Automobile Electrics: The Charging System

The Basics

The automotive storage battery is not capable of supplying the demands of the electrical system for an extended period of time. Every vehicle must be equipped with a means of replacing the current being drawn from the battery. A charging system is used to restore the electrical power to the battery that was used during engine starting. In addition, the charging system must be able to react quickly to high load demands required of the electrical system. It is the vehicle's charging system that generates the current to operate all of the electrical accessories while the engine is running.

The purpose of the charging system is to provide the electrical energy needed to charge the battery and to power all the electrical components and systems on the automobile. When the engine is not running, the battery provides this electrical energy. When the engine is running, the charging system takes over. The basic parts of a charging system are shown. The alternator is the heart of the charging system. It is an alternating-current generator mounted on the engine, which is driven by a belt from the crankshaft. The alternator develops alternating current, which is changed to direct current. Alternating current changes from positive (+) to negative (-) at a regular cycle. Direct current does not change from positive (+) to negative (-). Only direct current can be used to charge a battery.

A voltage regulator, either inside or outside the alternator, senses the electrical needs of the vehicle and adjusts the output of the alternator accordingly. An indicator light on the instrument panel allows the driver to observe whether the system is operating properly. The battery is connected electrically to the alternator, so that either one may supply the electrical needs, and so that the alternator can charge the battery.

Two basic types of charging systems have been used. The first was a DC generator, which was discontinued in the 1960s. Since that time the AC alternator has been the predominant charging device. The DC generator and the AC alternator both use similar operating principles.

As the battery drain continues, and engine speed increases, the charging system is able to produce more voltage than the battery can deliver. When this occurs, the electrons from the charging device are able to flow in a reverse direction through the battery's positive terminal. The charging device is now supplying the electrical system's load requirements; the reserve electrons build up and recharge the battery.

If there is an increase in the electrical demand and a drop in the charging system's output equal to the voltage of the battery, the battery and charging system work together to supply the required current.

The entire charging system consists of the following components:

1. Battery
2. AC or DC generator
3. Drive belt
4. Voltage regulator
5. Charge indicator (lamp or gauge)
6. Ignition switch
7. Cables and wiring harness

8. Starter relay (some systems)
9. Fusible link (some systems)

Principle of Operation

All charging systems use the principle of electromagnetic induction to generate electrical power. Electromagnetic principle states that a voltage will be produced if motion between a conductor and a magnetic field occurs. The amount of voltage produced is affected by:

1. The speed at which the conductor passes through the magnetic field.
2. The strength of the magnetic field.
3. The number of conductors passing through the magnetic field.

When the conductor is parallel with the magnetic field, the conductor is not cut by any flux lines. At this point in the revolution there is zero voltage and current being produced.

As the conductor is rotated 90 degrees, the magnetic field is at a right angle to the conductor. At this point in the revolution the maximum number of flux lines cut the conductor at the north pole. With the maximum amount of flux lines cutting the conductor, voltage and current are at maximum positive values.

When the conductor is rotated an additional 90 degrees, the conductor returns to being parallel with the magnetic field. Once again no flux lines cut the conductor, and voltage and current drop to zero.

An additional 90-degree revolution of the conductor results in the magnetic field being reversed at the top conductor. At this point in the revolution, the maximum number of flux lines cuts the conductor at the south pole. Voltage and current are now at maximum negative values.

When the conductor completes one full revolution, it returns to a parallel position with the magnetic field. Voltage and current return to zero. The sine wave is determined by the angle between the magnetic field and the conductor. It is based on the trigonometry sine function of angles. The sine wave shown plots the voltage generated during one revolution.

It is the function of the drive belt to turn the conductor. Drive belt tension should be checked periodically to assure proper charging system operation. A loose belt can inhibit charging system efficiency, and a belt that is too tight can cause early bearing failure.

DC Generators

The DC generator is similar to the DC starter motor used to crank the engine. The housing contains two field coils that create a magnetic field. Output voltage is generated in the wire loops of the armature as it rotates inside the magnetic field. This current is sent to the battery through the brushes.

The components must be polarized whenever a replacement DC generator or voltage regulator is installed. To polarize an externally grounded field circuit (A-type field circuit), use a jumper wire and connect between the BAT terminal and the ARM terminal of the voltage regulator. Make this jumper connection for just an instant. Do not hold the jumper wire on the terminals. For an internally grounded field circuit (B-type), jump the F terminal and the BAT terminal.

AC Generators

The DC generator was unable to produce the sufficient amount of current required when the engine was operating at low speeds. With the addition of more electrical accessories and components, the AC (alternating current) generator, or alternator, replaced the DC generator. The main components of the AC generator are:

1. The rotor
2. Brushes
3. The stator
4. The rectifier bridge
5. The housing
6. Cooling fan

Rotors

The rotor is constructed of several turns of copper wire around an iron core. There are metal plates bent over the windings at both ends of the rotor windings. The poles do not come into contact with each other, but they are interlaced. When current passes through the coil (1.5 to 3.0 amperes), a magnetic field is produced. The strength of the magnetic field is dependent on the amount of current flowing through the coil.

The poles will take on the polarity (north or south) of the side of the coil they touch. The right-hand rule will show whether a north or south pole magnet is created. When the rotor is assembled, the poles alternate north-south around the rotor. As a result of this alternating arrangement of poles, the magnetic flux lines will move in opposite directions between adjacent poles. This arrangement provides for several alternating magnetic fields to intersect the stator as the rotor is turning. These individual magnetic fields produce a current by induction in the stationary stator windings.

The wires from the rotor coil are attached to two slip rings that are insulated from the rotor shaft. The insulated stationary carbon brush passes field current into a slip ring, then through the field coil, and back to the other slip ring. Current then passes out of the grounded stationary brush.

Brushes

The field winding of the rotor receives current through a pair of brushes that ride against the slip rings. The brushes and slip rings provide a means of maintaining electrical continuity between stationary and rotating components. The brushes ride the surface of the slip rings on the rotor and are held tight against the slip rings by spring tension provided by the brush holders. The AC generator brushes conduct only the field current (2 to 5 amperes). The low current that the brushes must carry contributes to their longer life.

Direct current from the battery is supplied to the rotating field through the field terminal and the insulated brush. The second brush is the ground brush, which is attached to the AC generator housing. The stator contains three main sets of windings wrapped in slots around a laminated, circular iron frame. Each of the three windings has the same number of coils as the rotor has pairs of north and south poles. The coils of each winding are evenly spaced around the core. The three sets of windings alternate and overlap as they pass through the core. The overlapping is needed to produce the required phase angles.

The Stator

The rotor is fitted inside the stator. A small air gap (approximately 0.015 inch) is maintained between the rotor and the stator. This gap allows the rotor's magnetic field to energize all of the windings of the stator at the same time and to maximize the magnetic force.

Each group of windings has two leads. The first lead is for the current entering the winding. The second lead is for current leaving. There are two basic means of connecting the leads. The most common method is called the wye connection. In the wye connection one lead from each winding is connected to one common junction. From this junction the other leads branch out in a Y pattern. The other method of connecting the windings is called the delta connection. The delta connection connects the lead of one end of the winding to the lead at the other end of the next winding.

Each group of windings occupies one third of the stator, or 120 degrees of the circle. As the rotor revolves in the stator, a voltage is produced in each loop of the stator at different phase angles. The resulting overlap of sine waves that is produced is shown. Each of the sine waves is at a different phase of its cycle at any given time. As a result, the output from the stator is divided into three phases.

Diode Rectifier Bridge

The battery and the electrical system cannot accept or store AC voltage. For the vehicle's electrical system to be able to use the voltage and current generated in the AC generator, the AC current needs to be converted to DC current. A split-ring commutator cannot be used to rectify AC current to DC current because the stator is stationary in the AC generator. Instead, a diode rectifier bridge is used to change the current in an AC generator. Acting as a one-way check valve, the diodes switch the current flow back and forth so that it flows from the AC generator in only one direction.

When AC current reverses itself, the diode blocks and no current flows. If AC voltage passes through a positively biased diode, the diode will block off the negative pulse. The result is the scope pattern shown in 9-19. The AC current has been changed to a pulsing DC current.

An AC generator usually uses a pair of diodes for each stator winding, for a total of six diodes. Three of the diodes are positive biased and are mounted in a heat sink. The three remaining diodes are negative biased and are attached directly to the frame of the AC generator. By using a pair of diodes that are reversed biased to each other, rectification of both sides of the AC sine wave is achieved. The negative biased diodes allow for conducting current from the negative side of the AC sine wave and putting this current into the circuit. Diode rectification changes the negative current into positive output.

With each stator winding connected to a pair of diodes, the resultant waveform of the rectified voltage would be similar to that shown. With six peaks per revolution, the voltage will vary by only a couple of volts during each cycle.

The examples used so far have been for single-pole rotors in a three-winding stator. Most AC generators use either a twelve- or fourteen-pole rotor. Each pair of poles produces one complete sine wave in each winding per revolution. During one revolution a fourteen-pole rotor will produce seven sine waves. The rotor generates three overlapping sine wave voltage cycles in the stator. The total output of a fourteen-pole rotor per revolution would be twenty-one sine wave cycles. With final rectification, the waveform would be similar to the one shown.

Full-wave rectification is desired because using only half-wave rectification wastes the other half of the AC current. Full-wave rectification of the stator output uses the total potential by redirecting the current from the stator windings so that all current is in one direction.

A wye wound stator with each winding connected to a pair of diodes is shown. Each pair of diodes has one negative and one positive diode. During rotor movement two stator windings will be in series and the third winding will be neutral. As the rotor revolves it will energize a different set of windings. Also, current flow through the windings is reversed as the rotor passes. Current in any direction through two windings in series will produce DC current.

The action that occurs when the delta wound stator is used is shown. Instead of two windings in series, the three windings of the delta stator are in parallel. This makes more current available because the parallel paths allow more current to flow through the diodes.

AC Generator Housing and Cooling Fan

Most AC generator housings are a two-piece construction, made from cast aluminum. The two end frames provide support of the rotor and the stator. In addition, the end frames contain the diodes, regulator, heat sinks, terminals, and other components of the AC generator. The two end pieces are referred to as:

1. The drive end housing: This housing holds a bearing to support the front of the rotor shaft. The rotor shaft extends through the drive end housing and holds the drive pulley and cooling fan.

2. The slip ring end housing: This housing also holds a rotor shaft support bearing. In addition, it contains the brushes and has all of the electrical terminals. If the AC generator has an integral regulator, it is also contained in this housing.

The cooling fan draws air into the AC generator through the openings at the rear of the AC generator housing. The air leaves through openings behind the cooling fan.

CAUTION: Do not pry on the AC generator housing because any excess force can damage the housing.

AC Generator Currents

There are three principle circuits used in the AC generator:

1. The charging circuit: Consists of the stator windings and rectifier circuits.

2. The excitation circuit: Consists of the rotor field coil and the electrical connections to the coil.

3. The preexcitation circuit: Supplies the initial current for the field coil that starts the buildup of the magnetic field.

For the AC generator to produce current, the field coil must develop a magnetic field. The AC generator creates its own field current in addition to its output current.

For excitation of the field to occur, the voltage induced in the stator rises to a point that it overcomes the forward voltage drop of at least two of the rectifier diodes. Before the diode trio can supply field current, the anode side of the diode must be at least 0.6 volt more positive than the cathode side. When the ignition switch is turned on, the warning lamp current acts as a small magnetizing current through the field. This current preexcites the field, reducing the speed required to start its own supply of field current.

AC Generator Operation Overview

When the engine is running, the drive belt spins the rotor inside the stator windings. This magnetic field inside the rotor generates a current in the windings of the stator. Field current flowing through the slip rings to the rotor creates alternating north and south poles on the rotor.

The induced current in the stator is an alternating current because the magnetic fields are alternating. As the magnetic field begins to induce current in the stator's windings, the induced current starts to increase. The amount of current will peak when the magnetic field is the strongest. As the magnetic field begins to move away from the stator windings, the amount of current will start to decrease. Each of the three windings of the stator generates current, so the three combine to form a three-phase voltage output.

The most common type of stator is the wye connection. The output terminals (A, B, and C) apply voltage to the rectifier. Because only two stator windings apply voltage (because the third winding is always connected to diodes that are reverse biased), the voltages come from points A to B, B to C, and C to A.

To determine the amount of voltage produced in the two stator windings, find the difference between the two points. For example, to find the voltage applied from points A and B subtract the voltage at point B from the voltage at point A. If the voltage at point A is 8 volts positive and the voltage at point B is 8 volts negative, the difference is 16 volts. This procedure can be performed for each pair of stator windings at any point in time to get the sine wave patterns. The voltages in the windings are designated as VA, VB, and VC. Designations of VAB, VBC, and VCA refer to the voltage difference in the two stator windings. In addition, the numbers refer to the diodes used for the voltages generated in each winding pair.

The current induced in the stator passes through the diode rectifier bridge consisting of three positive and three negative diodes. At this point there are six possible paths for the current to follow. The path that is followed depends on the stator terminal voltages. If the voltage from points A and B is positive (point A is positive in respect to point B), current is supplied to the positive terminal of the battery from terminal A through diode 2. The negative return path is through diode 3 to terminal B.

Both diodes 2 and 3 are forward biased. The stator winding labeled C does not produce current because it is connected to diodes that are reverse biased. The stator current is rectified to DC current to be used for charging the battery and supplying current to the vehicle's electrical system.

When the voltage from terminals C and A is negative (point C is negative in respect to point A), current flow to the battery positive terminal is from terminal A through diode 2. The negative return path is through diode 5 to terminal C. This procedure is repeated through the four other current paths.

Regulation

The battery, and the rest of the electrical system, must be protected from excessive voltages. To prevent early battery and electrical system failure, regulation of the charging system is very important. Also the charging system must supply enough current to run the vehicle's electrical accessories when the engine is running.

AC generators do not require current limiters, because they limit their own current output. Current limit is the result of the constantly changing magnetic field because of the induced AC current. As the magnetic field changes, an opposing current is induced in the stator windings. The inductive reactance in the AC generator limits the maximum current that the AC generator can produce. Even though current (amperage) is limited by its operation, voltage is not. The AC generator is capable of producing as high as 250 volts, if it were not controlled.

Regulation of voltage is done by varying the amount of field current flowing through the rotor. The higher the field current, the higher the output voltage. By controlling the amount of resistance in series with the field coil, control of the field current and the AC generator output is obtained. To insure a full battery charge, and operation of accessories, most regulators are set for a system voltage between 13.5 and 14.5 volts.

If sensing voltage is below the regulator setting, an increase in charging output results by increasing field current. Higher sensing voltage will result in a decrease in field current and system output. A vehicle being driven with no accessories on and a fully charged battery will have a high sensing voltage. The regulator will reduce the charging voltage, and current, until it is at a level to run the ignition system while trickle charging the battery (2 to 4 amperes). If a heavy load is turned on (such as the headlights) the additional draw will cause a drop in the battery voltage. The regulator will sense this low system voltage and will reduce the field circuit resistance. This will allow more current to the field windings. With the increase of field current, the magnetic field is stronger and AC generator output is increased. When the load is turned off, the regulator senses the rise in system voltage and cuts back the amount of field current and ultimately AC generator output.

Another input that affects regulation is temperature. Because ambient temperatures influence the rate of charge that a battery can accept, regulators are temperature compensated. Temperature compensation is required because the battery is more reluctant to accept a charge at lower ambient temperatures. The regulator will increase the system voltage until it is at a high enough level that the battery will accept it.

Field Circuits

To properly test and service the charging system, it is important to identify the field circuit being used. Automobile manufacturers use three basic types of field circuits. The first type is called the A circuit. It has the regulator on the ground side of the field coil. The B+ for the field coil is picked up from inside the AC generator. By placing the regulator on the ground side of the field coil, the variable resistance will allow the control of field current by varying the current flow to ground. A resistance can be located anywhere in the series circuit and have the same effect.

The second type of field circuit is called the B circuit. In this case, the voltage regulator controls the power side of the field circuit. Also the field coil is grounded from inside the AC generator.

The third type of field circuit is called the isolated field. The AC generator has two field wires attached to the outside of the case. The voltage regulator can be located on either the ground (A circuit) or on the B+ (B circuit) side.

Electromechanical Regulators

There are two basic types of regulators: electromechanical and electronic. Also, on many newer model vehicles regulation is controlled by the computer. Even though the electromechanical regulator is obsolete, a study of its operation will help you to understand the more complex systems.

The external electromechanical regulator is a vibrating contact point design. The regulator uses electromagnetics to control the opening and closing of the contact points. Inside the regulator are two coils. One coil is the field relay and the second is the voltage regulator. The field relay coil and contact with no current flowing through the coil are shown. The contact points are open, preventing current flow. An electromagnetic field develops when current flows through the field relay coil. It pulls the contact arm down. Once the contact points close, current will flow.

The voltage regulator coil uses an electromagnetic field to open the contact points. With the points closed, current flows from the battery to the rotor. Current also flows to the regulator coil. As the battery charges, the battery's voltage increases. This increase in voltage strengthens the coil's attraction for the contact points. At a preset voltage level, the coil will overcome the contact point spring tension and open the points. This will prevent current from flowing to the rotor. Once the points open, voltage output of the AC generator drops, and the battery will start to discharge. As the battery voltage decreases, so does the regulator coil's magnetic strength. Spring tension will overcome the magnetic attraction and the points will close again. Once again current flows through the rotor and the AC generator is producing voltage. This action occurs several times per second.

When the ignition switch is in the RUN position with the engine off, the regulator will be in the position shown. With the ignition switch in RUN, current flow for the field will go through the ignition switch through the resistor and bulb, through the lower contacts of the voltage regulator (closed), and out of the F terminal to the AC generator, through the field coil, and to ground. The indicator lamp bulb will light because the bulb is in series with the field coil.

Once the engine is started, the AC generator will begin to produce voltage. At this time the system voltage may be below 13.5 volts, however, because the AC generator rotor is revolving, there is some production of voltage. This allows voltage out of the R terminal to energize the field relay coil. With the relay coil energized, the contact points close and direct battery voltage flows through terminal 3 and out terminal 4. The bulb will go out with battery voltage on both sides of the bulb. Simultaneously, battery voltage flows through the voltage regulator contact points to the field coil in the AC generator. Because the voltage regulator coil is also connected to the battery (above terminal 4), the lower than 13.5 volts is unable to produce a sufficient electromagnetic field to pull the contact points open. This condition will allow maximum AC generator output.

As the battery receives a charge from the AC generator, the battery voltage will increase to over 13.5 volts. The increased voltage will strengthen the electromagnetic field of the voltage regulator coil. The coil will attract the points and cause the lower contacts to open. Current will now flow through the resistor and out terminal F. Because an additional series resistance is added to the field coil circuit of the AC generator, field current is reduced, and AC generator output is also reduced to one half its rating.

If the AC generator is producing more voltage than the system requires, both battery and system voltage will increase. As this voltage increases to a level above 14.5 volts, the magnetic strength of the coil increases. This increase in magnetic strength will close the top set of contact points and apply a ground to the F terminal and the AC generator's field coil. Both sides of the field coil are grounded, thus no current will flow through it and there is no output.

Once the engine is shut off, there is no current from the R terminal; the field relay coil is deenergized, allowing the points to open. This prevents battery draw into the charging system.

Electronic Regulators

The second type of regulator is the electronic regulator. Electronic regulators can be mounted either externally or internally of the AC generator. There are no moving parts, so it can cycle between 10 and 7,000 times per second. This quick cycling provides more accurate control of the field current through the rotor. Electronic regulation control is through the ground side of the field current (A circuit).

Pulse width modulation controls AC generator output by varying the amount of time the field coil is energized. For example, assume that a vehicle is equipped with a 100-ampere alternator. If the electrical demand placed on the charging system requires 50 amperes of current, the regulator would energize the field coil for 50% of the time. If the electrical system's demand was increased to 75 amperes, the regulator would energize the field coil 75% of the cycle time.

The electronic regulator uses a zener diode that blocks current flow until a specific voltage is obtained, at which point it allows the current to flow. A simplified electronic regulator is shown.

AC generator voltage from the stator and diodes first goes through a thermistor. Current then flows to the zener diode. When the upper voltage limit (14.5 volts) is reached, the zener diode will conduct current to flow to the base of transistor 1. This turns transistor 1 on and switches off transistor 2. Transistor 2 controls field current to the AC generator. If transistor 2 is off, no current can flow through the field coil and the AC generator will not have any output. When no voltage is applied to the zener diode, current flow stops, transistor 1 is turned off, transistor 2 is turned on, and the field circuit is closed. The magnetic field is restored in the rotor, and the AC generator produces output voltage.

Many manufacturers are installing the voltage regulator internally in the AC generator. This eliminates some of the wiring needed for external regulators. The diode trio rectifies AC current from the stator to DC current that is applied to the field windings.

Current flow with the engine off and the ignition switch in the RUN position is illustrated. Battery voltage is applied to the field through the common point above R1. TR1 conducts the field current coming from the field coil, producing a weak magnetic field. The indicator lamp lights because TR1 directs current to ground and completes the lamp circuit.

Current flow with the engine running is illustrated. When the AC generator starts to produce voltage, the diode trio will conduct and battery voltage is available for the field and terminal 1 at the common connection. Placing voltage on both sides of the lamp removes any voltage potential, and the lamp goes out.

Current flow as AC generator output is being regulated is illustrated. The sensing circuit from terminal 2 passes through a thermistor to the zener diode (D2). When the system voltage reaches the upper voltage limit of the zener diode, the zener diode conducts current to TR2. When TR2 is biased it opens the field coil circuit and current stops flowing through the field coil. Regulation of this switching on and off is based on the sensing voltage received through terminal 2. With the circuit to the field coil opened, the sensing voltage decreases and the zener diode stops conducting. TR2 is turned off and the circuit for the field coil is closed.

Computer-Controlled Regulation

On many vehicles after the mid-1980s, the regulator function has been incorporated into the vehicle's engine computer. The operation is the same as the internal electronic regulator. Regulation of the field circuit is through the ground (A circuit).

The logic board's decisions, concerning voltage regulation, are based on output voltages and battery temperature. When the desired AC generator output voltage is obtained (based on battery temperature) the logic board duty-cycles a switching transistor. This transistor grounds the AC generator's field to control output voltage.

General Motors introduced an AC generator called the CS (charging system) series. This AC generator is smaller than previous designs. Additional features include two cooling fans (one external and one internal), and terminals designed to permit connections to an onboard computer through terminals L and F. The voltage regulator switches the field current on and off at a fixed frequency of about 400 times per second. Varying the on and off time of the field current controls voltage output.

Charging Indicators

There are four basic methods of informing the driver of the charging system's condition: indicator lamps, electronic voltage monitor, ammeter, and voltmeter.

Indicator Light Operation

As discussed earlier, most indicator lamps operate on the basis of opposing voltages. If the AC generator output is less than battery voltage, there is an electrical potential difference in the lamp circuit and the lamp will light. In the electromechanical regulator system, if the stator is not producing a sufficient amount of current to close the field relay contact points the lamp will light. If the voltage at the battery is equal to the output voltage, the two equal voltages on both sides of the lamp result in no electrical potential and the lamp goes out

Electronic regulators that use an indicator lamp operate on the same principle. If there is no stator output through the diode trio, then the lamp circuit is completed to ground through the rotor field and TR1.

On most systems, the warning lamp will be 'proofed' when the ignition switch is in the RUN position before the engine starts. This indicates that the bulb and indicator circuit are operating properly. Proofing the bulb is accomplished because there is no stator output without the rotor turning.

Electronic Voltage Monitor

The electronic voltage monitor module is used to monitor the system voltage. The lamp will remain off if the system voltage is above 11.2 volts. Once system voltage drops below 11.2 volts, a transistor amplifier in the module turns on the indicator lamp. This system can use either a lamp or a light-emitting diode.

Ammeter Operation

In place of the indicator light, some manufacturers install an ammeter. The ammeter is wired in series between the AC generator and the battery. Most ammeters work on the principle of d'Arsonval movement.

The movement of the ammeter needle under different charging conditions is illustrated. If the charging system is operating properly, the ammeter needle will remain within the normal range. If the charging system is not generating sufficient current, the needle will swing toward the discharge side of the gauge. When the charging system is recharging the battery, or is called on to supply high amounts of current, the needle deflects toward the charge side of the gauge.

It is normal for the gauge to read a high amount of current after initial engine start up. As the battery is recharged, the needle should move more toward the normal range.

Voltmeter Operation

Because the ammeter is a complicated gauge for most people to understand, many manufacturers use a voltmeter to indicate charging system operation. The voltmeter is usually connected between the battery positive and negative terminals.

When the engine is started, it is normal for the voltmeter to indicate a reading between 13.2 and 15.2 volts. If the voltmeter indicates a voltage level that is below 13.2, it may mean that the battery is discharging. If the voltmeter indicates a voltage reading that is above 15.2 volts, the charging system is overcharging the battery. The battery and electrical circuits can be damaged as a result of higher than normal charging system output.

The Charging System Part 2

A. Charging System Anatomy and Diagnosis

If we didn't have the charging system, stopping to give the battery a boost would be more common than refueling, and energy-hungry headlights would make long night drives nearly impossible. But, of course, self-charging has been a high priority with car makers since the beginning of the automotive era, and the components that make it possible have evolved from basic D.C. generators to electronically-regulated high-output alternators.

The most difficult part of servicing a charging system is usually diagnosis. Is the problem in the alternator, the regulator, or elsewhere? Also, if the alternator is at fault, can a repair be made or is unit replacement necessary? I hope the following will help you answer these questions.

The system

A modern charging system comprises an alternating current generator with an external voltage regulator that may be either electro-mechanical or electronic, or an internal electronic regulator. A description of an alternator's construction and operation is in order here. The rotor is composed of an electromagnetic coil wrapped around an iron core and enclosed in two six-claw pole pieces. It receives regulated voltage through a pair of brushes that bear on slip rings, and this causes it to produce a magnetic field. An engine-driven belt spins the rotor inside the stator -- three coils wrapped on a ring -- and this is where the current is induced (one of the reasons the alternator supplanted the D.C. generator is that in the latter current was induced in the armature or rotating member, so the amount of power available was limited by the capacity of the brushes).

But this set-up produces A.C., and automobiles need D.C. So, the current must be rectified (that is, converted from A.C. to D.C.), and this is accomplished by six diodes, a negative and a positive for each stator coil, and three exciter diodes that supply the field with current once the engine is running (when the ignition is first switched on and before the engine is started, field current comes from the battery through the charge indicator lamp).

Essentially, a diode is a one-way valve for electricity. It only allows current to flow in one direction, so it conducts during half of the A.C. cycle, and stops conducting during the other half. With the way the six diodes are wired to the stator, they make a smooth flow of D.C. possible. They also keep the battery from discharging when the engine is off by stopping the flow of current to ground, so they perform the same function as the cut-out relay in a D.C. generator system.

Field regulation

The amount of voltage produced by an alternator is dependent upon the strength of the magnetic field around the rotor, and that in turn is dependent on how much current is supplied to the rotor coil through the field circuit. This circuit is controlled by the voltage regulator, which may be either electro-mechanical or solid state (also known as electronic or transistorized). When the engine is running slowly, or when electrical demands are high, the regulator allows current to flow through the field for long periods of time, or even constantly. As the engine speeds up, the regulator interrupts the field circuit as necessary to keep voltage within the required range.

Illnesses

Symptoms of charging system illness include a low or dead battery, or one that's cooked from overcharging, alternator noise, dim bulbs, and a charge indicator light that shines at the wrong time. Whenever you encounter a vehicle that exhibits any such failing, it only makes sense to check the simplest things first.

The belt, for instance. Do-it-yourselfers sometimes replace alternators and/or regulators when the problem was simply that the dynamo wasn't getting sufficient mechanical input. Suspect slippage if the trouble only occurs when it's raining, or at high speeds. Pop the hood and give the belt a yank and a look.

Next, check for corroded battery terminals, broken wires and big-time shorts (I've seen several alternators in a row burn out on the same car because a missing grommet or a gap in insulation made them work themselves to death).

The main fusible link is sometimes overlooked. You'll find this in the wire that connects the positive battery terminal to the harness. If it's blown, find out what caused the short, correct the problem, then replace the link -- don't use ordinary wire. Be alert for bad grounds and any other potentially troublesome connections.

If you suspect that a short circuit is draining the battery, make sure all accessories are off (remember to close the doors so the courtesy light won't be on), remove the negative cable from the battery and connect a test light between the battery post and the cable clamp. If the light glows, remove fuses until it goes out, which will isolate the leaky circuit.

In the case of a no-charge condition, touch a screwdriver blade to the back of the alternator with the key on. Since there's no residual magnetism as in an old-fashioned DC generator, a strong attraction will let you know right off that the field circuit is complete.

Before you go any further, make sure the battery is in a reasonable state of health so you can trust the results of your investigations. This is a subject worthy of an article all its own, so suffice it to say here that hydrometer checks (providing you can get at that electrolyte) and capacity tests are both still valid today.

BUILT-IN DIAGNOSTIC AID

See what the idiot light or ammeter tells you -- after all, it's there for a purpose, and it may be what made the customer seek assistance. In a basic design, the charge indicator light circuit supplies the alternator with initial field current when the key's turned on, so the bulb glows. Once the engine is started, the field circuit is completed, and it winks out.

If the light doesn't go on with the key, suspect a bad bulb or socket, an open in the regulator or field circuit, or maybe a shorted positive diode. If the bulb's lit when the ignition's off, it's a good bet that one of the positive rectifiers is shorted, which will allow the battery to discharge to ground.

The most common problem indication you'll get, of course, is when it stays lit with the engine running, which should start you on the search for the component that's interfering with ampere production.

Rising voltage?

Using any old voltmeter you happen to have handy, you can perform a basic quick check to find out for sure if the system is charging or not. Simply connect the leads to the alternator output stud and ground, or across the battery terminals, check the reading with the engine off, then start it up and see if it rises (with some regulators, you'll have to rev it to 1,500 or so to get the relay to kick in). Specs vary, but we expect to see somewhere between 13.5 and 14.5 volts.

The most informative quick check possible is to connect a voltmeter across the battery terminals with the engine and all accessories off, note the reading, then start the engine and run it at 3,000 rpm. If the system is working, voltage should rise appreciably above the 12.6 or so you will have gotten initially. A range of 13.5 to 14.5 is common, but check specifications for the specimen at hand. If voltage continues to rise above the upper limit, the regulator is faulty.

Our friend full-fielding

No? Then you can try full-fielding, which is actually a process of elimination: If the system puts out with the regulator bypassed, then the alternator is obviously capable of doing its job. There are various ways of doing this depending on the design -- you know, grounding the little tab in the back of a Delcotron SI with a screwdriver, jumping a typical Mopar's field terminal (look for the green wire) to ground, connecting the BAT and FLD terminals of a garden-variety Ford, etc. Just keep in mind that the idea is to complete the field circuit. If the alternator wasn't producing current, but does now as indicated by a rise in voltage at the battery, you can be sure the regulator is at fault. If there's still no charging, the alternator is the culprit.

Unfortunately, some integral regulator designs have no provision for this test. In late model Volkswagens, for instance, the recommended procedure is to replace the voltage regulator with a new unit, then test output. If there's still no charging, the alternator is at fault.

Maxed out

But voltage isn't the whole story. The most comprehensive check of the charging system is the venerable current output test. If you have a battery/charging system tester, hook it up as the manufacturer recommends, turn off all accessories, and test as follows:

1. Disconnect the battery ground cable and the wire from the alternator's output stud.
2. Attach the ammeter in series between the output stud and the wire you just removed from it.
3. Clip the positive lead of the voltmeter to the stud and the negative to a proper ground.
4. Full-field the alternator as the car maker recommends.
5. Hook up a tach and reconnect the battery cable.
6. Turn the carbon pile off, and attach its leads to the battery posts.
7. Start the engine, let it idle, then adjust the carbon pile and speed until you get a combination of 15 volts and 1,250 rpm. Don't let the voltage exceed 16.
8. Check the ammeter reading against the output specs for that particular dynamo. Generally, you should be within 10 amps. If too little current is being produced, the alternator is at fault. But if the amps are right up there, the regulator or something else in the field circuit is causing the problem.

Of course, you may not have access to a professional-style tester. In that case, put an ordinary ammeter of sufficient capacity in series between the alternator's BAT terminal and its wire, start the engine, turn on all the electrical accessories you can find, and read the meter.

Wavy?

Ripple voltage is the leakage of AC into the electrical system due to a faulty diode, winding, etc. While nobody worried too much about this in the past, the advent of computerized controls made it suddenly important. After all, modern electronics need straight, pure DC or they'll become unhinged and probably drive you crazy when you try to figure out what's wrong. Ergo, it's a good idea to check for ripple voltage whenever you're presented with a problem that seems to have no answer. Various authorities give different maximum acceptable AC in the circuit, so look up the manufacturer's recommendation.

Of course, you have to know how to ascertain the amount of ripple present, and there are several ways. High-tech alternator testers include a ripple measurement feature. Or, you can use your DMM (Digital Multi-Meter) across the battery terminals, and simply switch to the AC volts function. Another possibility is the DLP (Digital Logic Probe -- less than $20 at Radio Shack). When touched to the alternator output stud, excessive AC will cause the yellow LED to pulse.

Inside

If your tests prove that the alternator is the problem, you can either replace it with a new or remanufactured unit, or disassemble it to find out exactly what's wrong. In a vehicle that displays a large number on its odometer, this may be a simple matter of worn-out brushes -- they should have at least .2 in. of carbon left. Test stator resistance by connecting an accurate ohmmeter between two of the three leads, then switch so that all the leads are tested against the others. A typical Bosch unit should produce a reading of about .15 ohm. Stator insulation should be checked by looking for continuity on the 1,000 ohm scale between any lead and the metal ring. You should see infinite resistance. Rotor resistance is taken across the slip rings. The unit mentioned should give a reading of 3.4 to 3.75 ohms. To check rotor insulation, connect the meter between one of the slip rings and the claw poles. Again, you should get a reading of infinity. Diodes are checked by looking for perfect continuity in one direction and none in the other, or by the use of a special tester.

Odd ends

I'll finish up with some random points:

- Some Japanese alternators are full-fielded in a similar manner to that of a common SI-series Delcotron (in case you've never heard, the SI stands for "Systems Integral"). Just use a screwdriver to ground terminal "F" through the hole in the back.
- Speaking of Delcotrons, relatively new CS-series (the initials stand for "Charging System," logically enough) units have no hole for full-fielding, don't use a diode trio, and have a four-terminal connector on the regulator (as opposed to two terminals in an SI). The CS-144 is serviceable, but the CS-130 is a unit-replacement item. By the way, the number after CS, as in "CS-130," represents the outside diameter of the stator laminations.
- Regardless of what caused you to condemn an alternator, before you buy a new or reman unit find out if there's anything left of those brushes. There doesn't seem to be any rhyme or reason why some wear out in 50K miles, while others seem to go on forever, so check them in every case. By the way, making index marks before splitting the case will speed reassembly.
- Some technicians we know are bucking the unit-replacement trend, preferring to fix alternators themselves so they can be sure of the quality of components and workmanship. Parts availability is sometimes a problem, however.
- Current consumption is growing. The Toyota Lexus, for instance, needs a 1,200 watt alternator to handle the demands of its myriad accessories -- that's 100 amps.
- Although 12 volts has been the universal automotive standard for decades, it looks like it will eventually be superseded by higher voltage systems to better power heavy-consumption accessories such as A/C compressors and electrically-boosted rack-and-pinion units.

Vanishing Voltage Regulators

Just think about this for a minute: The earliest cars had no electrical system whatsoever. A red-hot tube provided ignition, your biceps cranked the engine, and, if you were foolhardy enough to venture out at night, lanterns or gas lamps gave illumination. Music? No problem. Just drive past an outdoor concert. But it wasn't long before vehicle designers realized all the practical things that could be accomplished by a flow of electrons, and the roots of today's amazingly complicated electricals were established.

Originally, the accumulator (the old term for a rechargeable wet-cell battery) was rejuvenated only by occasional stops at a generator-equipped garage, but the on-board dynamo was a logical addition. One of the problems of integrating it into the automobile was controlling its output, and in the beginning this was done by the troublesome means of mechanically limiting armature speed. In 1905, the third brush concept was introduced, and the era of truly workable voltage regulation began. Seven years later, a regulator that cut resistance in and out of the generator's shunt winding appeared, and that basic idea sufficed for almost five decades.

Unsung advance

With the advent of the alternator, voltage regulators got simpler, then in the early seventies we started seeing electronic VR's, both remotely-mounted and integral with the juice maker. And that's about where it's been since. Except, that is, for one big departure that somehow escaped general notice: In '85, Chrysler introduced a charging system that used the engine control electronics to regulate field current, hence output.

With the excellent reliability record of dedicated integrated circuit regulators, why complicate matters by introducing the computer into the situation? For several good reasons. The battery, for instance. It's still a heavy component, and with engineers battling to trim every possible ounce from automobiles the possibility of making a small battery do the work of a large one through maintaining an ideal state of temperature-corrected charge is very attractive. Then there's the magnetic drag of the alternator, which can amount to several horsepower. If the charging rate can be managed just right, mpg can rise and potential rough idle problems caused by the parasitic loss at low rpm can be eliminated.

Finally, there's diagnosis. As you know if you've been doing car repairs for any length of time, it's not uncommon for the alternator to be replaced when the regulator's really at fault, and vice versa. Also, other possible problems are sometimes overlooked, such as a slipping belt or a bad connection, which can result in the unnecessary installation of new charging system components. It makes sense to include the charging system in the on-board diagnostics.

Regardless of whether or not you agree that these are sufficient justifications for making the leap to computer-controlled charging, the fact is that such systems are on the road now in large numbers and more are coming. So, learning about them is going to be essential.

Mopar's motivated modification mavens

Since Chrysler was the first to put this concept into mass production (come to think of it, the same can be said of alternators, and electronic voltage regulators and ignition -- quite a record of practical innovation), I'll deal specifically with the Mopar 40/90 amp system using a typical '86 specimen as my example. I'll go through this step by painstaking step, which may seem tedious, but is the only way to insure against arriving at an embarrassingly (and expensively) incorrect conclusion.

Okay, here's the scenario: You have a FWD domestic Chrysler product with what appears to be a charging system problem. Maybe the battery keeps going dead, the lights are dim, or the ammeter, voltmeter, or idiot light indicates a discharge. Also, you may have noticed that the Power Loss, Power Limited, or Check engine light on the dash is glowing, which means the OBD (On Board Diagnostic) program has detected and recorded trouble, in this case battery voltage that's too low (Code 16), or too high (Code 46).

Baseline

While you could start out by pulling any trouble codes that may be present, I suggest you pop the hood and look around for any obvious problems first. Is the belt loose or contaminated? Are the battery terminal connections clean and tight? What about the wiring? Next, do a thorough exam of the battery to make sure it's healthy and fully charged, a subject covered in other sections. It makes no sense to embark on a sophisticated diagnostic procedure until you've got a reasonable baseline.

Now you can activate the self-diagnostics. Since only two of the five charging system-related codes trigger the Power Loss/Power Limited light, you can feel justified in doing this even if the indicator wasn't glowing. As you may have heard by now, plugging a diagnostic readout box or scanner into the harness connector (found by the passenger's side strut tower) will give you trouble codes and allow you to perform other useful tests. Here, however, I'll look at the procedure using only what the dash light can tell you.

Turn the ignition on-off-on-off-on within the span of five seconds, then watch the light. It should shine for a few seconds as a bulb check, then, if any troubles have been recognized by the computer, fault codes will appear as two digit numbers represented by flashes. For example, four flashes, a short pause, then one flash indicates Code 41. If more than one fault is present, there will be a four-second interval before each succeeding code. A 55 means the message is over (you'll get that after the bulb check if no codes are in memory). By the way, if you've charged or replaced the battery, pull the fuse to the brain for long enough for forgetfulness to set in, reinstall the fuse, run the engine for several minutes, then shut it off and pull the codes. Otherwise, it'll take maybe 50 starts before any recorded faults will be erased.

I should caution you at this point that fault codes are simply an indication that a monitored circuit has at some time gone out of range or failed to operate as designed. The problem could be a broken wire, a poor connection, a defunct sensor, or, least likely, a bad computer. Codes are just a guide, not a definitive condemnation of a particular component.

Methodical

Suppose you got a Code 16, which means battery sensing voltage has dropped below four or between 7.5 and 8.5 for over 20 seconds. You should check for direct battery feed to the logic module (under the passenger's kick panel). With the key off, pull the 24-pin #2 connector from the LM (this is black on EFI models, blue on turbos), and check cavity #22 for the presence of battery voltage. Zero means you'll have to find and repair the break in the wire. If you see a reading within one volt of what the battery produces, the terminal in the cavity may be deformed so that it doesn't contact the module pin, or the module itself is shot.

If you got Code 46 (battery sensing voltage is more than one volt above the desired control voltage for more than 20 seconds) or 41 (field control not switching properly) and 46, the field circuit to the power module (tucked away in the fender beside the battery) should be suspect. Unplug the PM 10-way connector, switch on the ignition, and see if there's within one volt of battery voltage at cavity #8. No? Then fix the short in the alternator field circuit.

If voltage is okay, you'll have to test for this circuit's completeness through the power module. With the ignition off, plug the 10-way connector back in, pull the 12-way connector, turn the key to Run, and check the voltage at terminal F2 on the alternator. No juice means the PM is bad.

In cases where you got within one volt of battery strength at F2, find out how the wires are between the two modules. Make sure the key is off, unplug the logic module's #1 connector (white with EFI, red with turbo), then put an ohmmeter between cavity #11 of the 12-way power module connector and ground. Continuity means the circuit that goes to the cavity is shorted to ground, no continuity means the LM has gone away.

Full-fielding still applies

Code 47 (battery sense voltage below the desired control voltage for more than 20 seconds), or 41 and 47, gives you the go-ahead for a test you can sink your teeth into: full-fielding. With all the module connectors properly plugged in, attach a voltmeter across the battery, start the engine and observe the reading, then use a jumper to ground alternator terminal F2 for only as long as it takes to see if the needle moves (the saying, "a computer is nothing but a high-speed ground," is fitting here). No increase in voltage indicates that either the alternator itself is faulty, or its field isn't getting any juice. Kill the engine, turn the key back to run, then look for battery voltage at the alternator's F1 terminal. If you've got it, the alternator's bad. If you haven't, there's an open between the ignition switch and F1.

In cases where the voltage did rise when you grounded F2, a field control circuit problem is present. Start it up, put your voltmeter between cavity #2 of logic module #2 connector and ground, then jump cavity #5 of the other logic module connector to ground for a second. If the voltage reading rises, the brain is probably bad, but check terminal #5 for damage before making any rash buying decisions.

No increase in the reading means you should check the control wire to the power module. Kill the engine, pull the LM's #1 connector (white or red), switch the ignition on, and see if you've got battery voltage at cavity #5 of the connector. Zero volts? Then unplug the power module's 12-way connector and put an ohmmeter between cavity #5 of the white or red LM connector and cavity #11 of the PM connector. Continuity condemns the power module, an open circuit says the wire or terminals are bad.

If you saw 12 volts at cavity #5 in the last step, check the power module circuit as follows: With the key off, pull the 10-way connector from the PM, then turn the switch back on and see if you've got battery voltage at cavity #8. If so, a new power module is in order, but examine the cavity terminal just in case. If not, look for continuity between #8 and F2 of the alternator. An open points to a broken wire, continuity means you should find out if there's voltage at F1 of the alternator.

Battemp

I wouldn't blame you if you felt like bailing out of the whole procedure some steps ago, but nobody said it was going to be easy -- very little is these days. If you've stuck with me this far, you'll be glad to know you're almost done. Code 44 is set if the battery temperature sensor signal is out of range (below .04 or above 4.9 volts). Pull the logic module's #2 connector (black or blue), then hook an ohmmeter between cavity #20 of the connector and ground. If you see resistance (the amount isn't important), get a new LM. No resistance means you should unplug the power module's 12-way connector and read your ohmmeter again. If the circuit's open, the power module's defunct. Perfect continuity tells you to repair the wire that runs between cavity #20 of the LM connector and cavity #3 of the PM 12-way.

If there was no continuity between cavity #20 and ground in the last step, check the battery temperature sensor by touching one lead of your ohmmeter to pin #3 of the power module and the other to ground. If you find resistance, the wire from #20 to #3 cavities is the culprit. An open circuit means you can shop for a PM.

Furthermore

Beyond that, you can do a current output test with a voltmeter, ammeter, and carbon pile attached in the traditional manner. Give the field a full dose of power by probing the R3 terminal (dark green wire) of the 8-way connector in the alternator harness with a grounded jumper. While the SMEC (Single Module Engine Controller) electronics you'll find on later Chrysler products will give you different connectors to deal with, and, of course, eliminate checks of the wiring between the logic and power modules, the trouble codes are the same, and you still full-field by grounding R3.
