the magnetic field can be increased by increasing the number of turns of conductor wire wound on the rotor. A higher output alternator rotor has more turns of wire than an alternator rotor with a low rated output.
   b. The strength of the magnetic field also depends on the current through the field coil (rotor). Because magnetic field strength is measured in ampere-turns, the greater the amperage or the number of turns, or both, the greater the alternator output.

ALTERNATOR VOLTAGE REGULATION

PRINCIPLES An automotive alternator must be able to produce electrical pressure (voltage) higher than battery voltage to charge the battery. Excessively high voltage can damage the battery, electrical components, and the lights of a vehicle. Basic principles include the following:

- If no (zero) amperes of current existed throughout the field coil of the alternator (rotor), alternator output would be zero because without field current a magnetic field does not exist.
- The field current required by most automotive alternators is less than 3 amperes. It is the *control* of the *field* current that controls the output of the alternator.
- Current for the rotor flows from the battery positive post, through the rotor positive brush, into the rotor field winding, and exits the rotor winding through the rotor ground brush. Most voltage regulators control field current by controlling the amount of field current through the ground brush.
- The voltage regulator simply opens the field circuit if the voltage reaches a predetermined level, then closes the field

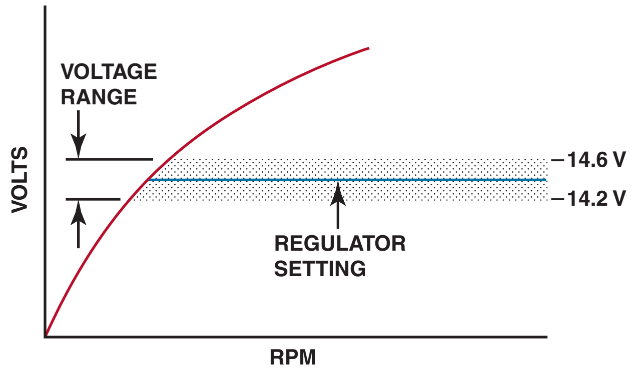

FIGURE 54–17 Typical voltage regulator range.

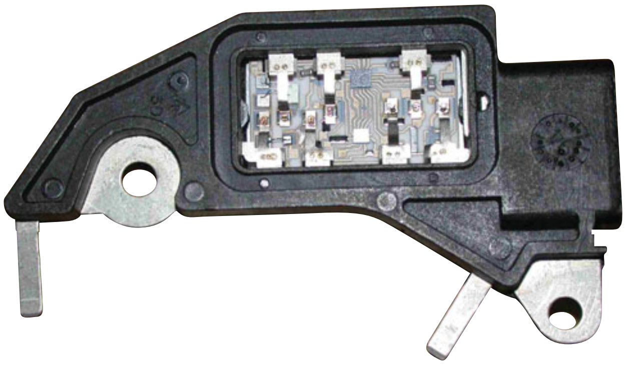

FIGURE 54–18 A typical electronic voltage regulator with the cover removed showing the circuits inside.

circuit again as necessary to maintain the correct charging voltage. ● **SEE FIGURE 54–17.**

- The electronic circuit of the voltage regulator cycles between 10 and 7,000 times per *second* as needed to accurately control the field current through the rotor, and therefore control the alternator output.

REGULATOR OPERATION

- The control of the field current is accomplished by opening and closing the *ground* side of the field circuit through the rotor on most alternators.
- The zener diode is a major electronic component that makes voltage regulation possible. A zener diode blocks current flow until a specific voltage is reached, then it permits current to flow. Alternator voltage from the stator and diodes is first sent through a thermistor, which changes resistance with temperature, and then to a zener diode. When the upper-limit voltage is reached, the zener diode conducts current to a transistor, which then opens the field (rotor) circuit. The electronics are usually housed in a separate part inside the alternator.● **SEE FIGURES 54–18 AND 54–19.**

BATTERY CONDITION AND CHARGING VOLTAGE If the automotive battery is discharged, its voltage will be lower than the voltage of a fully charged battery. The alternator will supply charging current, but it may not reach the maximum charging voltage. For example, if a vehicle is jump started and run at a fast idle (2,000 RPM), the charging voltage may be only 12 volts. In this case, the following may occur.

- As the battery becomes charged and the battery voltage increases, the charging voltage will also increase, until the voltage regulator limit is reached.

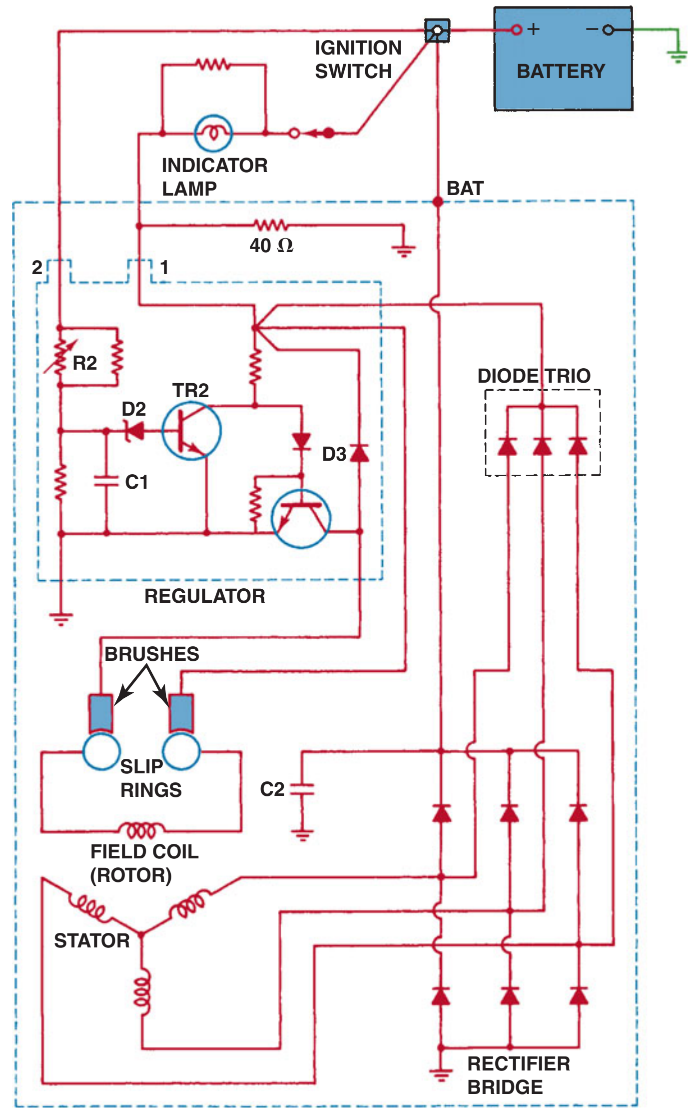

FIGURE 54–19 Typical General Motors SI-style alternator with an integral voltage regulator. Voltage present at terminal 2 is used to reverse bias the zener diode (D2) that controls TR2. The positive brush is fed by the ignition current (terminal I) plus current from the diode trio.

- Then the voltage regulator will start to control the charging voltage. A good, but discharged, battery should be able to convert into chemical energy all the current the alternator can produce. As long as alternator voltage is higher than battery voltage, current will flow from the alternator (high voltage) to the battery (lower voltage).
- Therefore, if a voltmeter is connected to a discharged battery with the engine running, it may indicate charging voltage that is lower than normally acceptable.

In other words, the condition and voltage of the battery *do* determine the charging rate of the alternator. It is often stated that the battery is the true "voltage regulator" and that the voltage regulator simply acts as the upper-limit voltage control. This is the reason why all charging system testing *must* be performed with a reliable and known to be good battery, at least 75% charged, to be assured of accurate test results. If a discharged battery is used during charging system testing, tests could mistakenly indicate a defective alternator and/or voltage regulator and could cause the stator windings to overheat.

TEMPERATURE COMPENSATION All voltage regulators (mechanical or electronic) provide a method for increasing the charging

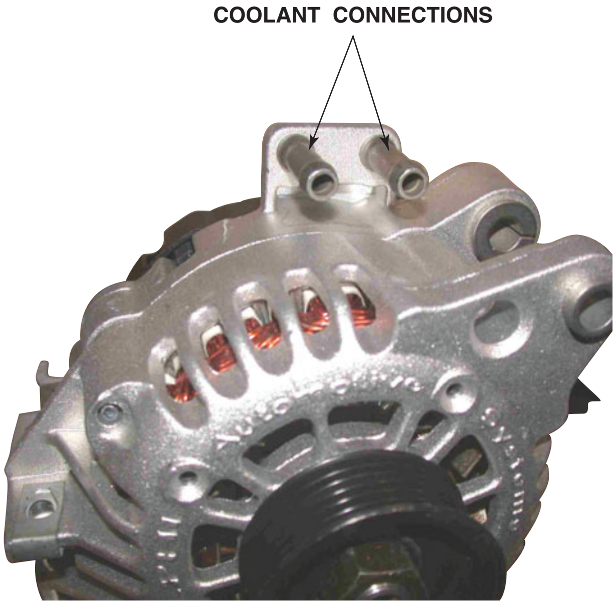

FIGURE 54–20 A coolant-cooled alternator showing the hose connections where coolant from the engine flows through the rear frame of the alternator.

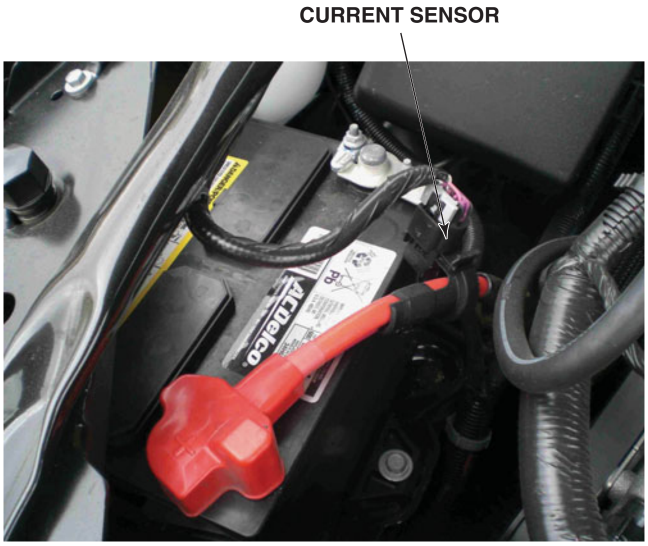

FIGURE 54–21 A Hall-effect current sensor attached to the positive battery cable is used as part of the EPM system.

voltage slightly at low temperatures and for lowering the charging voltage at high temperatures. A battery requires a higher charging voltage at low temperatures because of the resistance to chemical reaction changes. However, the battery would be overcharged if the charging voltage were not reduced during warm weather. Electronic voltage regulators use a temperature-sensitive resistor in the regulator circuit. This resistor, called a **thermistor,** provides lower resistance as the temperature increases. A thermistor is used in the electronic circuits of the voltage regulator to control charging voltage over a wide range of underhood temperatures.

NOTE: Voltmeter test results may vary according to temperature. Charging voltage tested at 32°F (0°C) will be higher than for the same vehicle tested at 80°F (27°C) because of the temperature-compensation factors built into voltage regulators.

ALTERNATOR COOLING

Alternators create heat during normal operation and this heat must be removed to protect the components inside, especially the diodes and voltage regulator. The types of cooling include:

- External fan
- Internal fan(s)
- Both an external fan and an internal fan
- Coolant cooled (● **SEE FIGURE 54–20.**)

COMPUTER-CONTROLLED ALTERNATORS

TYPES OF SYSTEMS Computers can interface with the charging system in three ways.

1. The computer can *activate* the charging system by turning on and off the field current to the rotor. In other words, the computer, usually the powertrain control module (PCM), controls the field current to the rotor.
2. The computer can *monitor* the operation of the alternator and increase engine speed if needed during conditions when a heavy load is demanded by the alternator.
3. The computer can *control* the alternator by controlling alternator output to match the needs of the electrical system. This system detects the electrical needs of the vehicle and commands the alternator to charge only when needed to improve fuel economy.

GM ELECTRICAL POWER MANAGEMENT SYSTEM A typical system used on some General Motors vehicles is called **electrical power management (EPM).** It uses a Hall-effect sensor attached to the negative or positive battery cable to measure the current leaving and entering the battery. ● **SEE FIGURE 54–21.**

The engine control module (ECM) controls the alternator by changing the on-time of the current through the rotor. ● **SEE FIGURE 54–22.**

The on-time, called **duty cycle,** varies from 5% to 95%. ● **SEE CHART 54–1.**

This system has six modes of operation.

1. **Charge mode.** The charge mode is activated when any of the following occurs.
   - Electric cooling fans are on high speed.
   - Rear window defogger is on.
   - Battery state of charge (SOC) is less than 80%.
   - Outside (ambient) temperature is less than 32°F (0°C).
2. **Fuel economy mode.** This mode reduces the load on the engine from the alternator for maximum fuel economy. This mode is activated when the following conditions are met.
   - Ambient temperature is above 32°F (0°C).
   - The state of charge of the battery is 80% or higher.
   - The cooling fans and rear defogger are off.

   The target voltage is 13 volts and will return to the charge mode, if needed.
3. **Voltage reduction mode.** This mode is commanded to reduce the stress on the battery during low-load conditions. This mode is activated when the following conditions are met.
   - Ambient temperature is above 32°F (0°C).
   - Battery discharge rate is less than 7 amperes.
   - Rear defogger is off.
   - Cooling fans are on low or off.
   - Target voltage is limited to 12.7 volts.