

8

Charging System Operation

LEARNING OBJECTIVES

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

- Identify charging system development and principles.
- Explain the operation of a DC generator.
- Identify AC charging system components and explain charging voltage.
- Explain diode rectification.
- Identify AC generator components and explain their function.
- Explain current production in an AC generator (alternator) operation.
- Identify different OEM AC generators and explain those differences.
- Explain how voltage is regulated in an AC generator.
- Identify the different types of voltage regulators and explain how they operate.

KEY TERMS

AC Generators
Delta-Type Stator
Diode
Field Circuit
Full-Wave Rectification
Half-Wave Rectification
Output Circuit
Rotor
Sine Wave Voltage
Single-Phase Current
Single-Phase Voltage
Sliprings and Brushes
Stator
Three-phase Current
Voltage Regulator
Y-Type Stator

INTRODUCTION

The charging system converts the engine's mechanical energy into electrical energy. This electrical energy is used to maintain the battery's state of charge and to operate the loads of the automotive electrical system. In this chapter we will use the conventional theory of current: Electrons move from positive to negative (+ to -).

During cranking, all electrical energy for the vehicle is supplied by the battery. After the engine is running, the charging system must produce enough electrical energy to recharge the battery and to supply the demands of other loads in the electrical system. If the starting system is in poor condition and draws too much current, or if the charging system cannot recharge the battery and supply the additional loads, more energy must be drawn from the battery for short periods of time.

CHARGING SYSTEM DEVELOPMENT

For many years, automotive charging systems used only direct current (DC) generators to provide electrical energy. Internally, generators produce an alternating current voltage, which is mechanically rectified by the commutator into direct current voltage. Systems using DC generators are called DC charging systems. Vehicles with DC generators are very rare today.

AC generators or alternators also produce alternating current (AC), but there was no simple way to rectify the current until semiconductor technology finally provided the answer in the form of diodes, or one-way electrical valves. Since the mid-1960s, virtually all new automobiles have diode-rectified AC generators (alternators) in their charging systems.

AC generators (alternators) replaced DC generators back in the late fifties, except for Volkswagen, which used DC generators until 1975. In the automotive charging system, they have the following advantages:

- Weigh less per ampere of output
- Can be operated at much higher speed
- Pass less current through the brushes with only a few amperes of field current, reducing brush wear
- Govern their own maximum current output, requiring no external current regulation
- Can produce current when rotated in either direction, although their cooling fans usually are designed for one-way operation.

DC GENERATOR

The principles of electromagnetic induction are employed in generators for producing DC current. The basic components of a DC generator are

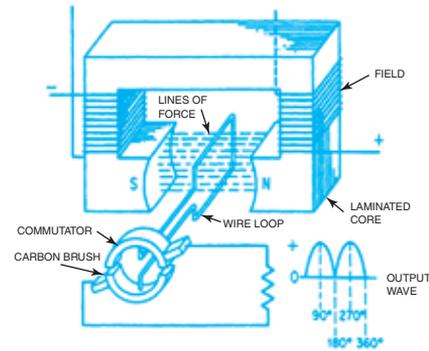


Figure 8-1. DC generator.

shown in Figure 8-1. A framework composed of laminated iron sheets or other ferromagnetic metal has a coil wound on it to form an electromagnet. When current flows through this coil, magnetic fields are created between the pole pieces, as shown. Permanent magnets could also be employed instead of the electromagnet.

To simplify the initial explanation, a single wire loop is shown between the north and south pole pieces. When this wire loop is turned within the magnetic fields it cuts the lines of force and a voltage is induced. If there is a complete circuit from the wire loop, current will flow. The wire loop is connected to a split ring known as a commutator, and carbon brushes pick off the electric energy as the commutator rotates. Connecting wires from the carbon brushes transfer the energy to the load circuit.

When the wire loop makes a half-turn, the energy generated rises to a maximum level and drops to zero, as shown in Figure 8-1. If the wire loop completed a full rotation, the induced voltage would reverse itself and the current would flow in the opposite direction (AC current) after the initial half-turn. To provide for an output having a single polarity (DC current), a split-ring commutator is used. Thus, for the second half-turn, the carbon brushes engage commutator segments opposite to those over which they slid for the first half-turn, keeping the current in the same direction. The output waveform is not a steady-level DC, but rises and falls to form a pattern referred to as *pulsating DC*. Thus, for a complete 360-degree turn of the wire loop, two waveforms are produced, as shown in Figure 8-1.

CHARGING VOLTAGE

Although the automotive electrical system is called a 12-volt system, the AC generator (alternator) must produce more than 12 volts. A fully charged

battery produces about 2.1 volts per cell; this means the open-circuit voltage of a fully charged 12-volt battery, which has six cells, is approximately 12.6 volts. If the AC generator cannot produce more than 12.6 volts, it cannot charge the battery until the system voltage drops under 12.6 volts. This would leave nothing extra to serve the other electrical demands put on the system by lights, air conditioning, and power accessories.

Alternating-current charging systems are generally regulated to produce a maximum output of 14.5 volts. Output of more than 16 volts will overheat the battery electrolyte and shorten its life. High voltage also damages components that rely heavily on solid-state electronics, such as fuel injection and engine control systems. On the other hand, low voltage output causes the battery to become sulfated. The charging system must be maintained within the voltage limits specified by the manufacturer if the vehicle is to perform properly.

AC Charging System Components

The automotive charging system. (Figure 8-2) contains the following:

- A battery, which provides current to initiate the magnetic field required to operate the AC generator (alternator) and, in turn, is charged and maintained by the AC generator.
- An AC generator (alternator), which is belt-driven by the engine and converts mechanical motion into charging voltage and current.

The simple AC generator (alternator) shown in Figure 8-3 consists of a magnet rotating inside a fixed-loop stator, or conductor. The alternating

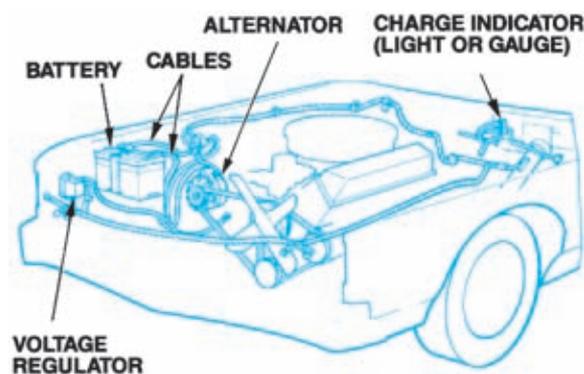


Figure 8-2. Major components of an automotive charging system. (DaimlerChrysler Corporation)

current produced in the conductor is rectified by diodes for use by the electrical system.

- A **voltage regulator**, which limits the field current and thus the AC generator (alternator) output voltage according to the electrical system demand. A regulator can be either an electromechanical or a solid-state device. Some late-model, solid-state regulators are part of the vehicle's onboard computer.
- An ammeter, a voltmeter, or indicator warning lamp mounted on the instrument panel to give a visual indication of charging system operation.

Charging System Circuits

The charging system consists of the following major circuits (Figure 8-4):

- The **field circuit**, which delivers current to the AC generator (alternator) field
- The **output circuit**, which sends voltage and current to the battery and other electrical components

Single-Phase Current

AC Generators (alternators) induce voltage by rotating a magnetic field inside a fixed conductor. The greatest current output is produced when the rotor is parallel to the stator with its magnetic field at right angles to the stator, as in Figure 8-3. When the rotor makes one-quarter of a revolution and is at right angles to the stator with its magnetic field parallel to the stator, as in Figure 8-5, there is no

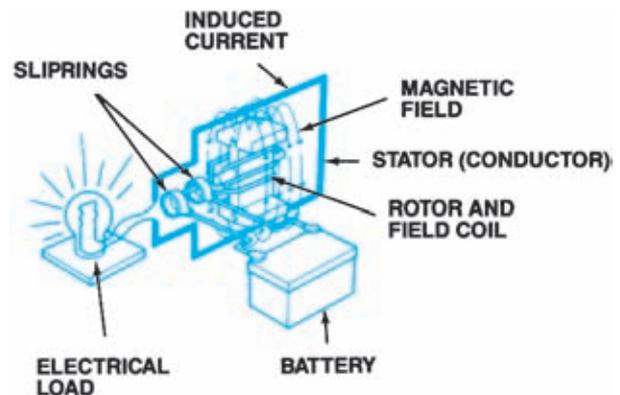


Figure 8-3. An AC generator (alternator) is based on the rotation of a magnet inside a fixed-loop conductor. (DaimlerChrysler Corporation)

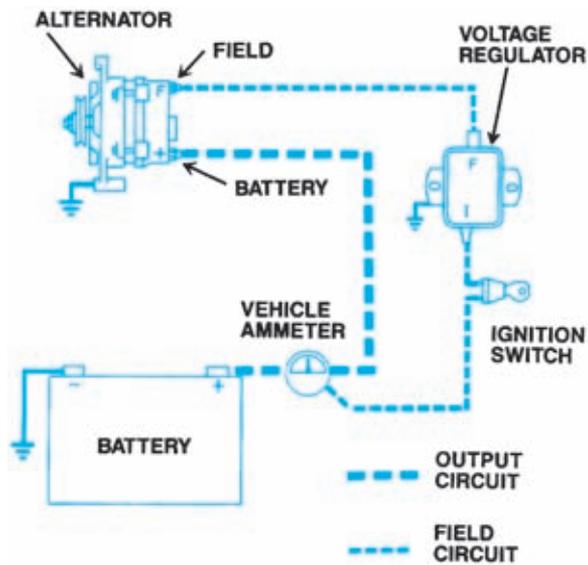


Figure 8-4. The output circuit and the field circuit make up the automotive charging system. (DaimlerChrysler Corporation)

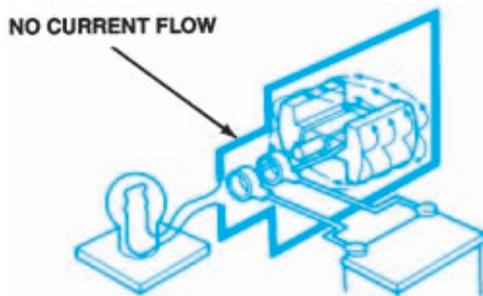


Figure 8-5. No current flows when the rotor's magnetic field is parallel to the stator. (DaimlerChrysler Corporation)

current output. Figure 8-6 shows the voltage levels induced across the upper half of the looped conductor during one revolution of the rotor.

The constant change of voltage, first to a positive peak and then to a negative peak, produces a **sine wave voltage**. This name comes from the trigonometric sine function. The wave shape is controlled by the angle between the magnet and the conductor. The sine wave voltage induced across one conductor by one rotor revolution is called a **single-phase voltage**. Positions 1 through 5 of Figure 8-6 show complete sine wave single-phase voltage.

This single-phase voltage causes alternating current to flow in a complete circuit because the voltage switches from positive to negative as the rotor

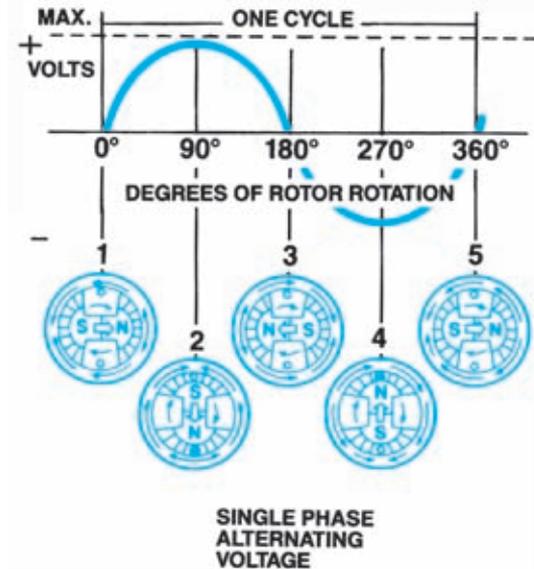


Figure 8-6. These are the voltage levels induced across the upper half of the conductor during one rotor revolution. (DaimlerChrysler Corporation)

turns. The alternating current caused by a single-phase voltage is called **single-phase current**.

DIODE RECTIFICATION

If the single-phase voltage shown in Figure 8-6 made current travel through a simple circuit, the current would flow first in one direction and then in the opposite direction. As long as the rotor turned, the current would reverse its flow with every half revolution. The battery cannot be recharged with alternating current. Alternating current must be rectified to direct current to recharge the battery. This is done with diodes.

A **diode** acts as a one-way electrical valve. If a diode is inserted into a simple circuit, as shown in Figure 8-7, one-half of the AC voltage is blocked. That is, the diode allows current to flow from X to Y, as shown in position A. In position B, the current cannot flow from Y to X because it is blocked by the diode. The graph in Figure 8-7 shows the total current.

The first half of the current, from X to Y, was allowed to pass through the diode. It is shown on the graph as curve XY. The second half of the current, from Y to X, was not allowed to pass through the diode. It does not appear on the graph because it never traveled through the circuit. When the

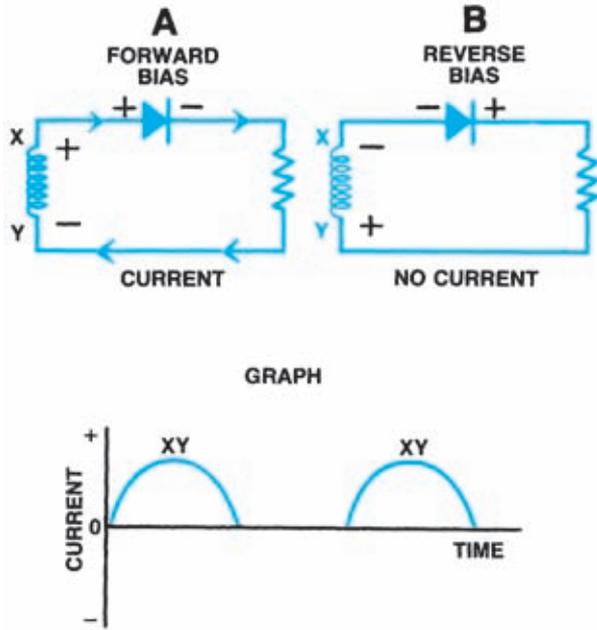


Figure 8-7. A single diode in the circuit results in half-wave rectification. (Delphi Automotive Systems)

voltage reverses at the start of the next rotor revolution, the current is again allowed through the diode from X to Y.

An AC generator with only one conductor and one diode would show this current output pattern. However, this output would not be very useful because half of the time there is no current available. This is called **half-wave rectification**, since only half of the AC voltage produced by the AC generator is allowed to flow as DC voltage.

Adding more diodes to the circuit, as shown in Figure 8-8, allows more of the AC voltage to be rectified to DC. In position A, current moves from X to Y. It travels from X, through diode 2, through the load, through diode 3, and back to Y. In position B, current moves from Y to X. It travels from Y, through diode 4, through the load, through diode 1, and back to X.

Notice that in both cases current traveled through the load in the same direction. This is because the AC has been rectified to DC. The graph in Figure 8-8 shows the current output of an AC generator with one conductor and four diodes.

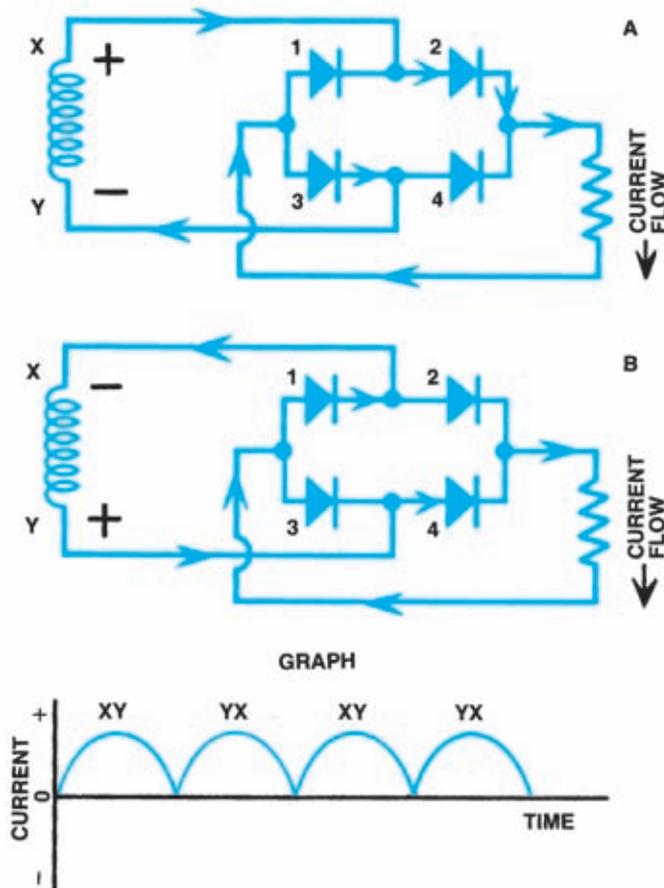


Figure 8-8. More diodes are needed in the circuit for full-wave rectification. (Delphi Automotive Systems)

There is more current available because all of the voltage has been rectified. This is called **full-wave rectification**. However, there are still moments when current is at zero. Most automotive AC generators use three conductors and six diodes to produce overlapping current waves so that current output is *never* at zero.

Heat Sinks

The term *heat sink* is commonly used to describe the block of aluminum or other material in which the AC generator diodes are mounted. The job of the heat sink is to absorb and carry away the heat in the diodes caused by electrical current through them. This action keeps the diodes cool and prevents damage. An internal combustion engine is also a heat sink. The engine is designed so that the combustion and friction heat are carried away and dissipated to the atmosphere. Although they are not thought of as heat sinks, many individual parts of an automobile—such as the brake drums—are also designed to do this important job.

AC GENERATOR (ALTERNATOR) COMPONENTS

The previous illustrations have shown the principles of AC generator operation. To provide enough direct current for an automobile, AC generators must have a more complex design. But no matter how the design varies, the principles of operation remain the same.

The design of the AC generator limits its maximum output. To change this maximum value for different applications, manufacturers change the design of the stator, rotor, and other components. The following paragraphs describe the major parts of an automotive AC generator.

Rotor

The **rotor** carries the magnetic field. Unlike a DC generator, which usually has only two magnetic poles, the AC generator rotor has several north (N) and south (S) poles. This increases the number of flux lines within the AC generator and increases the voltage output. A typical automotive rotor (Figure 8-9) has 12 poles: 6 N and 6 S. The rotor consists of two steel rotor halves, or pole pieces,

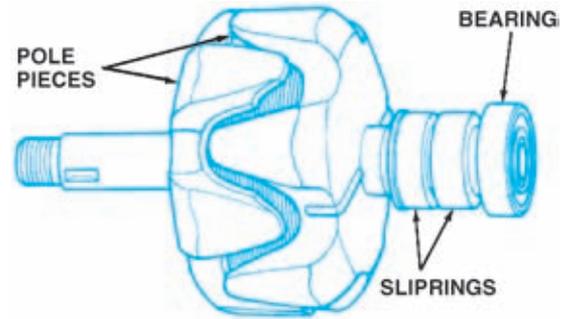


Figure 8-9. Rotor. (DaimlerChrysler Corporation)

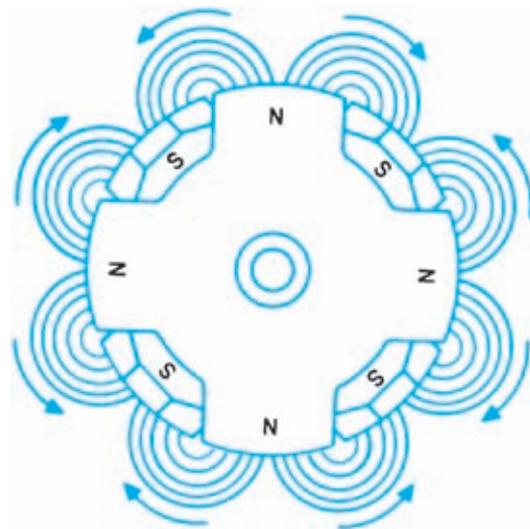


Figure 8-10. The flux lines surrounding an 8-pole rotor. (DaimlerChrysler Corporation)

with fingers that interlace. These fingers are the poles. Each pole piece has either all N or all S poles. The magnetic flux lines travel between adjacent N and S poles (Figure 8-10). Keep in mind that an alternator is an AC generator; in some European manufacturers' service manuals, the AC generator (alternator) is referred to as a generator.

Along the outside of the rotor, note that the flux lines point first in one direction and then in the other. This means as the rotor spins inside the AC generator, the fixed conductors are being cut by flux lines, which point in alternating directions. The induced voltage alternates, just as in the example of a simple AC generator with only two poles. Automotive AC generators may have any number of poles, as long as they are placed N-S-N-S. Common designs use eight to fourteen poles.

The rotor poles may retain some magnetism when the AC generator is not in operation, but this

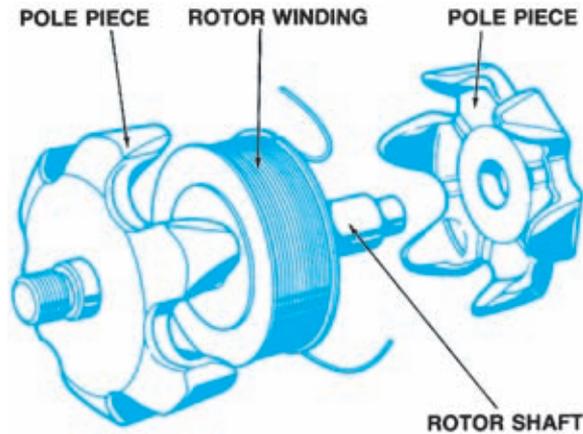


Figure 8-11. The magnetic field of the rotor is created by current through the rotor winding. (Reprinted by permission of Robert Bosch GmbH)

residual magnetism is not strong enough to induce any voltage across the conductors. Current produces the magnetic field of the rotor through the rotor winding, which is a coil of wire between the two pole pieces (Figure 8-11). This is also called the excitation winding, or the field winding. Varying the amount of field current through the rotor winding varies the strength of the magnetic field, which affects the voltage output of the AC generator. A soft iron core is mounted inside the rotor-winding (Figure 8-12). One pole piece is attached to either end of the core; when field current travels through the winding, the iron core is magnetized, and the pole pieces take on the magnetic polarity of the end of the core to which they are attached. Current is supplied to the winding through **sliprings and brushes**.

The combination of a soft iron rotor core and steel rotor halves provides better localization and permeability of the magnetic field. The rotor pole pieces, winding, core, and sliprings are pressed onto a shaft. The ends of this shaft are supported by bearings in the AC generator housing. Outside the housing, a drive pulley is attached to the shaft, as shown in Figure 8-13. A belt, driven by the engine crankshaft-pulley, passes around the drive pulley to turn the AC generator shaft and rotor assembly.

Stator

The three AC generator conductors are wound onto a cylindrical, laminated core. The lamination prevents unwanted eddy currents from forming in the core. The assembled piece is called a

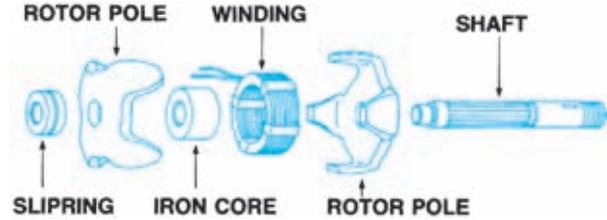


Figure 8-12. Exploded view of the parts of the complete rotor assembly. (DaimlerChrysler Corporation)

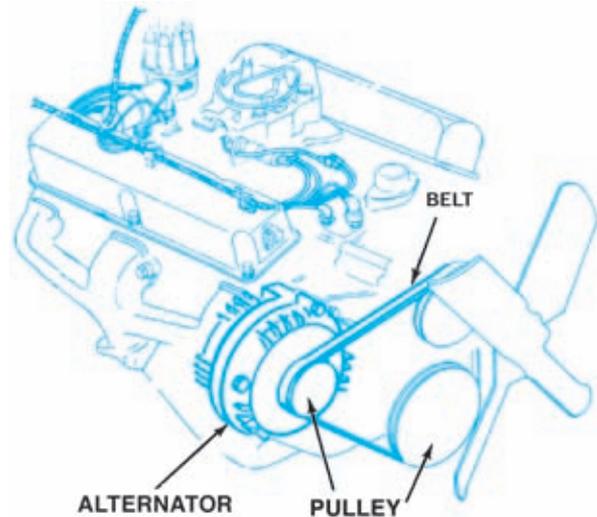


Figure 8-13. AC generator (alternator) and drive pulley. (DaimlerChrysler Corporation)

stator (Figure 8-14). The word stator comes from the word “stationary” because it does not rotate, as does the commutator conductor of a DC generator. Each conductor, called a stator winding, is formed into a number of coils spaced evenly around the core. There are as many coil conductors as there are pairs of N-S rotor poles. Figure 8-15 shows an incomplete stator with only one of its conductors installed: There are seven coils in the conductor, so the matching rotor would have seven pairs of N-S poles, for a total of fourteen poles. There are two ways to connect the three-stator windings.

Housing

The AC generator housing, or frame, is made of two pieces of cast aluminum (Figure 8-16). Aluminum is lightweight and non-magnetic and conducts heat well. One housing piece holds a bearing for the end of the rotor shaft where the



Figure 8-14. An AC generator (alternator) stator.

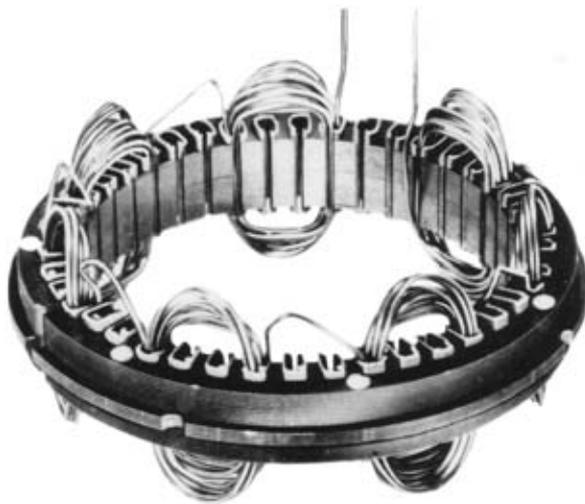


Figure 8-15. A stator with only one conductor installed. (Delphi Automotive Systems)

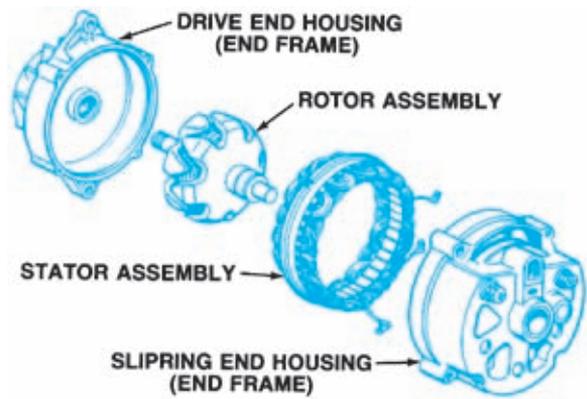


Figure 8-16. AC generator (alternator) housing encloses the rotor and stator.

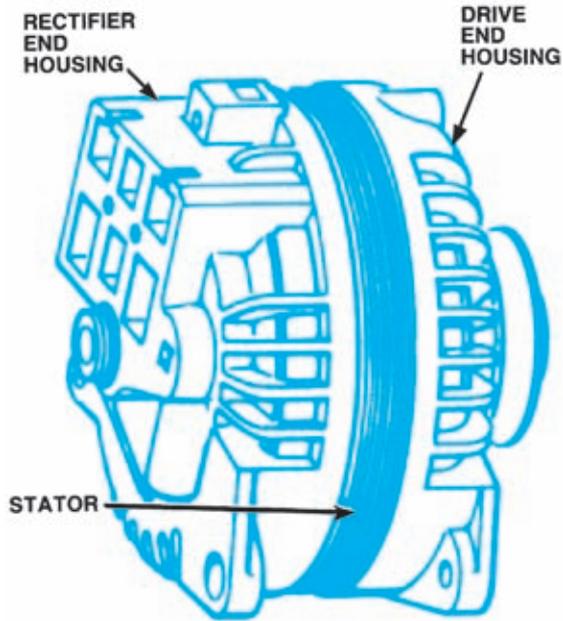


Figure 8-17. AC generator (alternator) with exposed stator core.

drive pulley is mounted. This is often called the drive-end housing, or front housing, of the AC generator. The other end holds the diodes, the brushes, and the electrical terminal connections. It also holds a bearing for the slipping end of the rotor shaft. This is often called the slipping-end housing, or rear housing. Together, the two pieces completely enclose the rotor and the stator windings.

The end housings are bolted together. Some stator cores have an extended rim that is held between the two housings (Figure 8-17). Other stator cores provide holes for the housing bolts, but do not extend to the outside of the housings (Figure 8-18). In both designs, the stator is rigidly bolted in place inside the AC generator housing. The housing is part of the electrical ground path because it is bolted directly to the engine. Anything connected to the housing that is not insulated from the housing is grounded.

Sliprings and Brushes

The sliprings and brushes conduct current to the rotor winding. Most automotive AC generators have two sliprings mounted on the rotor shaft. The sliprings are insulated from the shaft and from each other. One end of the rotor winding is connected to each slipring (Figure 8-19). One brush rides on each ring to carry current to and

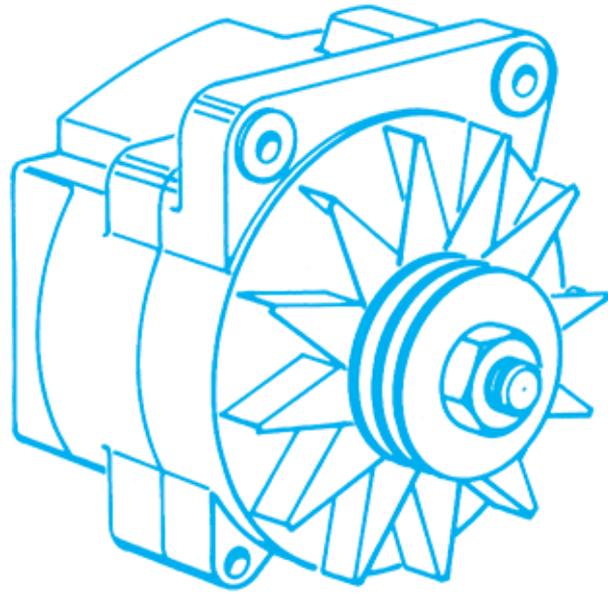


Figure 8-18. AC generator (alternator) with the stator core enclosed.

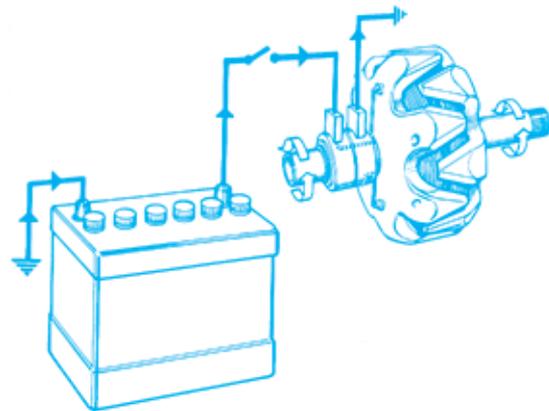


Figure 8-19. The sliprings and brushes carry current to the rotor windings.

from the winding. A brush holder supports each brush and a spring applies force to keep the brush in constant contact with the rotating slipring. The brushes are connected parallel with the AC generator output circuit. They draw some of the AC generator current output and route it through the rotor winding. Current through the winding must be DC. Field current in an AC generator is usually about 1.5 to 3.0 amperes. Because the brushes carry so little current, they do not require as much maintenance as DC generator brushes, which must conduct all of the current output.

For more information about generator maintenance, see the section on “Disassembly, Cleaning, and Inspection” in Chapter 8 of the *Shop Manual*.

Diode Installation

Automotive AC generators that have three stator windings generally use six diodes to rectify the current output. The connections between the conductors and the diodes vary slightly, but each conductor is connected to one positive and one negative diode, as shown in Figure 8-20.

The three positive diodes are always insulated from the AC generator housing. They are connected to the insulated terminal of the battery and to the rest of the automotive electrical system. The battery cannot discharge through this connection because the bias of the diodes blocks any current from the battery. The positive diodes only conduct current traveling from the conductors toward the battery.

The positive diodes are mounted together on a conductor called a heat sink (Figure 8-21). The heat sink carries heat away from the diodes, just as the radiator carries heat away from the engine. Too much heat damages the diodes.

In the past, the three negative diodes were pressed or threaded into the AC generator rear housing. On high-output AC generators, they may be mounted in a heat sink for added protection. In either case, the connection to the AC generator housing is a ground path; the negative diodes

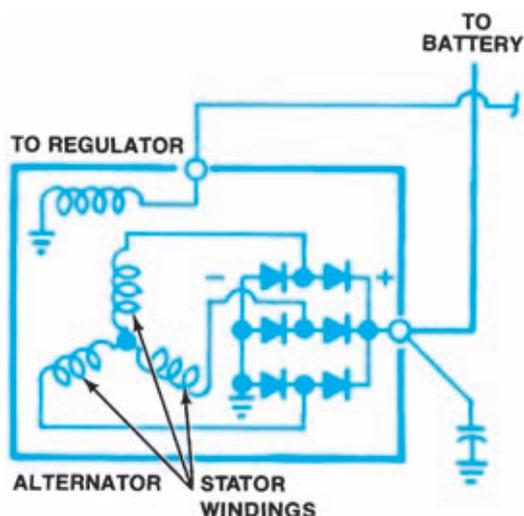


Figure 8-20. Each conductor is attached to one positive and one negative diode.

conduct only the current traveling from ground into the conductors. Each group of three or more negative or positive diodes can be called a diode bridge, a diode trio, or a diode plate. Some manufacturers use complete rectifier assemblies containing all the diodes and connections on a printed circuit board. This assembly is replaced as a unit if any of the individual components fail.

Each stator winding connects to its proper negative diode through a circuit in the rectifier. A capacitor generally is installed between the output terminal at the positive diode heat sink to ground at the negative diode heat sink. This capacitor is used to eliminate voltage-switching transients at the stator, to smooth out the AC voltage fluctuations, and to reduce electromagnetic interference (EMI).

CURRENT PRODUCTION IN AN AC GENERATOR

After studying the principles of AC generator operation and its components, the total picture of how an automotive AC generator produces current becomes clear.

Three-Phase Current

The AC generator stator has three windings. Each is formed into a number of coils, which are spaced evenly around the stator core. The voltages induced across each winding by one rotor revolution are shown in the graphs of Figure 8-22. The

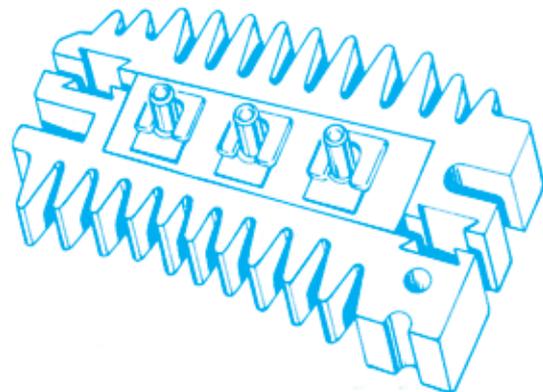


Figure 8-21. Positive and negative diodes may be mounted in a heat sink for protection.

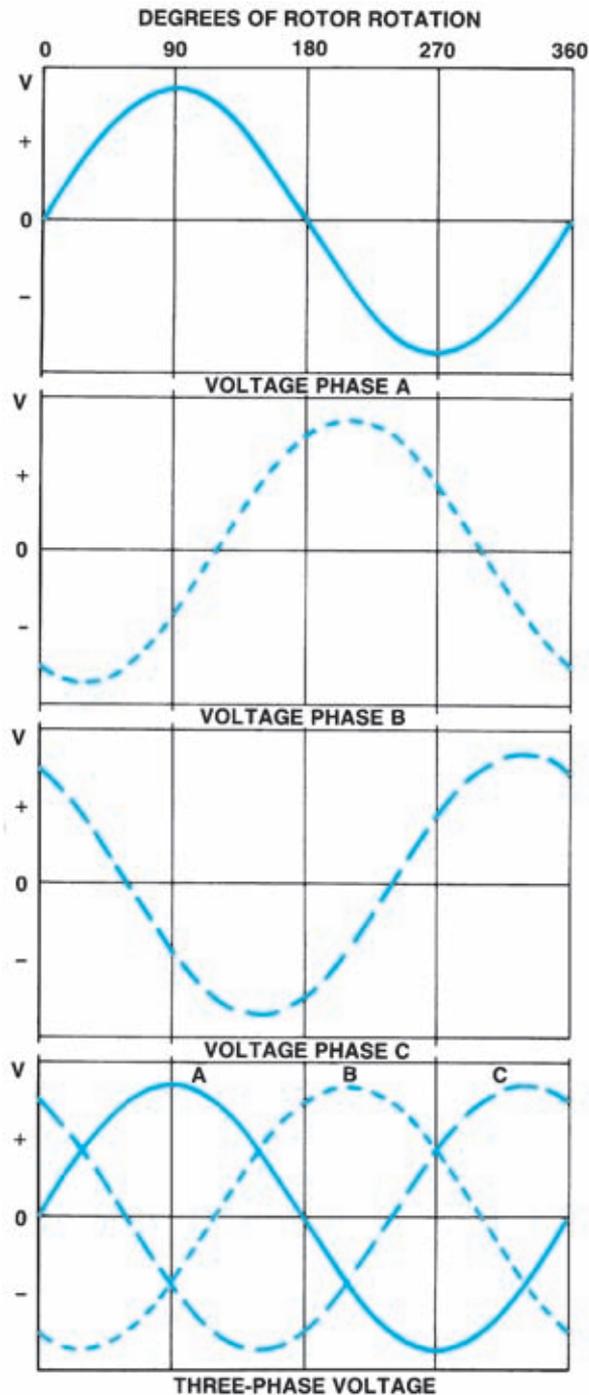


Figure 8-22. The single-phase voltages of three conductors create a three-phase voltage output. (Reprinted by permission of Robert Bosch GmbH)

total voltage output of the AC generator is three overlapping, evenly spaced, single-phase voltage waves, as shown in the bottom graph of the illustration. If the stator windings are connected into a complete circuit, the three-phase voltages cause an AC output called **three-phase current**.

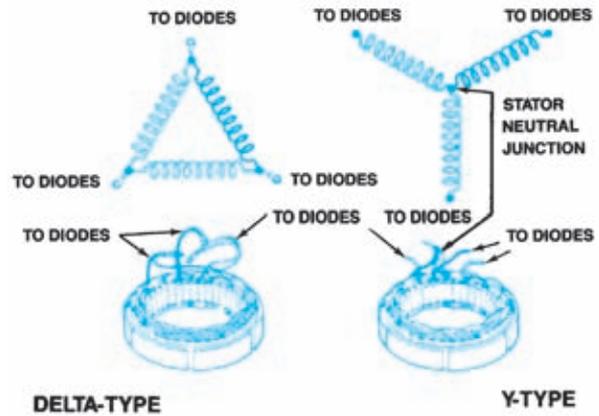


Figure 8-23. Two types of stator windings. (Daimler-Chrysler Corporation)

Stator Types

When the three conductors are completely wound on the stator core, six loose ends remain. The way in which these ends are connected to the diode rectifier circuitry determines if the stator is a Y-type or a Delta-type (Figure 8-23). Both kinds of stators produce three-phase current and the rectification produces DC output. However, the voltage and current levels within the stators differ.

Y-Type Stator Design

In the **Y-type stator** or Y-connected stator, one end of each of the three windings is connected at a neutral junction (Figure 8-23). The circuit diagram of the Y-type stator (Figure 8-24) looks like the letter Y. This is also sometimes called a wye or a star connection. The free end of each conductor is connected to a positive and a negative diode.

In a Y-type stator (Figure 8-24), two windings always form a series circuit between a positive and a negative diode. At any given instant, the position of the rotor determines the direction of current through these two windings. Current flows from the negative voltage to the positive voltage. A complete circuit from ground, through a negative diode, through two of the windings, and through a positive diode to the AC generator output terminal, exists throughout the 360-degree rotation of the rotor. The induced voltages across the two windings added together produce the total voltage at the output terminal. The majority of AC generators in use today have Y-type stators because of the need for high voltage output at low speeds.

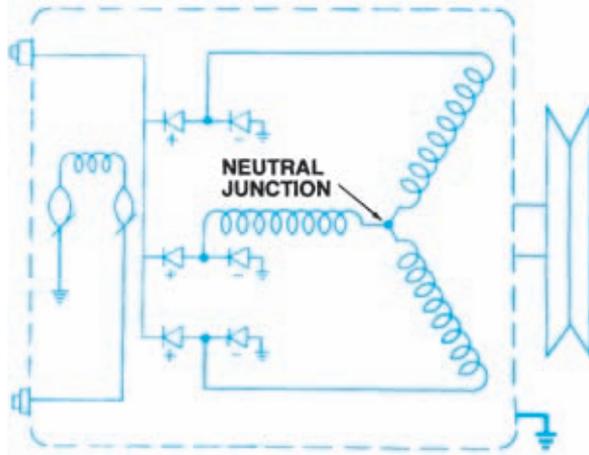


Figure 8-24. Y-type stator circuit diagram. (DaimlerChrysler Corporation)

■ Unrectified AC Generators

Although the battery cannot be recharged with AC, other automotive accessories can be designed to run on unrectified alternator output. Motorola has made AC generators with separate terminals for AC output. Ford has offered a front-and-rear-window defroster that heats the windows with three-phase, 120-volt AC. An additional AC generator supplies the high-voltage current. This second AC generator is mounted above the standard 12-volt AC generator and driven by the same belt.

The Ford high-voltage AC generator has a Y-type stator. Field current draw is more than 4 amps, and there is no regulator in the field circuit. Output is 2,200 watts at high engine speed. All of the wiring between the AC generator and the defrosters is special, shielded wiring with warning tags at all connectors. Ford test procedures use only an ohmmeter, because trying to test such high output could be dangerous.

Some AC generators include a center tap lead from the neutral junction to an insulated terminal on the housing (Figure 8-25). The center tap may control the field current, to activate an indicator lamp, to control the electric choke on a carburetor, or for other functions.

Delta-Type Stator Design

The **delta-type stator** or delta-connected stator has the three windings connected end-to-end (Figure 8-26). The circuit diagram of a delta-type stator (Figure 8-26) looks like the Greek letter delta

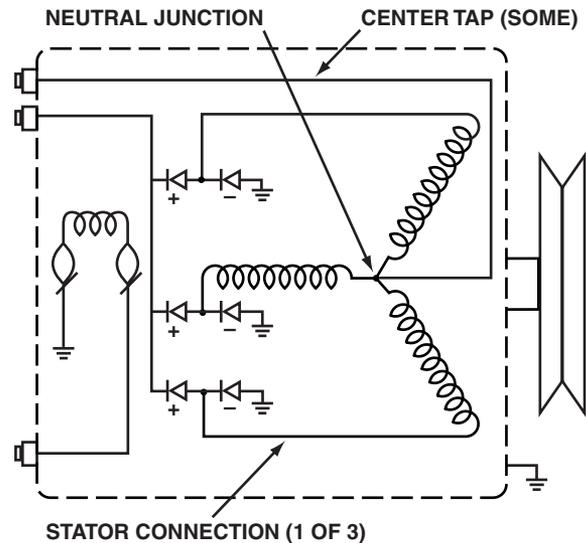


Figure 8-25. A Y-type stator circuit diagram. The center tap connects to the neutral junction of the Y-type stator of some AC generators. (DaimlerChrysler Corporation)

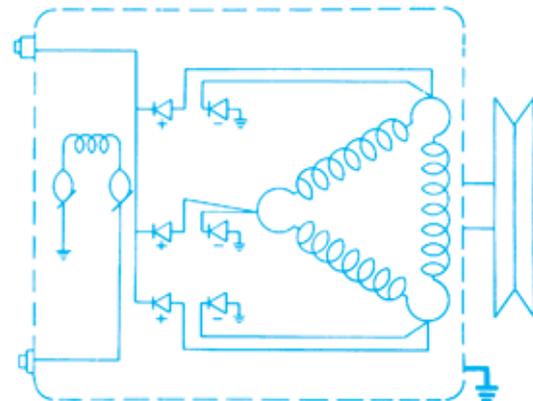


Figure 8-26. Circuit diagram of a delta-type stator.

(Δ), a triangle. There is no neutral junction in a delta-type stator. The windings always form two parallel circuit paths between one negative and two positive diodes. Current travels through two different circuit paths between the diodes (Figure 8-27). The current-carrying capacity of the stator is double because there are two parallel circuit paths. Delta-type stators are used when a high current output is needed.

Phase Rectification

The current pattern during rectification is similar in any automotive AC generator. The only differences are specific current paths through Y-type and delta-type stators as shown in Figures 8-27 and 8-28.

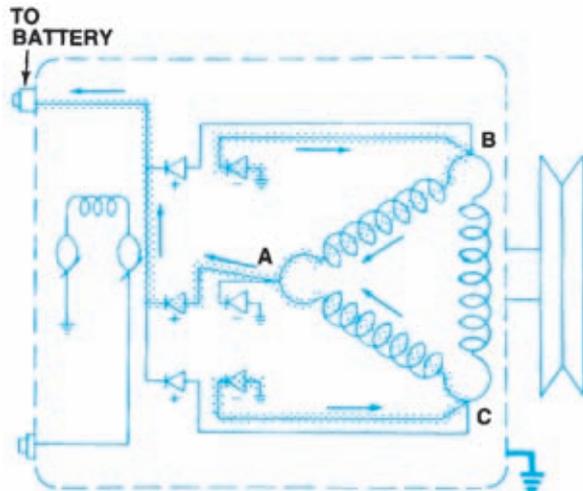


Figure 8-27. A typical current path during rectification in a delta-type stator. (DaimlerChrysler Corporation)

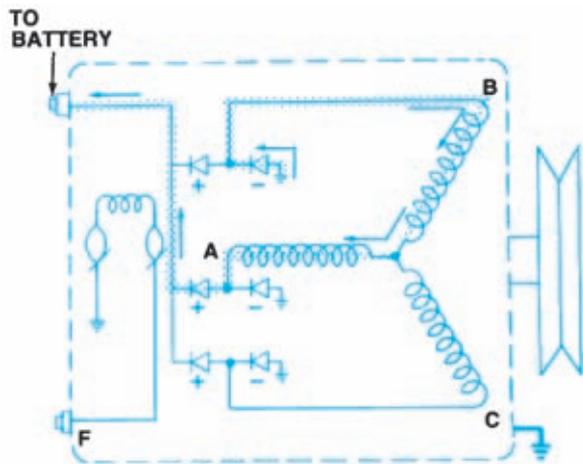


Figure 8-28. A typical current path during rectification in a Y-type stator. (DaimlerChrysler Corporation)

Rectification with Multiple-Pole Rotors

The three-phase voltage output used in the examples (Figure 8-29) is the voltage, which would result if the rotor had only one N and one S pole. Actual AC generator rotors have many N and S poles. Each of these N-S pairs produces one complete voltage sine wave per rotor revolution, across each of the three windings. One complete sine wave begins at zero volts, climbs to a positive peak, drops past zero to a negative peak, then returns to zero, or baseline voltage. In Figure 8-30, the sine wave voltage caused by a single pole is shown as a dashed line. The actual voltage trace from one winding of a 12-pole AC generator is

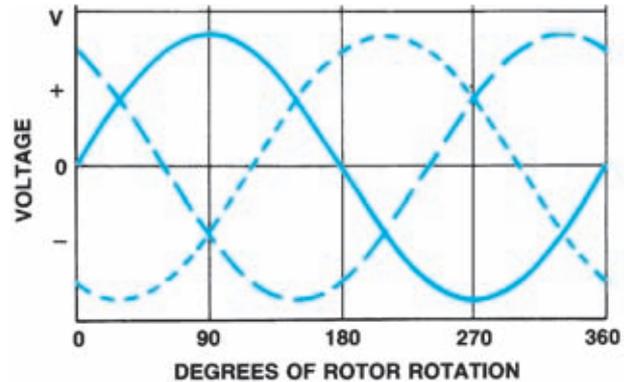


Figure 8-29. The three-phase voltage from one revolution of the rotor. (Reprinted by permission of Robert Bosch GmbH)

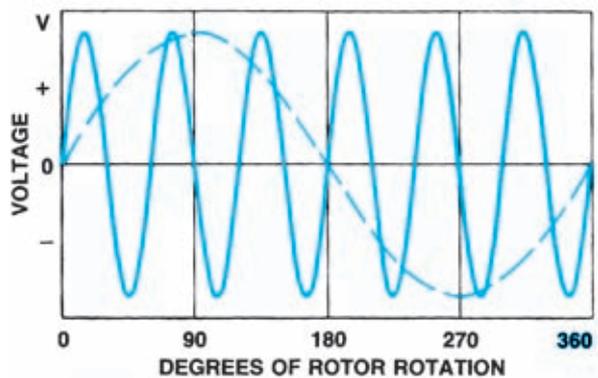


Figure 8-30. An AC generator (alternator) with six pairs of N-S poles would produce the solid line voltage trace. The dashed line represents an alternator with one pair. (Reprinted by permission of Robert Bosch GmbH)

shown as a solid line. The entire stator output is three of these waves, evenly spaced and overlapping (Figure 8-31). The maximum voltage value from these waves pushes current through the diodes (Figure 8-32).

After rectification, AC generator (alternator) output is DC voltage, which is slightly lower than the maximum voltage peaks of the stator output. The positive portion of the AC sine wave greater than the DC output voltage is viewable on an oscilloscope in what is called an AC generator (alternator) ripple pattern (Figure 8-33).

Excitation Field Circuit

Field current through the rotor windings creates the magnetic field of the rotor. Field current is drawn from the AC generator output circuit once

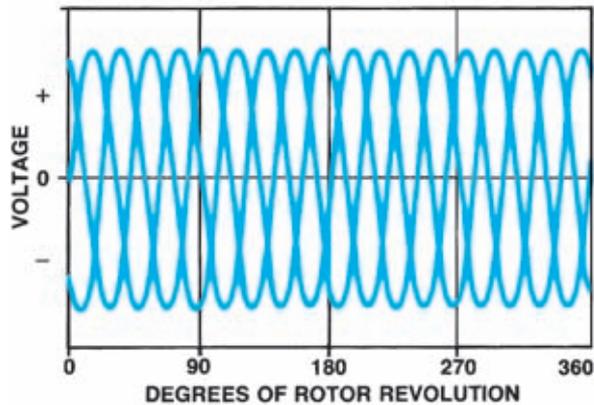


Figure 8-31. This is the total output of a three-winding, multiple-pole AC generator.

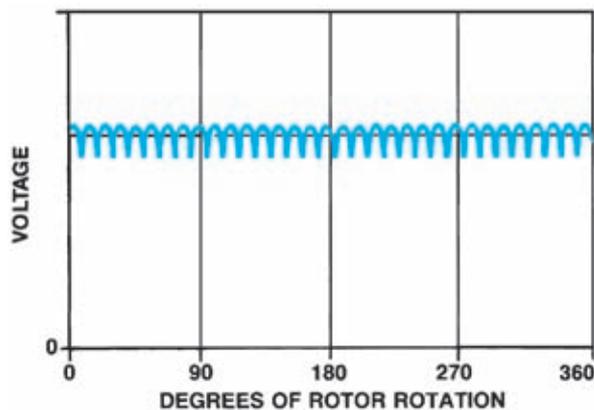


Figure 8-33. AC generator (alternator) ripple is the AC voltage exceeding DC output voltage.

the AC generator has begun to produce current. However, there is not enough residual magnetism in the rotor poles to induce voltage during start up. An AC generator cannot start operation independently. Field current must be drawn from another source in order to magnetize the rotor and begin AC generator output.

The other source is the vehicle battery connected to the rotor winding through the excitation, or field, circuit. Battery voltage “excites” the rotor magnetic field and begins output. When the engine is off, the battery must be disconnected from the excitation circuit. If not, it could discharge through the rotor windings to ground. Some AC generators use a relay to control this circuit. Other systems use the voltage regulator or a part of the ignition switch to control the excitation circuit.

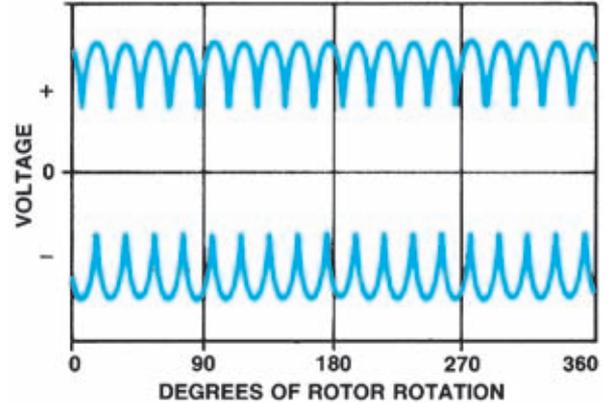


Figure 8-32. The diodes receive the maximum voltage values.

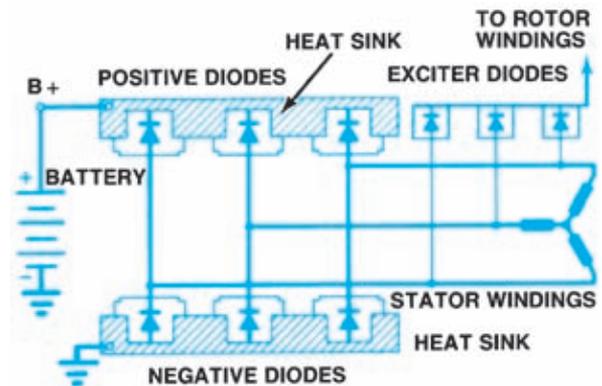


Figure 8-34. Some AC generators (alternators) have additional diodes to rectify field current. (Reprinted by permission of Robert Bosch GmbH)

Once the AC generator has started to produce current, field current is drawn from the AC generator output. The current may be drawn after it has been rectified by the output diodes. Some AC generators draw field current from unrectified AC output, which is then rectified by three additional diodes to provide DC to the rotor winding (Figure 8-34). These additional diodes are called the exciter diodes or the field diodes.

Circuit Types

AC generators (alternators) are designed with different types of field circuits. The two most common types are A-circuits and B-circuits. Circuit types are determined by where the voltage regulator is connected and from where the field current is drawn.

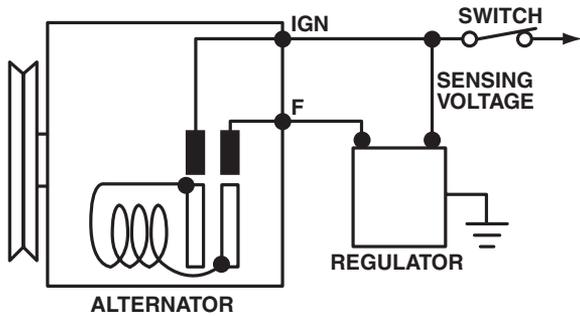


Figure 8-35. An A-circuit. (Regulator is after the field.)

A-Circuit

The A-circuit AC generator (Figure 8-35) is also called an externally grounded field AC generator. Both brushes are insulated from the AC generator housing. One brush connects to the voltage regulator, where it is grounded. The second brush connects to the output circuit within the AC generator, where it draws current for the rotor winding. The regulator connects between the rotor field winding and ground. This type of circuit is often used with solid-state regulators, which are small enough to be mounted on the AC generator housing.

B-Circuit

The B-circuit AC generator (Figure 8-36) is also called an internally grounded field AC generator. One brush is grounded within the AC generator housing. The other brush is insulated from the housing and connected through the insulated voltage regulator to the AC generator output circuit. The rotor field winding is between the regulator and ground. This type of circuit is most often used with electromagnetic voltage regulators, which are mounted away from the AC generator housing.

Self-Regulation of Current

The maximum current output of an AC generator is limited by its design. As induced voltage causes current to travel in a conductor, a counter-voltage is also induced in the same conductor. The counter-voltage is caused by the expanding magnetic field of the original induced current. The counter-voltage tends to oppose any change in the original current.

The more current the AC generator puts out, the greater this counter-voltage becomes. At a certain point, the counter-voltage is great enough to com-

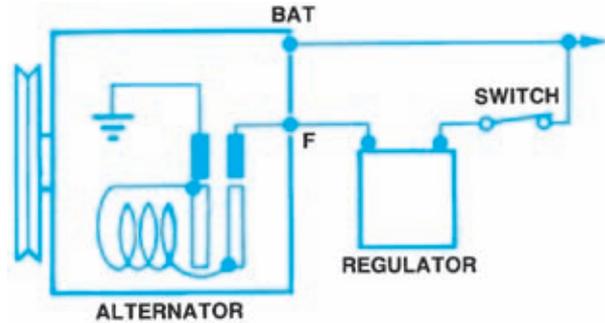


Figure 8-36. A B-circuit. (Regulator is before the field.)

pletely stop any further increase in the AC generator's current output. At this point, the AC generator has reached its maximum current output. Therefore, because the two voltages continue to increase as AC generator speed increases, a method of regulating AC generator voltage is required.

For more information about testing AC generators, see the following sections in Chapter 8 of the *Shop Manual*: "Testing Specific Models," "Unit Removal," "Disassembly, Cleaning, and Inspection," and "Bench Tests."

VOLTAGE REGULATION

AC generator regulators limit voltage output by controlling field current. The location of the regulator in the field circuit determines whether the AC generator is an A-circuit or a B-circuit. Voltage regulators basically add resistance to field current in series.

AC generator output voltage is directly related to field strength and rotor speed. An increase in either factor increases voltage output. Similarly, a decrease in either factor decreases voltage output. Rotor speed is controlled by engine speed and cannot be changed simply to control the AC generator. Controlling the field current in the rotor winding can change field strength; this is how AC generator voltage regulators work. Figure 8-37 shows how the field current (dashed line) is lowered to keep AC generator output (solid line) at a constant maximum, even when the rotor speed increases.

At low rotor speeds, the field current is at full strength for relatively long periods of time, and is reduced only for short periods (Figure 8-38A). This causes a high average field current. At high

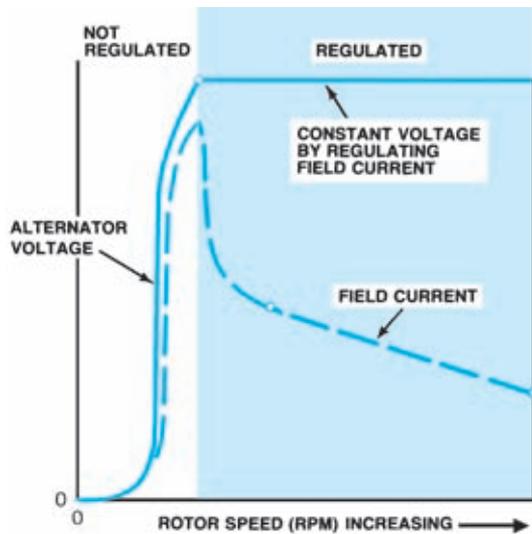


Figure 8-37. Field current is decreased as rotor speed increases, to keep AC generator (alternator) output voltage at a constant level.

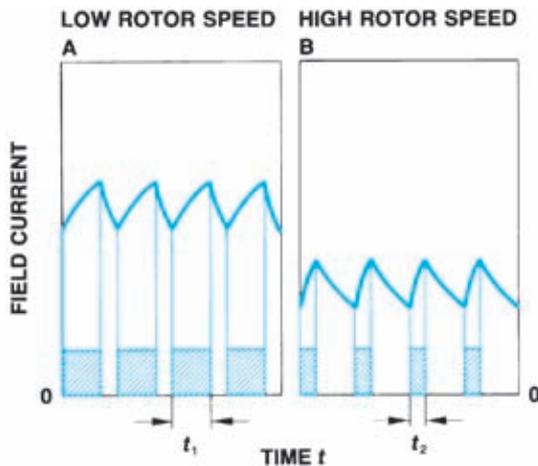


Figure 8-38. The field current flows for longer periods of time at low speeds (t_1) than at high speeds (t_2). (Reprinted by permission of Robert Bosch GmbH)

rotor speeds, the field current is reduced for long periods of time and is at full strength only for short periods (Figure 8-38B). This causes a low average field current.

On older vehicles, an electromagnetic regulator controlled the field circuit. However, in the 1970s, semiconductor technology made solid-state voltage regulators possible. Because they are smaller and have no moving parts, solid-state regulators replaced the older electromagnetic types in AC charging systems. On newer vehicles, the solid-state regulator may be a separate component built

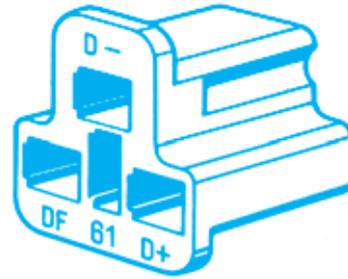


Figure 8-39. Most regulators use a multiple-plug connector to ensure connections are properly made. (Reprinted by permission of Robert Bosch GmbH)

into the AC generator or incorporated into the powertrain control module (PCM).

Some solid-state regulators are mounted on the inside or outside of the AC generator housing. Remotely mounted voltage regulators often use a multiple-plug connector (Figure 8-40) to ensure all connections are properly made. This eliminates exposed wiring and connections, which are prone to damage.

ELECTROMAGNETIC REGULATORS

Electromagnetic voltage regulators, sometimes called electromechanical regulators, operate the same whether used with old DC generators or more common AC generators. The electromagnetic coil of the voltage regulator is connected from the ignition switch to ground. This forms a parallel branch receiving system voltage, either from the AC generator output circuit or from the battery. The magnetic field of the coil acts upon an armature to open and close contact points controlling current to the field.

Double-Contact Voltage Regulator

At high rotor speeds, the AC generator may be able to force too much field current through a single-contact regulator and exceed the desired output. This is called voltage creep, or voltage drift. Single-contact regulators are used only with low-current-output alternators. Almost all electromagnetic voltage regulators used with automotive

AC generators are double-contact units (Figure 8-40). When the first set of contacts opens at lower rotor speeds, current passes through a resistor wired in series with the field circuit. These contacts are

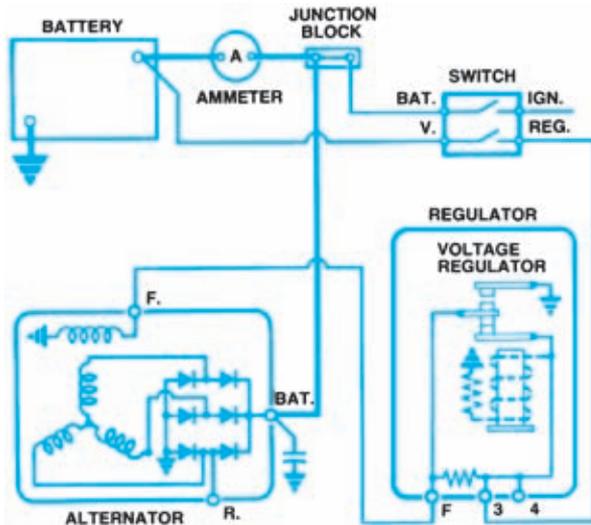


Figure 8-40. The circuit diagram of a double-contact regulator. (Delphi Automotive Systems)

called the series contacts. The value of the regulating resistor is kept very low to permit high field current when needed. At higher rotor speeds, the coil further attracts the armature and a second set of contacts is closed. This grounds the field circuit, stopping the field current. These contacts are called the shorting contacts because they short-circuit the field to ground. The double-contact design offers consistent regulation over a broad range of AC generator speeds.

SOLID-STATE REGULATORS

Solid-state regulators completely replaced the older electromagnetic design on late-model vehicles. They are compact, have no moving parts, and are not seriously affected by temperature changes. The early solid-state designs combine transistors with the electromagnetic field relay. The latest and most compact is the integrated circuit (IC) regulator (Figure 8-41). This combines all control circuitry and components on a single

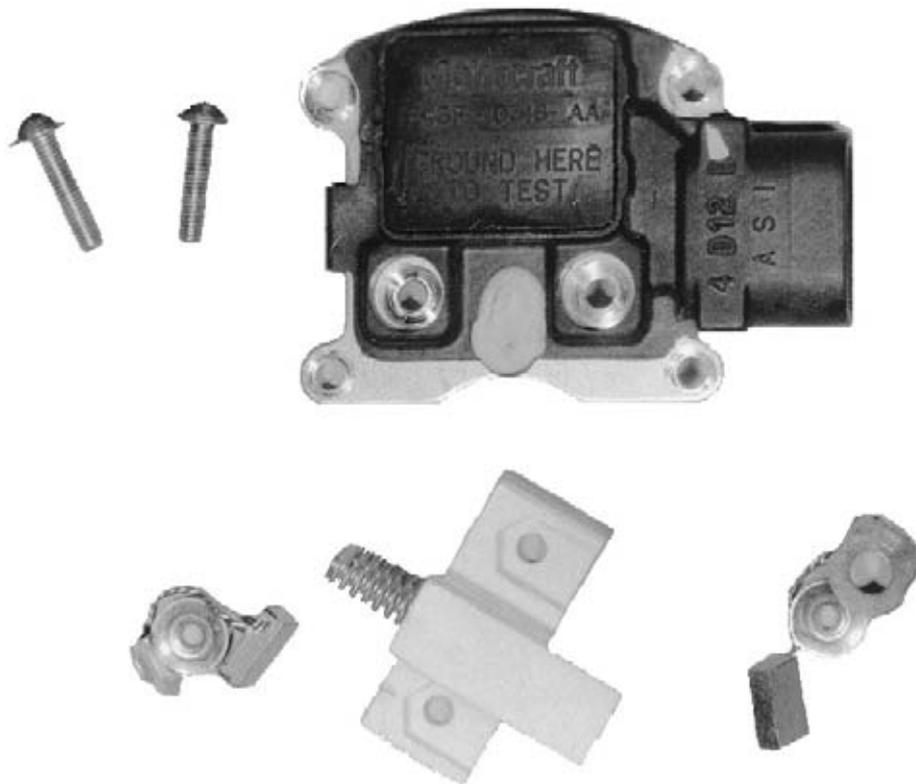


Figure 8-41. An example of the latest integrated circuit regulator design, a Ford IAR regulator and brush holder.

silicon chip. Attaching terminals are added and the chip is sealed in a small plastic module that mounts inside, or on the back of, the AC generator. Because of their construction, however, all solid-state regulators are non-serviceable and must be replaced if defective. No adjustments are possible.

Here is a review of most components of a solid-state regulator:

- Diodes
- Transistors
- Zener diodes
- Thermistors
- Capacitors

Diodes are one-way electrical check valves. Transistors act as relays. A Zener diode is specially doped to act as a one-way, electrical check valve until a specific reverse voltage level is reached. At that point, the Zener diode allows reverse current to pass through it.

The electrical resistance of a thermistor, or thermal resistor, changes as temperature changes. Most resistors used in automotive applications are called negative temperature coefficient (NTC) resistors because their resistance decreases as temperature increases. The thermistor in a solid-state regulator reacts to temperature to ensure proper battery charging voltage. Some manufacturers, in order to smooth out any abrupt voltage surges and protect the regulator from damage, use a capacitor. Diodes may also be used as circuit protection.

General Regulator Operation

Figure 8-42 is a simplified circuit diagram of a solid-state regulator. This A-circuit regulator is contained within the housing. Terminal 2 on the AC generator is always connected to the battery, but battery discharge is limited by the high resistance of R2 and R3. The circuit allows the regulator to sense battery voltage.

When the ignition switch is closed in the circuit shown in Figure 8-43, current travels from the battery to ground through the base of the TR1 transistor. This causes the transistor to conduct current through its emitter-collector circuit from the battery to the low-resistance rotor winding, which energizes the AC generator field and turns on the warning lamp. When the AC generator begins to produce current (Figure 8-44), field current is drawn from unrectified AC generator output and rectified by the diode trio, which is charging

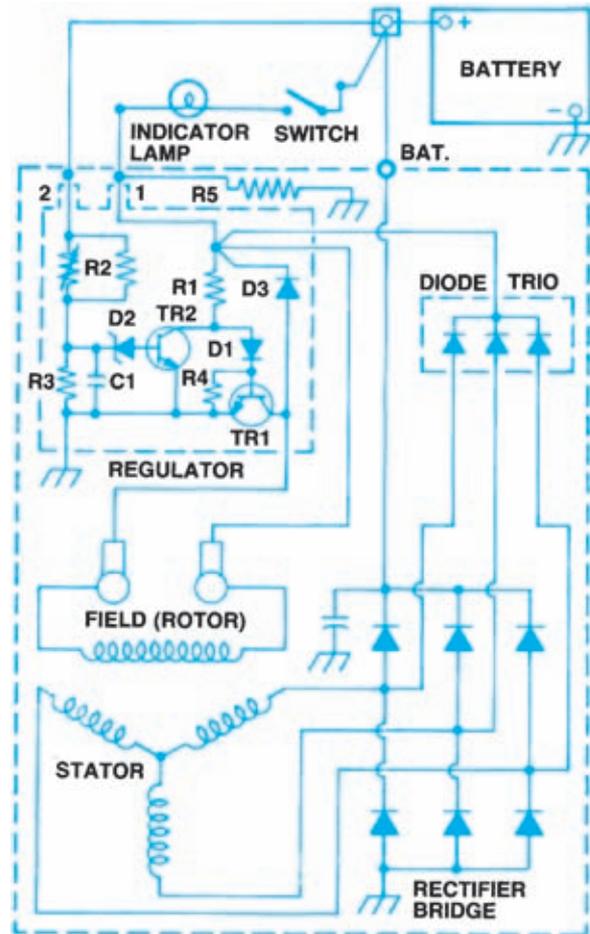


Figure 8-42. Circuit diagram of a typical solid-state voltage regulator. (Delphi Automotive Systems)

voltage. The warning lamp is turned off by equal voltage on both sides of the lamp.

When the AC generator has charged the battery to a maximum safe voltage level (Figure 8-45), the battery voltage between R2 and R3 is high enough to cause Zener diode D2 to conduct in reverse bias. This turns on TR2, which shorts the base circuit of TR1 to ground. When TR1 is turned off, the field circuit is turned off at the ground control of TR1.

With TR1 off, the field current decreases and system voltage drops. When voltage drops low enough, the Zener diode switches off and current is no longer applied to TR2. This opens the field circuit ground and energizes TR1. TR1 turns back on. The field current and system voltage increase. This cycle repeats many times per second to limit the AC generator voltage to a predetermined value.

The other components within the regulator perform various functions. Capacitor C1 provides

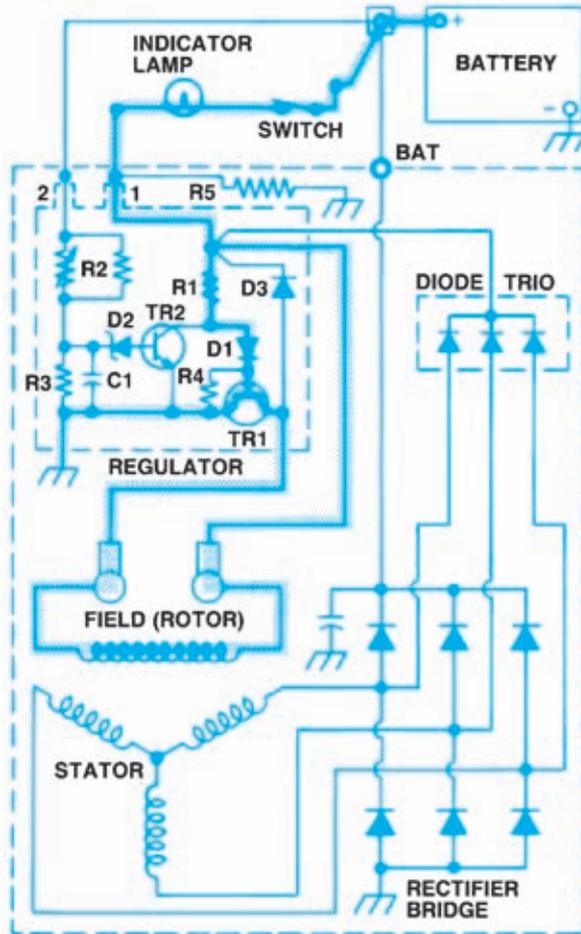


Figure 8-43. Field current in a typical solid-state regulator during starting. (Delphi Automotive Systems)

stable voltage across resistor R3. Resistor R4 prevents excessive current through TR1 at high temperatures. To prevent circuit damage, diode D3 bypasses high voltages induced in the field windings when TR1 turns off. Resistor R2 is a thermistor, which causes the regulated voltage to vary with temperature. R5 allows the indicator lamp to turn off if the field circuit is open.

For more information about voltage regulators, see the “Voltage Regulator Service Section” in Chapter 8 of the *Shop Manual*.

Specific Solid-State Regulator Designs

GM Delco-Remy (Delphi)

The Delco-Remy solid-state automotive regulator is used in Figures 8-43 to 8-46 to explain the basic

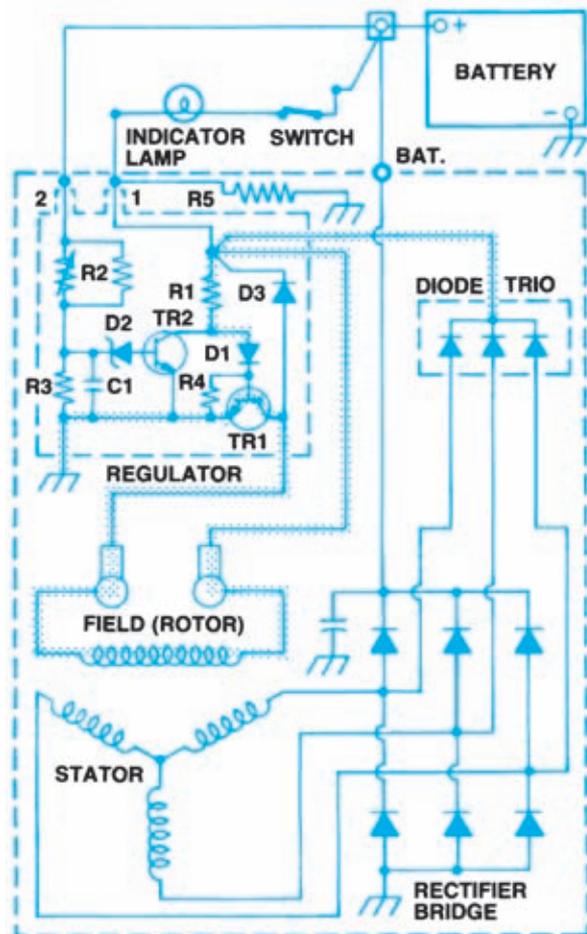


Figure 8-44. Field current drawn from AC generator (alternator) output. (Delphi Automotive Systems)

operation of these units. This is the integral regulator unit of the SI series AC generators. The 1 and 2 terminals on the housing connect directly to the regulator. The 1 terminal conducts field current from the battery or the AC Generator (alternator) and controls the indicator lamp. The 2 terminal receives battery voltage and allows the Zener diode to react to it.

Unlike other voltage regulators, the multifunction IC regulator used with Delco-Remy CS-series AC generators (Figure 8-46) switches the field current on and off at a fixed frequency of 400 Hz (400 times per second). The regulator varies the duty cycle, or percentage of on time to total cycle time, to control the average field current and to regulate voltage. At high speeds, the on time might be 10 percent with the off time 90 percent. At low speeds with high electrical loads, this ratio could be reversed: 90 percent on time and 10 percent off time. Unlike the SI series, CS AC generators have

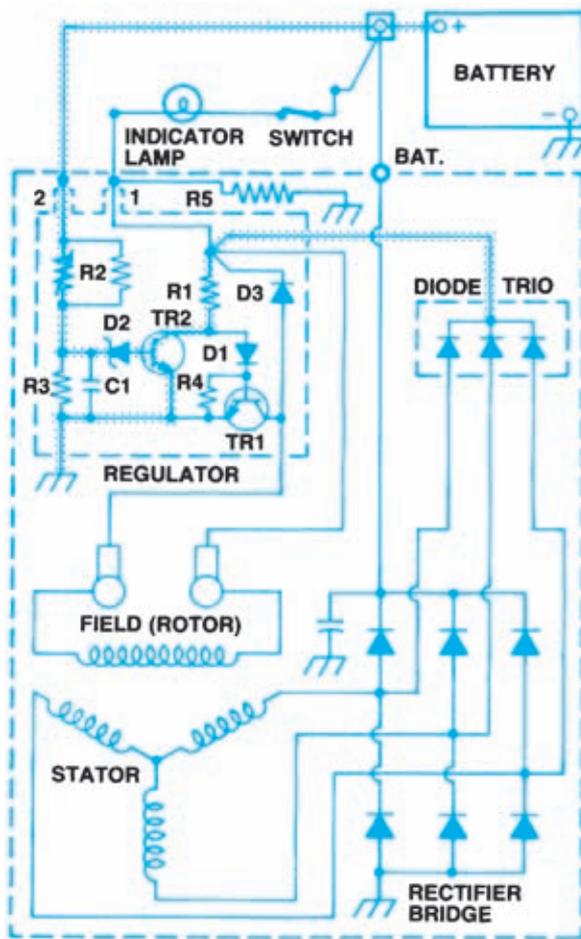


Figure 8-45. When AC generator (alternator) output voltage reaches a maximum safe level, no current is allowed in the rotor winding. (Delphi Automotive Systems)

no test hole to ground the regulator for full-field testing. The regulator cannot be tested with an ohmmeter; a special tester is required.

Motorcraft

At one time, Motorcraft AC generators used both remote-mounted and integral solid-state regulators. Motorcraft regulator terminals are designated as follows:

- A+ or A- connects the battery to the field relay contacts.
- S- connects the AC generator output to the field relay coil.
- F- connects the field coil to the regulator transistors.
- I- connects the ignition switch to the field relay and regulator contacts (only on vehicles with a warning lamp).

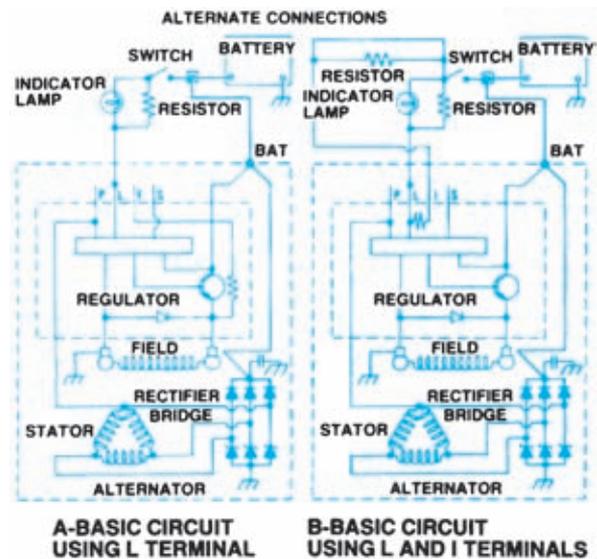


Figure 8-46. GM CS AC generator (alternator) regulator circuit. (Delphi Automotive Systems)

Ford began using a remote-mounted, fully solid-state regulator on its intermediate and large models in 1978. The functions of the I, A+, 8, and F terminals are identical to those of the transistorized regulator. On systems with an ammeter, the regulator is color coded blue or gray, and the T terminal is not used. On warning lamp systems, the regulator is black, and all terminals can be used. The two models are not interchangeable, and cannot be substituted for the earlier solid-state unit with a relay or for an electromagnetic regulator. However, Ford does provide red or clear service replacement solid-state regulators, which can be used with both systems.

The Motorcraft integral alternator/regulator (JAR) introduced in 1985 uses an IC regulator, which is also mounted on the outside of the rear housing. This regulator differs from others because it contains a circuit indicating when the battery is being overcharged. It turns on the charge indicator lamp if terminal A voltage is too high or too low, or if the terminal 8 voltage signal is abnormal.

DaimlerChrysler

The DaimlerChrysler solid-state regulator depends on a remotely mounted field relay to open and close the isolated field or the A-circuit AC generator field. The relay closes the circuit only when the ignition switch is turned on. The voltage regulator (Figure 8-47) contains two transistors that are turned on and off by a Zener diode. The Zener diode reacts to system voltage to start and stop field

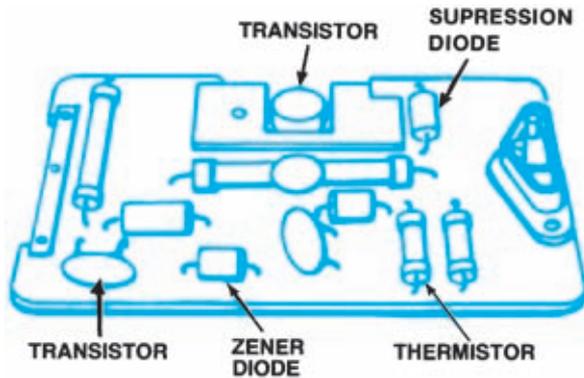


Figure 8-47. DaimlerChrysler solid-state voltage regulator. (DaimlerChrysler Corporation)

current. The field current travels through what DaimlerChrysler calls a field-suppression diode, which limits current to control AC generator output. The regulator also contains a thermistor to control battery charging voltage at various temperatures. The regulator has two terminals: One is connected to the ignition system; the other is connected to the alternator field.

Computer-Controlled Regulation

DaimlerChrysler Corporation eliminated the separate regulator by moving its function to the powertrain control module (PCM) in 1985. When the ignition is turned on, the PCM logic module or logic circuit checks battery temperature to determine the control voltage (Figure 8-48). A pre-driver transistor in the logic module or logic circuit then signals the power module or power circuit driver transistor to turn the AC generator current on (Figure 8-49). The logic module or logic circuit continually monitors battery temperature and system voltage. At the same time, it transmits output signals to the power module or power circuit driver to adjust the field current as required to maintain output between 13.6 and 14.8 volts. Figure 8-50 shows the complete circuitry involved.

General Motors has taken a different approach to regulating CS charging system voltage electronically. Turning the ignition switch on supplies voltage to activate a solid-state digital regulator, which uses pulse-width modulation (PWM) to supply rotor current and thus control output voltage. The rotor current is proportional to the PWM pulses from the digital regulator.

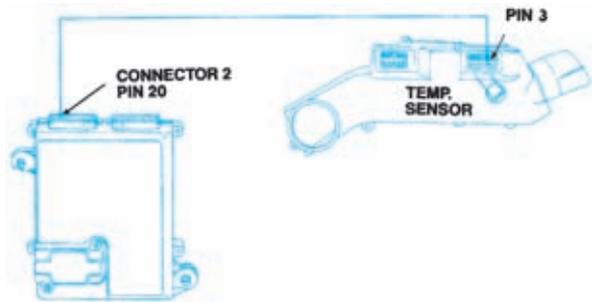


Figure 8-48. DaimlerChrysler solid-state voltage regulator. (DaimlerChrysler Corporation)

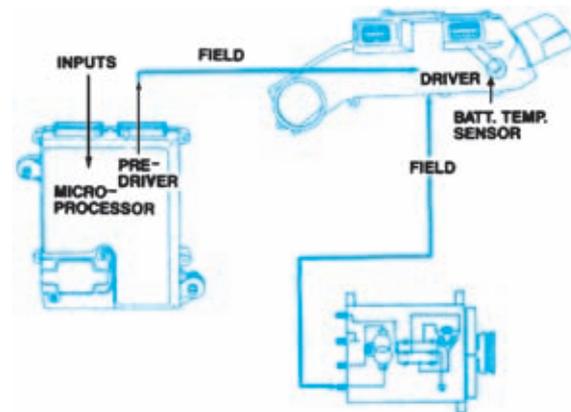


Figure 8-49. Battery temperature circuit of the DaimlerChrysler computer regulated charging system. (DaimlerChrysler Corporation)

With the ignition on, narrow width pulses are sent to the rotor, creating a weak magnetic field. As the engine starts, the regulator senses AC generator rotation through AC voltage detected on an internal wire. Once the engine is running, the regulator switches the field current on and off at a fixed frequency of about 400 cycles per second (400 Hz). By changing the pulse width, or on-off time, of each cycle, the regulator provides a correct average field current for proper system voltage control.

A lamp driver in the digital regulator controls the indicator warning lamp, turning on the bulb when it detects an under- or over-voltage condition. The warning lamp also illuminates if the AC generator is not rotating. The PCM does not directly control charging system voltage, as in the DaimlerChrysler application. However, it does monitor battery and system voltage through an ignition switch circuit. If the PCM reads a voltage above 17 volts, or less than 9 volts for longer than

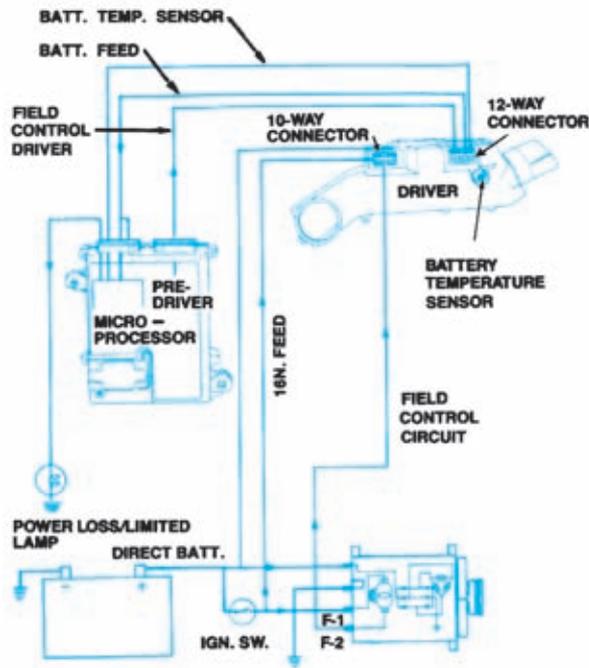


Figure 8-50. DaimlerChrysler computer-regulated charging system internal field control. (DaimlerChrysler Corporation)

10 seconds, it sets a code 16 in memory and turns on the malfunction indicator lamp (MIL).

Diagnostic Trouble Codes (DTC)

On late-model DaimlerChrysler vehicles, the onboard diagnostic capability of the engine control system detects charging system problems and records up to five diagnostic trouble codes (DTC) in the system memory. Some of the codes light a MIL on the instrument panel; others do not. Problems in the General Motors CS charging system cause the PCM to turn on the indicator lamp and set a single code in memory.

CHARGE/VOLTAGE/CURRENT INDICATORS

A charging system failure cripples an automobile. Therefore, most manufacturers provide some way for the driver to monitor the system operation. The indicator may be an ammeter, a voltmeter, or an indicator lamp.

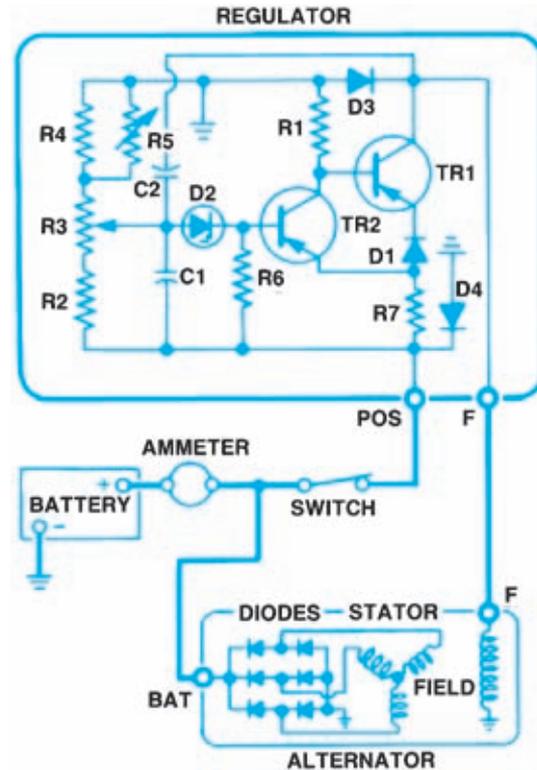


Figure 8-51. GM ammeter. (GM Service and Parts Operations)

Ammeter

An instrument panel ammeter measures charging system current into and out of the battery and the rest of the electrical system (Figure 8-51). The ammeter reads the voltage drop of the circuit. When current is traveling from the AC generator into the battery, the ammeter moves in a positive or charge direction. When the battery takes over the electrical system's load, current travels in the opposite direction and the needle moves into the negative, or discharge, zone. The ammeter simply indicates which is doing the most work in the electrical system, the battery or the AC generator (alternator). Some ammeters are graduated to indicate the approximate current in amperes, such as 5, 10, or 20. Others simply show an approximate rate of charge or discharge, such as high, medium, or low. Some ammeters have a resistor parallel so the meter does not carry all of the current, these are called shunt ammeters. While the ammeter tells the driver whether the charging system is functioning normally, it does not give a good picture of the battery condition. Even when the ammeter indicates a charge, the current output

may not be high enough to fully charge the battery while supplying other electrical loads.

Voltmeter

The instrument panels of many late-model vehicles contain a voltmeter instead of an ammeter (Figure 8-52). A voltmeter measures electrical pressure and indicates regulated generator voltage output or battery voltage, whichever is greater. System voltage is applied to the meter through the ignition switch contacts. Figure 8-53 shows a typical voltmeter circuit.

The voltmeter tells a driver more about the condition of the electrical system of a vehicle than an ammeter. When a voltmeter begins to indicate lower-than-normal voltage, it is time to check the battery and the voltage regulator.

Indicator Lamps

Most charging systems use an instrument panel indicator, or warning lamp, to show general



Figure 8-52. Automotive voltmeter in instrument panel.

charging system operation. Although the lamp usually does not warn the driver of an overcharged battery or high charging voltage, it lights to show an undercharged battery or low voltage from the AC generator.

The lamp also lights when the battery supplies field current before the engine starts. The lamp is often connected parallel to a resistor; therefore, field current travels even if the bulb fails. The lamp is wired so it lights when battery current travels through it to the AC generator field. When the alternator begins to produce voltage, this voltage is applied to the side of the lamp away from the battery. When the two voltages are equal, no voltage drops are present across the lamp and it goes out. When indicator lamps are used, the regulator must be able to monitor when the AC generator is charging. One method is to use “stator” or neutral voltage. This signal is present only when the AC generator is charging, and is one-half of charging voltage. When stator voltage is about three volts, it energizes a relay to open the indicator lamp ground circuit (Figure 8-53).

Figure 8-54 shows a typical warning lamp circuit installation. In figure 9-14, a 500-ohm resistor is used for warning lamp systems and a 420-ohm resistor for electronic display clusters. In Figure 8-54, a 40-ohm resistor (R5) is installed near the integral regulator. In each case, the grounded path ensures the warning lamp lights if an open occurs in the field circuitry.

As previously discussed, indicator lamps can also be controlled by the field relay. The indicator lamp for a Delco-Remy CS system works differently than most others. It lights if charging voltage is either too low or too high. Any problem in the charging system causes the lamp to light at full brilliance.

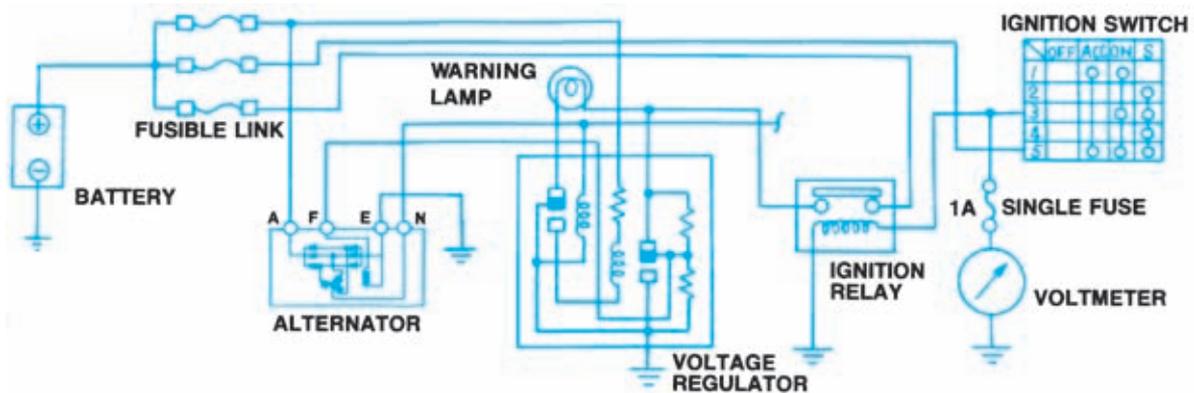


Figure 8-53. A typical voltmeter circuit.

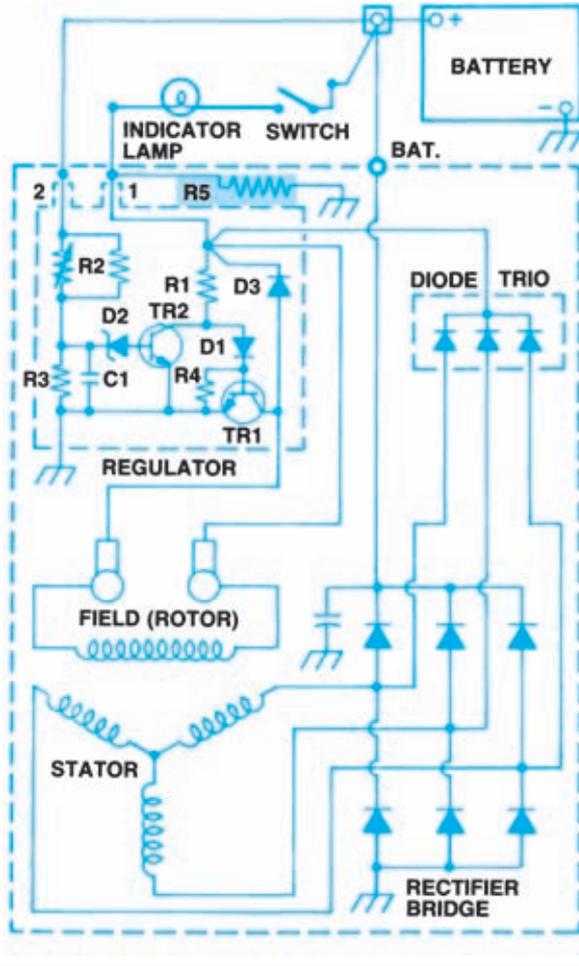


Figure 8-54. GM warning lamp circuit. (GM Service and Parts Operations)

CHARGING SYSTEM PROTECTION

If a charging system component fails or malfunctions, excessive current or heat, voltage surges, and other uncontrolled factors could damage wiring and other units in the system. To protect the system from high current, fusible links are often wired in series at various places in the circuitry. Figure 8-55 shows some typical fusible link locations.

COMPLETE AC GENERATOR OPERATION

When the ignition is first switched from off to on, before cranking the engine, a charge lamp comes on. This indicates, of course, that the AC generator is not generating a voltage. At the same time, battery voltage is applied to the rotor coil so that when the rotor begins to spin, the magnetic fields cut across the stator windings and produce current (Figure 8-56).

After the engine starts, the rotor is spinning fast enough to induce current from the stator. The current travels through the diodes and out to the battery and electrical system (Figure 8-57). Once the IC regulator senses system voltage is greater than

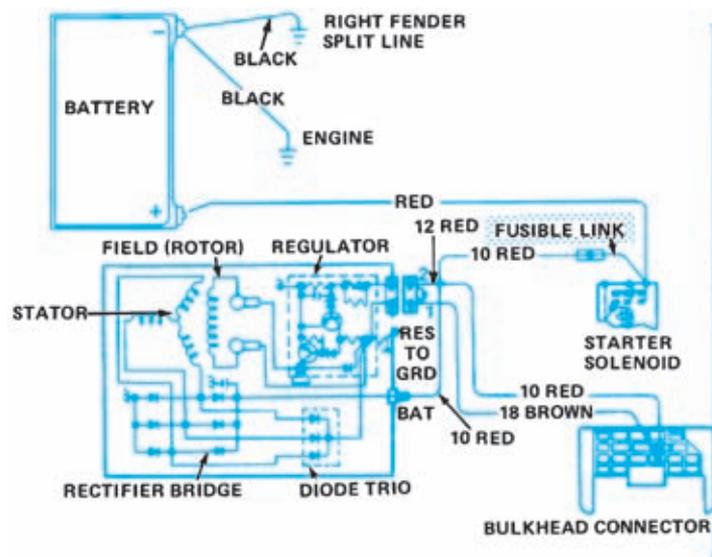


Figure 8-55. GM fusible links.

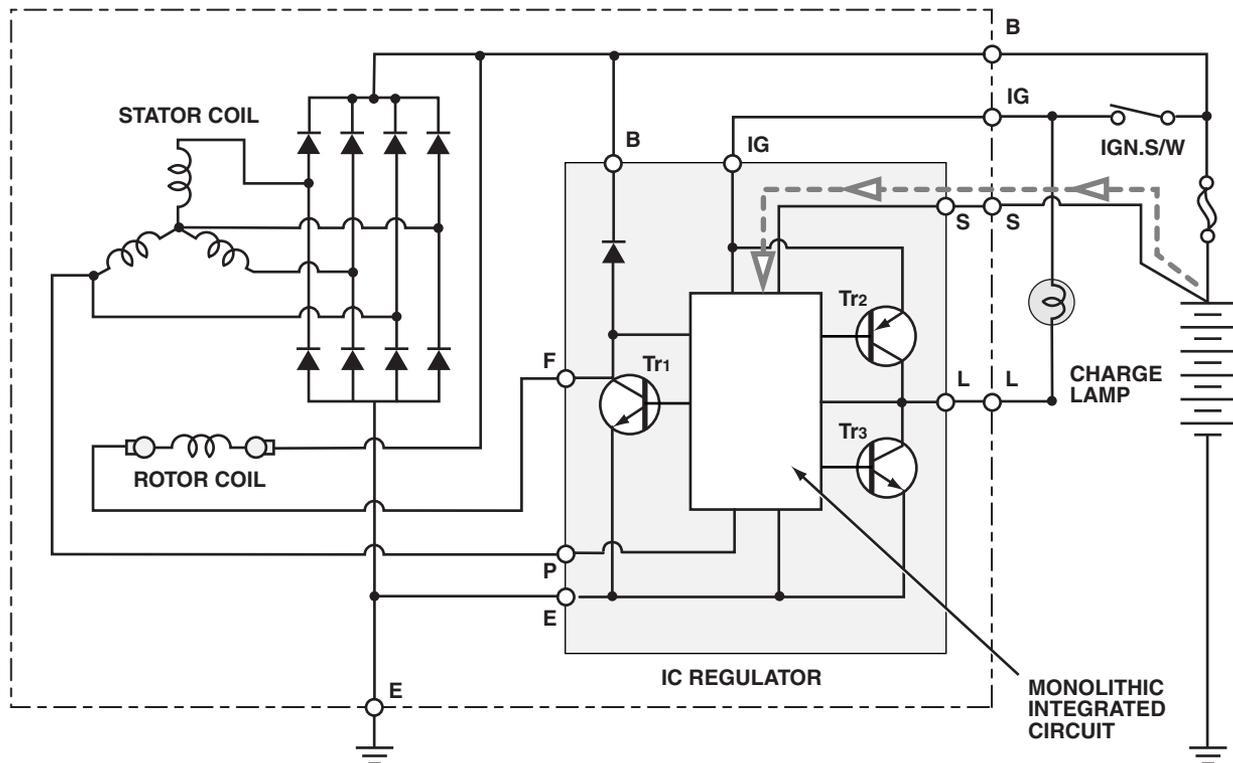


Figure 8-56. When AC generator voltage is too high, the regulator momentarily cuts off current to the rotor coils, eliminating the magnetic field. The rotor continues to spin, but no voltage is generated. (Reprinted by permission of Toyota Motor Corporation)

battery voltage, it redirects current to switch off the charge lamp.

During normal operation, AC generator voltage exceeds the typically specified 14.5 volts at times. To protect the battery and delicate components in the electrical system, the IC regulator shuts off current to the rotor, cutting AC generator output to zero (Figure 8-58). Note that even though the AC generator is momentarily “turned off,” the charge lamp does not come on. Within a split second, the IC regulator re-energizes the rotor again once output falls below the minimum. The IC regulator switches battery voltage on and off this way to control output and maintain system voltage at an ideal level.

AC GENERATOR (ALTERNATOR) DESIGN DIFFERENCES

Original equipment manufacturers (OEM) use various AC generator designs for specific applications. It has been noted that such factors as maxi-

imum current output and field circuit types affect AC generator construction. The following paragraphs describe some commonly used automotive AC generators.

Delphi (Delco-Remy) General Motors Applications

Delphi, formerly the Delco-Remy division of General Motors Corporation, is now a separate corporation that supplies most of the electrical devices used on GM vehicles, as well as those of some other manufacturers. The trademark name for Delco-Remy alternators was Delcotron generators. The alternator model number and current output can be found on a plate attached to, or stamped into, the housing.

DN-Series

The 10-DN series AC generator or alternator uses an external electromagnetic voltage regulator. Six individual diodes are mounted in the rear housing (Figure 8-59) with a capacitor for protection. A 14-pole rotor and Y-type stator

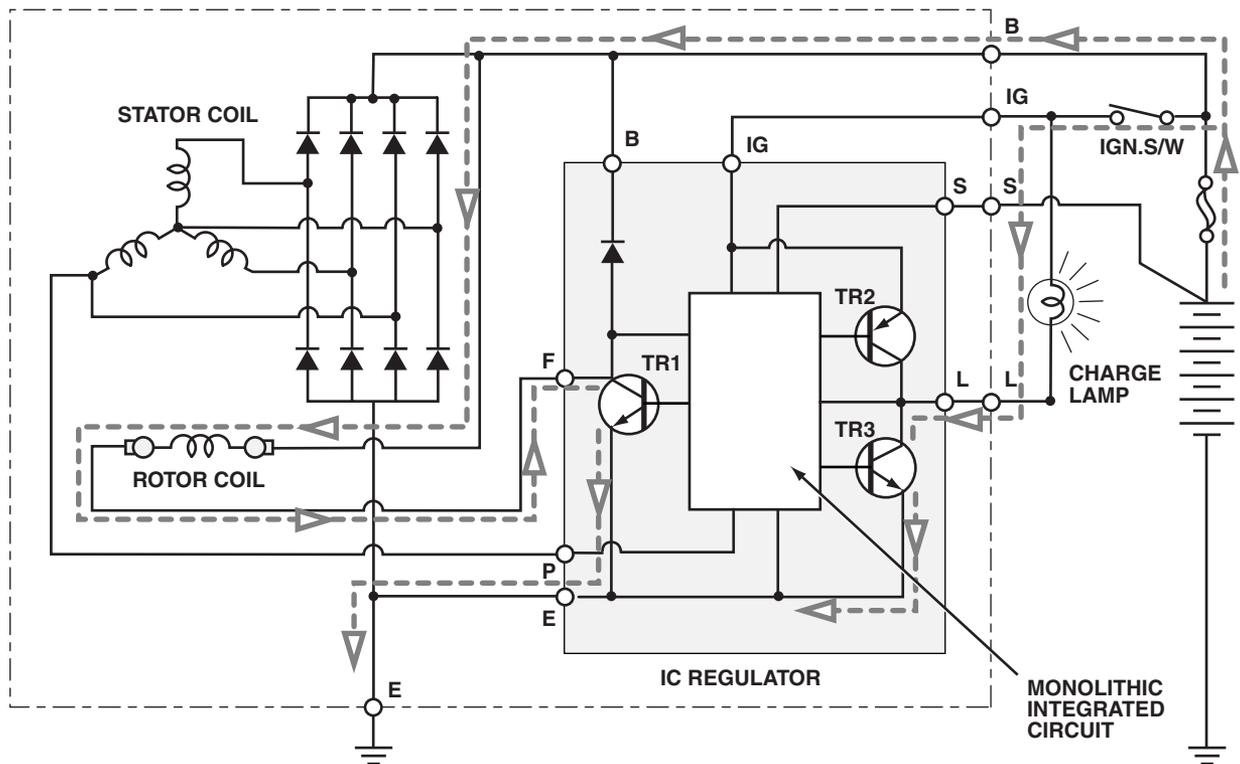


Figure 8-57. When the ignition is on and the engine is not running, the regulator energizes the rotor coil to build a magnetic field in the stator. The regulator turns on the charge light, indicating that the AC generator is not generating a voltage. (Reprinted by permission of Toyota Motor Corporation)

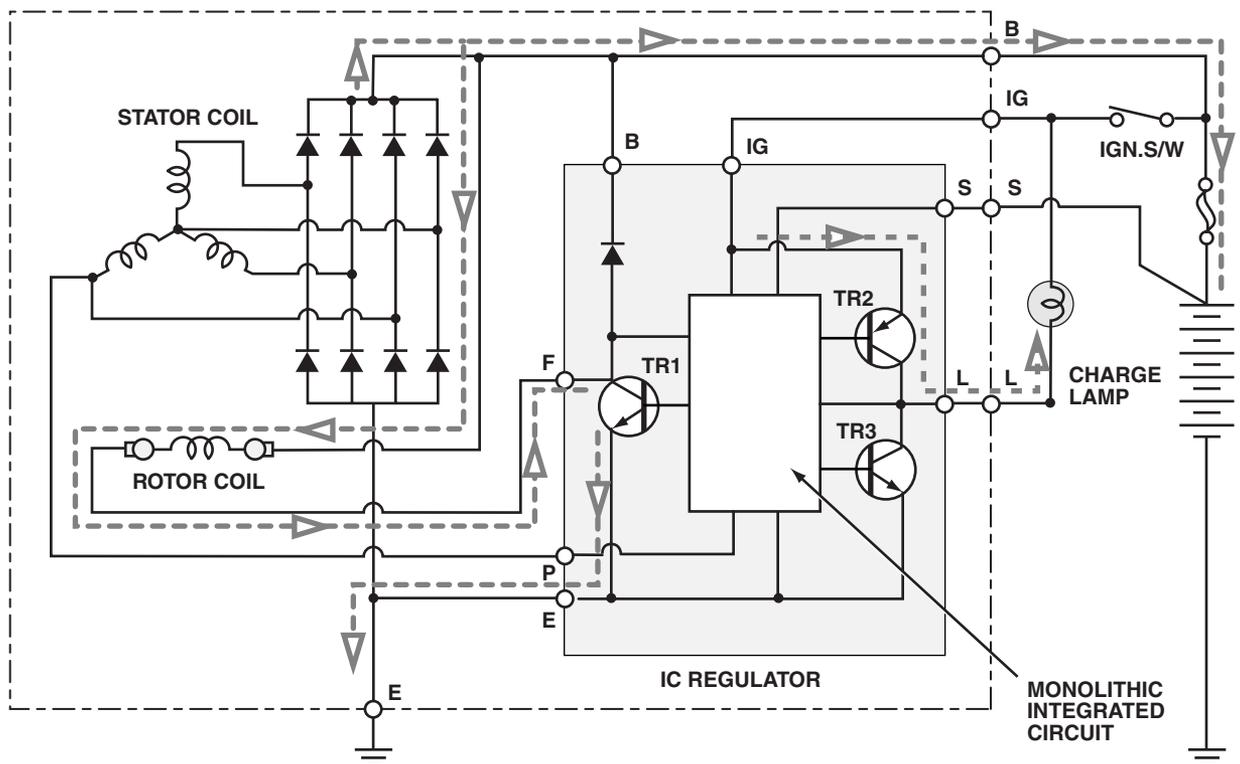


Figure 8-58. After the engine is running, the AC generator generates a voltage greater than the battery. The charge light goes out, indicating normal operation. (Reprinted by permission of Toyota Motor Corporation)

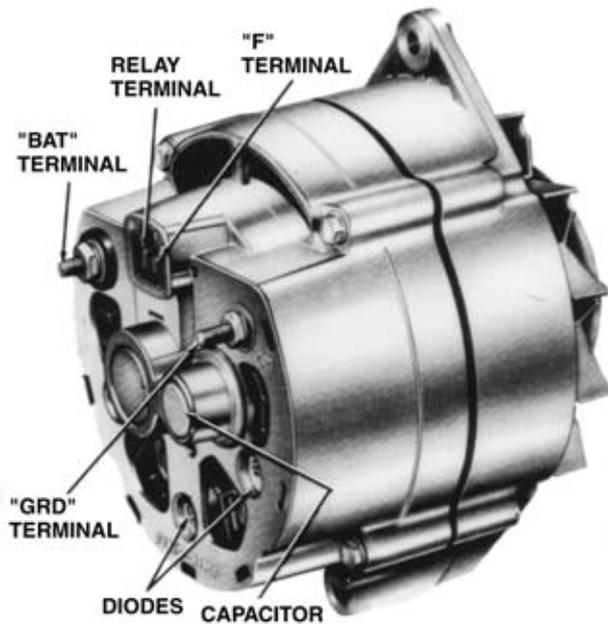


Figure 8-59. A 10-SI series AC generator (alternator). (Delphi Automotive Systems)

provide current output. Field current is drawn from rectified output and travels through a B-circuit. The terminals on a 10-DN are labeled BAT, GRD, R, and F. If the AC generator is used with an external electromagnetic regulator, the following applies:

- BAT connects AC generator output to the insulated terminal of the battery.
- GRD, if used, is an additional ground path.
- R, if used, is connected to a separate field relay controlling the indicator lamp.
- F connects the rotor winding to the voltage regulator.

Some 10-DN alternators are used with a remotely mounted solid-state regulator. The voltage control level of this unit is usually adjustable. The terminal connections are the same for electromagnetic and solid-state regulators.

SI Series

The 10-SI series AC generator uses an internally mounted voltage regulator and came into use in the early 1970s. The most common early model Delcotron alternators are part of the SI series and include models 10, 12, 15, and 27 as shown in Figure 8-60. A 14-pole rotor is used in most models. The 10-SI and 12-SI models have Y-type

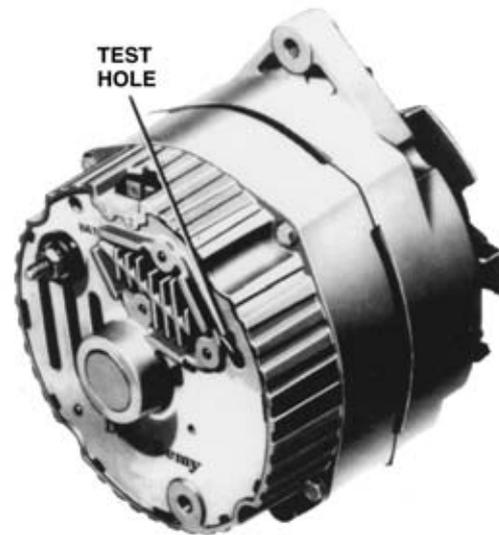


Figure 8-60. A 10-SI series AC generator [Delcotron]. (Delphi Automotive Systems)

stators, and the 15-SI and 27-SI models have delta-type stators. Two general SI designs have been used, with major differences appearing in the rear housing diode installation, regulator appearance, field circuitry, and ground path.

Most SI models have a rectifier bridge that contains all six rectifying diodes (Figure 8-61). The regulator is a fully enclosed unit attached by screws to the housing. Field current is drawn from unrectified AC generator output and rectified by an additional diode trio. All SI models have A-circuits, their terminals are labeled BAT, No. 1, and No. 2.

- The BAT terminal connects AC generator output to the insulated terminal of the battery.
- The No. 1 terminal conducts battery current to the rotor winding for the excitation circuit and is connected to the indicator lamp.
- The No. 2 terminal receives battery voltage so the voltage regulator can react to system operating conditions.

All SI models have a capacitor installed in the rear housing to protect the diodes from sudden voltage surges and to filter out voltage ripples that could produce EMI. The 27-SI, which is intended principally for commercial vehicles, has an adjustable voltage regulator (Figure 8-62). The voltage is adjusted by removing the adjustment cap, rotating it until the desired setting of low,

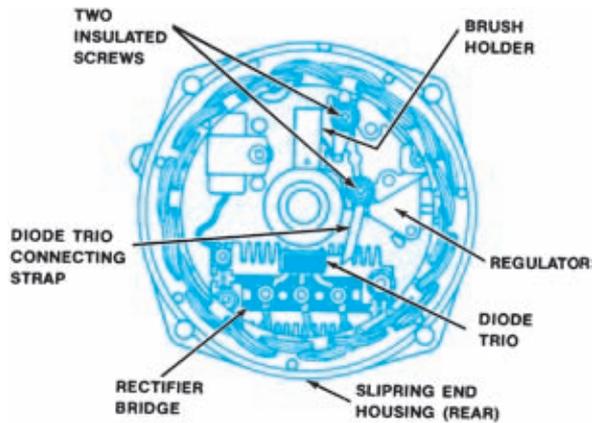


Figure 8-61. The rear end housing of the later-model 10-SI. (Delphi Automotive Systems)

medium, medium-high, or high is opposite the arrow on the housing, and reinstalling it in the new position. Repair or replace a 27-SI AC generator only if it fails to pass an output test after the regulator has been adjusted.

CS Series

The smaller Delco-Remy CS series AC generators introduced on some 1986 GM cars (Figure 8-63) maintain current output similar to larger AC generators. This series includes models CS-121, CS-130, and CS-144. The number following the CS designation denotes the outer diameter of the stator lamination in millimeters. All models use a delta-type stator. Field current is taken directly from the stator, eliminating the field diode trio. An integral cooling fan is used on the CS-121 and CS-130.

Electronic connections on CS AC generators include a BAT output terminal and either a one- or two-wire connector for the regulator. Figure 8-64 shows the two basic circuits for CS AC generators, but there are a number variations. Refer to the vehicle service manual for complete and accurate circuit diagrams. The use of the P, F, and S terminals is optional.

- The P terminal, connected to the stator, may be connected to a tachometer or other such device.
- The F terminal connects internally to field positive and may be used as a fault indicator.
- The S terminal is externally connected to battery voltage to sense the voltage to be controlled.

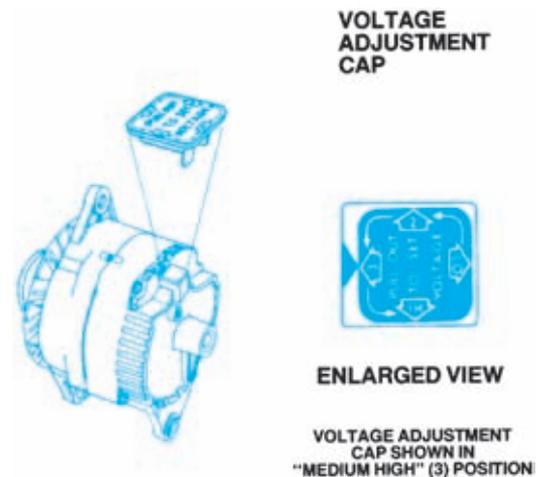


Figure 8-62. The Delco 27-SI alternator has an adjustable voltage regulator. (Delphi Automotive Systems)

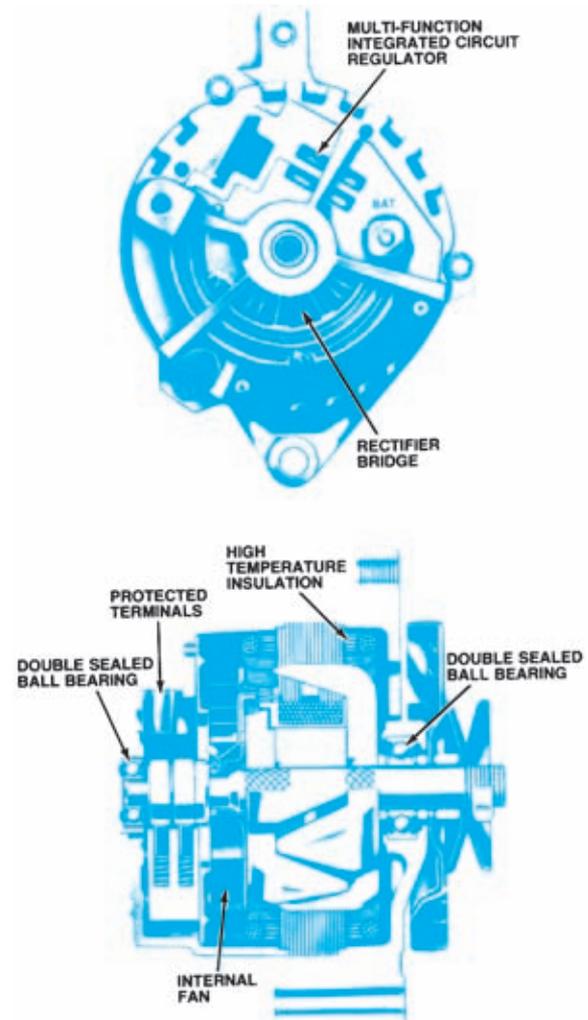


Figure 8-63. Typical Delco-Remy CS series AC generator (alternator) construction. (Delphi Automotive Systems)

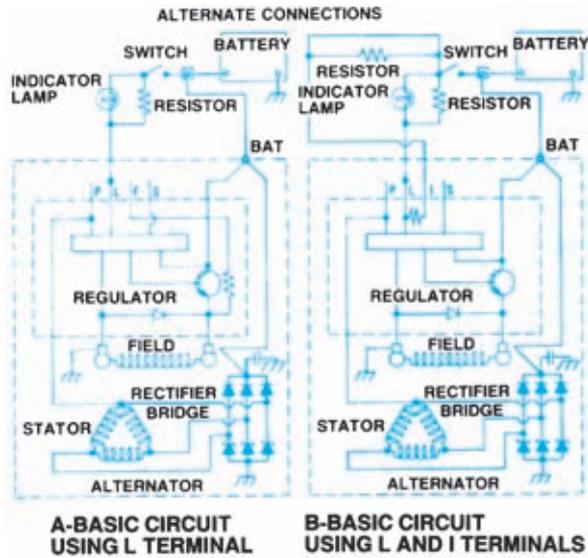


Figure 8-64. Two basic circuits for CS AC generators (alternator). (Delphi Automotive Systems)

- The L terminal connects the regulator to the indicator lamp and battery.

The indicator lamp in a CS charging system works differently than in other Delco-Remy systems: Any defect causes it to light at full brilliance. The lamp also lights if charging voltage is either too low or too high. If the regulator has an I terminal, its wire supplies field current in addition to that applied internally, either directly from the switch or through a resistor.

Motorcraft

Motorcraft, a division of Ford Motor Company, makes most of the AC generators used on domestic Ford vehicles. Model and current rating identifications for later models are stamped on the front housing with a color code. Motorcraft AC generators prior to 1985 are used with either an electromechanical voltage regulator or a remotely mounted solid-state regulator. One exception to this is the 55-ampere model of 1969–1971, which has a solid-state regulator mounted on the rear housing. This model has an A-circuit; all others are B-circuit. The Motorcraft integral alternator/regulator (IAR) model was introduced on some front-wheel drive Ford models in 1985. This AC generator (alternator) has a solid-state regulator mounted on its rear housing. Some Motorcraft charging systems continue to use an external solid-state regulator with either a rear-

terminal or side-terminal AC generator. These charging systems are called external voltage regulator (EVR) systems to differentiate them from integral alternator/regulator (IAR) systems.

Integral Alternator/Regulator Models

The Motorcraft IAR AC generators are rated at 40 to 80 amperes. The sealed rectifier assembly is attached to the slipring-end housing. On early models, the connecting terminals (BAT and STA) protruded from the side of the AC generator in a plastic housing. Current models use a single pin stator (STA) connector and separate output stud (BAT). The brushes are attached to, and removed with, the regulator. A Y-type stator is used with a 12-pole rotor. Some applications have an internal cooling fan.

Turning the ignition on sends voltage to the regulator I terminal through a resistor in the circuit. System voltage is sensed and field current is drawn through the regulator A terminal until the ignition is turned off, which shuts off the control circuit.

If the vehicle has a heated windshield, output is switched from the battery to the windshield by an output control relay. This allows output voltage to increase above the normal regulated voltage and vary with engine speed. The regulator I circuit limits the increase to 70 volts, which is controlled by the heated windshield module during the approximate four-minute cycle of heated windshield operation. When the cycle times out, the charging system returns to normal operation.

DaimlerChrysler

DaimlerChrysler Corporation manufactured all of the AC generators for its domestic vehicles until the late 1980s, when it phased in Bosch and Nippondenso AC generators for use on all vehicles.

DaimlerChrysler used two alternator designs from 1972 through 1984. The standard-duty alternator, rated from 50 to 65 amperes, is identified by an internal cooling fan and the stator core extension between the housings. The heavy-duty 100-ampere alternator has an external fan and a totally enclosed stator core. Identification also is stamped on a color-coded tag on the housing.

All models have a 12-pole rotor and use a remotely mounted solid-state regulator. The brushes can be replaced from outside the housing. Individual diodes are mounted in positive and negative heat

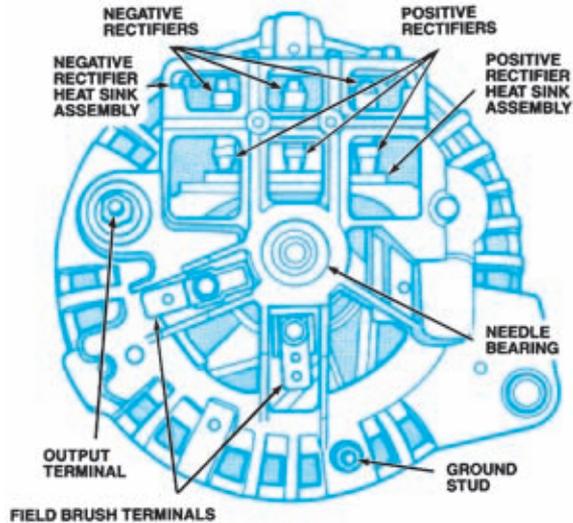


Figure 8-65. The terminals on a DaimlerChrysler standard-duty AC generator (alternator). (DaimlerChrysler Corporation)

sink assemblies, and are protected by a capacitor. The terminals on the standard-duty AC generator are labeled BAT, GRD, and FLD (Figure 8-65).

- The BAT terminal connects AC generator output to the insulated terminal of the battery.
- The GRD terminal is the ground connection.
- The FLD terminals connect to the insulated brushes. On the 100-ampere model, the FLD terminal has two separate prongs that fit into a single connector (Figure 8-66). The additional GRD terminal is a ground path.

DaimlerChrysler standard-duty AC generators have a Y-type stator connected to six diodes. Although both brush holders are insulated from the housing, one is indirectly grounded through the negative diode plate, making it a B-circuit. The 100-ampere AC generator has a delta-type stator. Each of the conductors is attached to two positive and two negative diodes. These 12 diodes create additional parallel circuit branches for high-current output.

DaimlerChrysler eliminated the use of a separate voltage regulator on most 1985 and later fuel injected and turbocharged engines by incorporating the regulator function into the powertrain control module (PCM), as shown in Figure 8-67.

The computer-controlled charging system was introduced with the standard DaimlerChrysler AC generator on GLH and Shelby turbo models. All other four-cylinder engines used either a new DaimlerChrysler 40/90-ampere AC generator or a

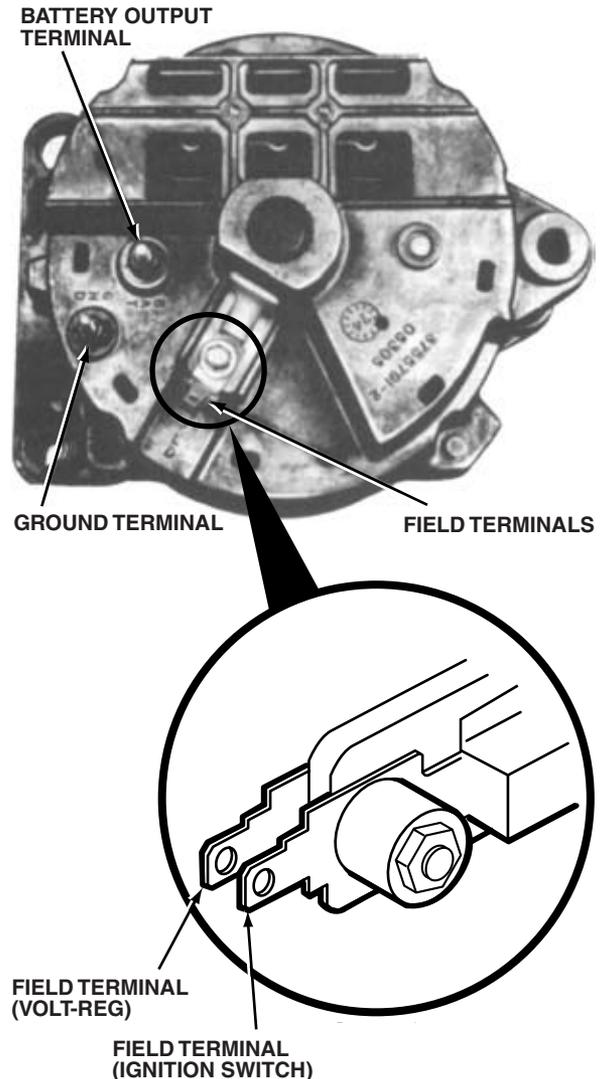


Figure 8-66. The terminals on a 100-amp DaimlerChrysler AC generator (alternator). (DaimlerChrysler Corporation)

modified Bosch 40/90-ampere or 40/100-ampere model.

The DaimlerChrysler-built AC generator uses a delta-type stator. The regulator circuit is basically the isolated-field type, but field current is controlled by integrated circuitry in the logic and power modules (Figure 8-68) or the logic and power circuits of the single-module engine control computer (SMEC) or single-board engine control computer (SBEC). In addition to sensing system voltage, the logic module or circuit senses battery temperature as indicated by system resistance. The computer then switches field current on and off in a duty

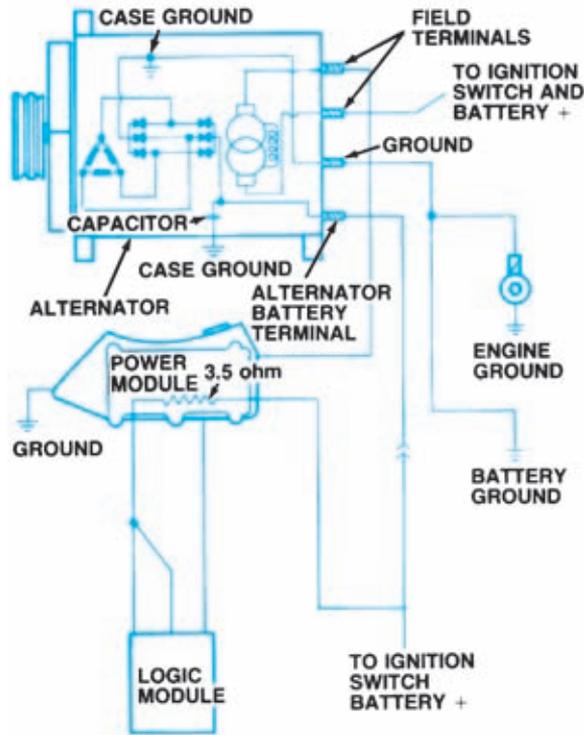


Figure 8-67. Typical DaimlerChrysler computer voltage regulation with DaimlerChrysler 40/90-ampere AC generator (alternator). Circuit connections vary on different models. (DaimlerChrysler Corporation)

cycle that regulates charging voltage, as in any other system. The DaimlerChrysler computer-controlled charging system has the following important features:

- It varies charging voltage relative to ambient temperature and the system voltage requirements.
- A self-diagnostic program can detect charging system problems and record fault codes in system memory. Some codes will light the POWER LOSS, POWER LIMITED, or MALFUNCTION INDICATOR lamp on the instrument panel; others will not.

Turning the ignition on causes the logic circuit to check battery temperature to determine the control voltage. A predriver transistor in the logic module or logic circuit signals a driver transistor in the power module or power circuit to turn on the AC generator field current (Figure 8-68). The logic module or logic circuit constantly monitors system voltage and battery temperature and signals the driver in the power module or power circuit when field current adjustment is necessary to keep output voltage within the specified 13.6-to-14.8-volt range.

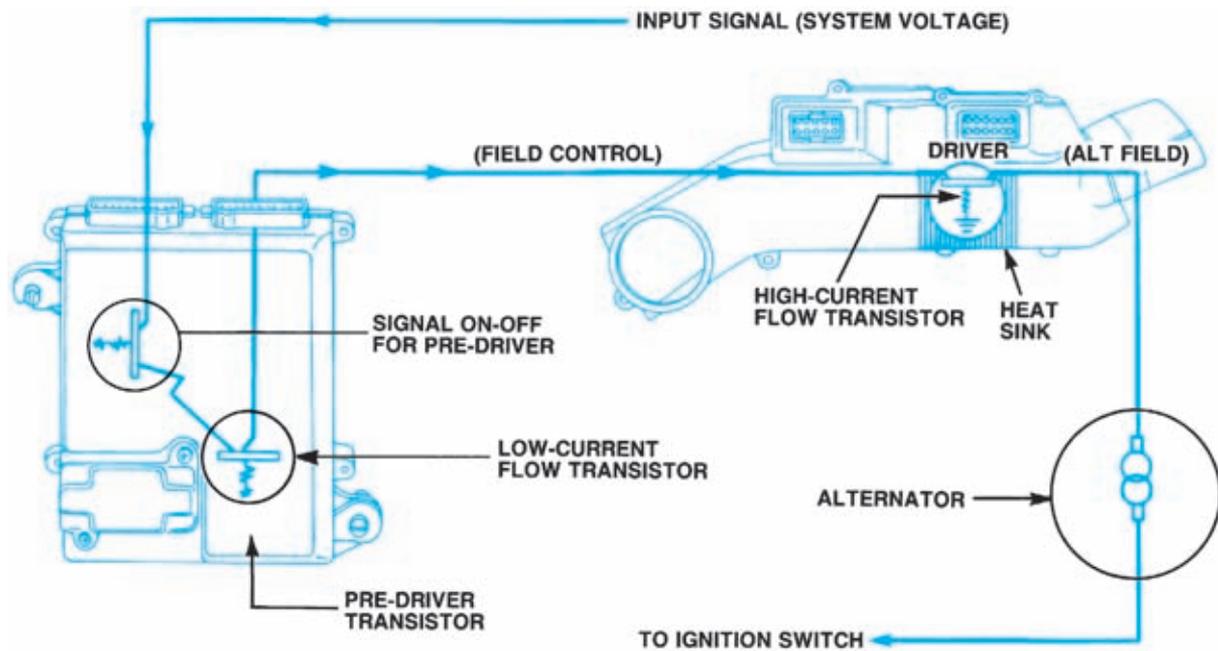


Figure 8-68. DaimlerChrysler computer-regulated charging system internal field control. (DaimlerChrysler Corporation)

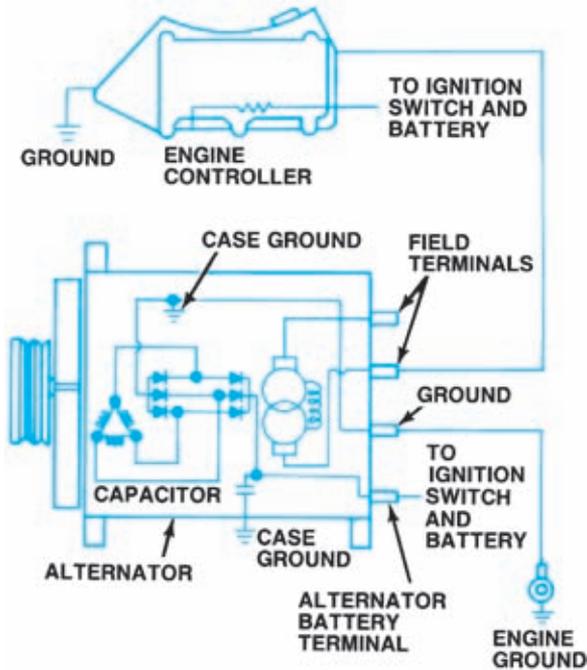


Figure 8-69. Current DaimlerChrysler charging system. (DaimlerChrysler Corporation)

Bosch AC Generators (Alternators)

Modified Bosch 40/90-ampere and 40/100-ampere AC generators (alternators) were introduced in 1985 for use with the DaimlerChrysler computer-controlled charging system. These Bosch dual-output AC generators have a Y-type stator and were modified by removing their internal voltage regulators and changing the external leads. They are fully interchangeable with DaimlerChrysler dual-output AC generators of the same rating. Use of dual-output AC generators was phased out in favor of a single-output Bosch alternator when DaimlerChrysler ceased manufacture of its own alternators in 1989. Current DaimlerChrysler charging systems with a Bosch AC generator (84 or 86 amperes) are essentially the same design as those used with the dual-output AC generators (Figure 8-69). However, an engine controller replaces the separate logic and power modules.

Nippondenso AC Generators

Some current DaimlerChrysler vehicles use Nippondenso AC generators with an output range of 68 to 102 amperes. These are virtual clones of the Bosch design, even to the external wiring connections (Figure 8-70). Charging system circuitry is the same, as are test procedures.

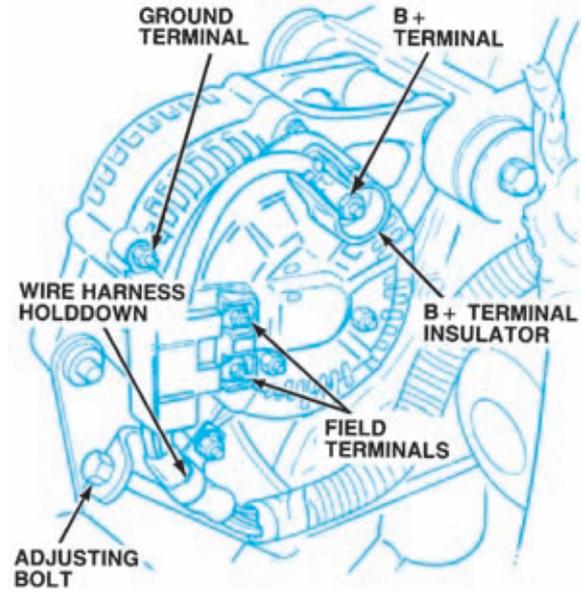


Figure 8-70. Nippondenso and Bosch AC generators used on DaimlerChrysler vehicles have identical connections. (DaimlerChrysler Corporation)

Import Vehicle Charging Systems

Many European vehicles have Bosch AC generators featuring Y-type stators. Bosch models with a remote regulator use six rectifiers and have a threaded battery terminal and two-way spade connector on the rear housing. Those with an integral regulator contain 12 rectifiers and have a threaded battery stud marked B+ and a smaller threaded stud marked D+. This smaller stud is used for voltage from the ignition switch. Models with internal regulators also have a diode trio to supply field current initially and a blocking diode to prevent current from flowing back to the ignition system when the ignition is turned off.

Several manufacturers such as Hitachi, Nippondenso, and Mitsubishi provide AC generators for Japanese vehicles. While all function on the same principles just studied, the design and construction of some units are unique. For example, Figure 8-71 shows a Mitsubishi AC generator that uses an integral regulator with double Y-stator and 12 diodes in a pair of rectifier assemblies to deliver high current with high voltage at low speeds. A diode trio internally supplies the field, and a 50-ohm resistor in the regulator performs the same function as the Bosch blocking diode.

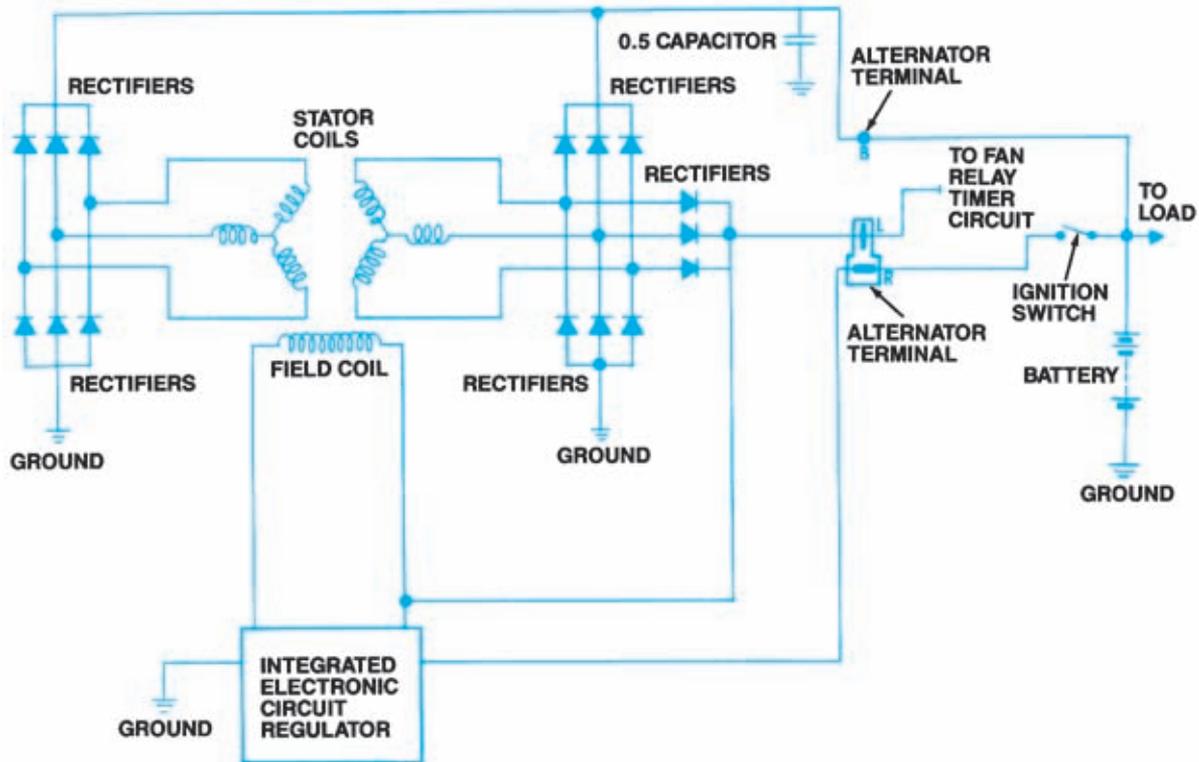


Figure 8-71. Mitsubishi charging system. (Mitsubishi)

SUMMARY

The sine wave voltage induced across one AC generator (alternator) conductor generates single-phase current. By connecting the AC generator conductor diodes, the AC is fully rectified to DC. In an actual automotive AC generator, there are more than two magnetic poles and one conductor. Common AC generators have from 8 to 14 poles on a rotor, and three conductors wound to create a stator. The rotor and stator are held in a two-piece housing. Two brushes attached to the housings, but often insulated from it, ride on sliprings to carry current to the rotor winding. The diodes are installed in the same end housing as the brushes. Three positive diodes are insulated from the housing; three negative diodes are grounded to the housing.

Stators with three conductors produce three-phase current. The three conductors may be connected to make a Y-type or a delta-type stator. The rectification process is the same for both types, although the current paths through the stators differ. Rectified output from a multiple-pole AC generator is a rippling DC voltage.

Because the rotor does not retain enough magnetism to begin induction, an excitation circuit must carry battery current to the rotor winding. The rotor winding is part of an externally grounded field, or A-circuit; or an internally grounded field, or B-circuit.

Because a counter-voltage is induced in the stator windings, AC generator current output is self-limiting. Voltage regulation is still needed. Those with integrated circuits have replaced electromagnetic voltage regulators. Voltage regulators now in use are completely solid-state designs. They replaced the electromagnetic type regulators in AC charging systems because they are smaller and have no moving parts. Because of the construction of solid-state regulators, they are non-serviceable and must be replaced if defective. Their function is the same: to control AC generator output by modulating current through the field windings of the AC generator.

Indicators allow the driver to monitor the performance of the charging system: These include ammeters, voltmeters, or warning lamps. An ammeter measures the charging system current into and out of the battery and the entire electrical system. A voltmeter measures electrical

pressure and indicates regulated AC generator voltage output or battery voltage. Indicator lamps illuminate on the instrument panel of the vehicle and indicate to the driver general charging system operation status.

Wiring and other components in the charging system may be damaged if the system fails or malfunctions due to excessive current or heat, voltage surges, and other uncontrolled factors. Fusible links are used in these circuits to protect the circuit from high current.

Common AC generators used by domestic manufacturers include the Delco-Remy SI and CS series used by OM; the Motorcraft IAR, rear-terminal, and side-terminal models used by Ford; and the DaimlerChrysler-built, Bosch, and Nippondenso models used by DaimlerChrysler. Most European imports use Bosch AC generators, while Asian imports use alternators made by several manufacturers, including Hitachi, Nippondenso, and Mitsubishi.

Review Questions

1. Alternators induce voltage by rotating:
 - a. A magnetic field inside a fixed conductor
 - b. A conductor inside a magnetic field
 - c. A stator inside a field
 - d. A spring past a stator
2. In an alternator, induced voltage is at its maximum value when the angle between the magnetic lines and the looped conductor is:
 - a. 0 degrees
 - b. 45 degrees
 - c. 90 degrees
 - d. 180 degrees
3. The sine wave voltage induced across one conductor by one rotor revolution is called:
 - a. Single-phase current
 - b. Open-circuit voltage
 - c. Diode rectification
 - d. Half-phase current
4. Alternating current in an alternator is rectified by:
 - a. Brushes
 - b. Diodes
 - c. Slip rings
 - d. Transistors
5. An alternator with only one conductor and one diode would show which of the following current output patterns?
 - a. Three-phase current
 - b. Open-circuit voltage
 - c. Half-wave rectification
 - d. Full-wave rectification
6. An alternator consists of:
 - a. A stator, a rotor, sliprings, brushes, and diodes
 - b. A stator, an armature, sliprings, brushes, and diodes
 - c. A stator, a rotor, a commutator, brushes, and diodes
 - d. A stator, a rotor, a field relay, brushes, and diodes
7. A typical automotive alternator has how many poles?
 - a. 2 to 4
 - b. 6 to 8
 - c. 8 to 14
 - d. 12 to 20
8. The three alternator conductors are wound onto a cylindrical, laminated metal-piece called:
 - a. Rotor core
 - b. Stator core
 - c. Armature core
 - d. Field core
9. Automotive alternators that have three conductors generally use how many diodes to rectify the output current?
 - a. Three
 - b. Six
 - c. Nine
 - d. Twelve
10. Which of the following is *not* true of the positive diodes in an alternator?
 - a. They are connected to the insulated terminal of the battery.
 - b. They conduct only the current moving from ground into the conductor.
 - c. They are mounted in a heat sink.
 - d. The bias of the diodes prevents the battery from discharging.
11. A group of three or more like diodes may be called:
 - a. Diode wing
 - b. Diode triplet
 - c. Diode dish
 - d. Diode bridge
12. Y-type stators are used in alternators that require:
 - a. Low voltage output at high alternator speed
 - b. High voltage output at low alternator speed
 - c. Low voltage at low alternator speed
 - d. High voltage at high alternator speed
13. Which of the following is true of a delta-type stator?
 - a. There is no neutral junction.
 - b. There is no ground connection.
 - c. The windings always form a series circuit.
 - d. The circuit diagram looks like a parallelogram.
14. Delta-type stators are used:
 - a. When high-voltage output is needed
 - b. When low-voltage output is needed

- c. When high-current output is needed
 - d. When low-current output is needed
15. Which of the following is a commonly used type of field circuit in automotive alternators?
- a. X-circuit
 - b. Y-circuit
 - c. Connected-field circuit
 - d. A-circuit
16. Alternator output voltage is directly related to:
- a. Field strength
 - b. Rotor speed
 - c. Both field strength and rotor speed
 - d. Neither field strength nor rotor speed
17. Double-contact voltage regulators contain all of the following except:
- a. An armature
 - b. An electromagnet
 - c. Two sets of contact points
 - d. A solenoid
18. The shorting contacts of a double-contact regulator:
- a. Increase voltage creep
 - b. Increase field current
 - c. React to battery temperature changes
 - d. Short the field circuit to the alternator
19. Which of the following can *not* be used in a totally solid-state regulator?
- a. Zener diodes
 - b. Thermistors
 - c. Capacitors
 - d. Circuit breakers
20. Which of the following is used to smooth out any abrupt voltage surges and protect a regulator?
- a. Transistor
 - b. Capacitor
 - c. Thermistor
 - d. Relays
21. Which of the following is used to monitor the charging system?
- a. Ammeter
 - b. Ohmmeter
 - c. Dynamometer
 - d. Fusible link
22. Warning lamps are installed so that they will not light when the following is true:
- a. The voltage on the battery side of the lamp is higher.
 - b. Field current is flowing from the battery to the alternator.
 - c. The voltage on both sides of the lamp is equal.
 - d. The voltage on the resistor side of the lamp is higher.
23. Maximum current output in an alternator is reached when the following is true:
- a. It reaches maximum designed speed.
 - b. Electrical demands from the system are at the minimum.
 - c. Induced countervoltage becomes great enough to stop current increase.
 - d. Induced countervoltage drops low enough to stop voltage increase.
24. The regulator is a charging system device that controls circuit opening and closing:
- a. Ignition-to-battery
 - b. Alternator-to-thermistor
 - c. Battery-to-accessory
 - d. Voltage source-to-battery
25. Which of the following methods is used to regulate supply current to the alternator field?
- a. Fault codes
 - b. Charge indicator lamp
 - c. Pulse-width modulation
 - d. Shunt resistor