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SEGV3008-01

General Service Information

Electrical System for All Caterpillar Products

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Systems Operation - Fundamentals
Electrical System for All Caterpillar Products

Publication Date -01/06/2004 **Date Updated -28/06/2004**
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Basic Circuit Theory

SMCS - 1400; 1450

Introduction to Basic Circuit Theory

This information covers basic direct current theory by reviewing the three basic types of electrical circuits and the laws that apply to each type circuit:

- Series Circuits
- Parallel Circuits
- Series-Parallel Circuits

Series Circuit

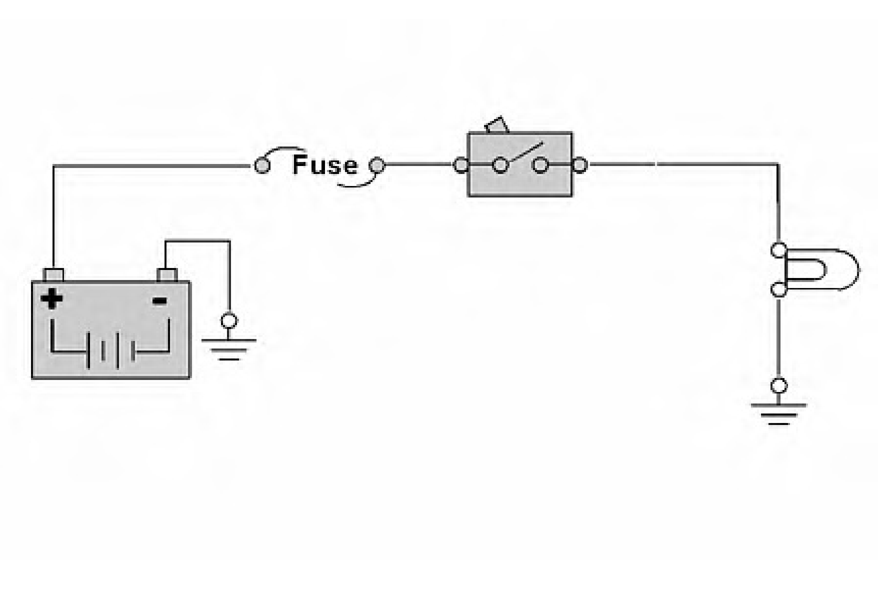

Illustration 1 g01070312

A series circuit is the simplest kind of circuit. In a series circuit, each electrical device is connected to other electrical devices. There is only one path for current to flow. In Illustration 1, current flows from the battery (+) through a fuse (protection device) and a switch (control device) to the lamp (load) and then returns to frame ground. All circuit devices and components are connected in series. The following rules apply to all series circuits:

- At any given point in the circuit, the current value is the same.
- The total circuit resistance is equal to the sum of all the individual resistances. This is called an equivalent resistance.
- The voltage drop across all circuit loads is equal to the applied source voltage.

The following rules are for a series circuit:

- Voltage is the sum of all voltage drops.
- Current is the same at any given point in the circuit.
- Resistance is the sum of all individual resistances.

Applying the Rules

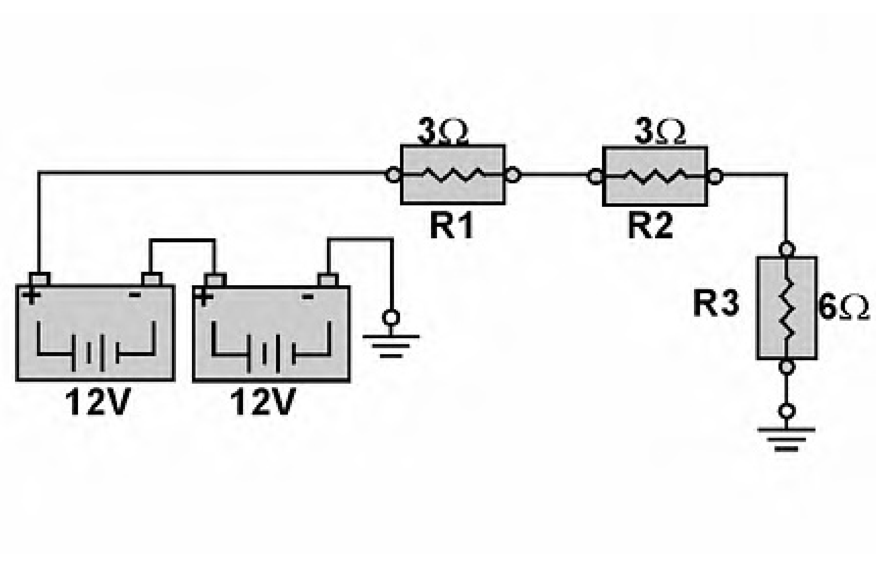

Illustration 2 g01070313

Illustration 2 shows that the circuit is made up of various devices and of various components. This includes a 24 volt power source. Since two of the circuit values are given (voltage and resistance), solving for the unknown value is simple.

The first step in solving the above circuit, is to determine the total circuit resistance.

The following equation is used for determining total resistance:

R_t = R1 + R2 + R3, or R_t = 3Ohms + 3Ohms + 6Ohms, or R_t = 12Ohms.

Since the value for the power source was given as 24 volts and the circuit resistance has been calculated as 12Ohms, the only value remaining to calculate is the current flow. Total circuit current is calculated by using the Ohm's Law Circle and by writing the following equation:

$I = E/R$, or $I = 24V/12Ohms$, or $I = 2$ amperes.

The remaining step is to plug the value for current flow into each of the resistive loads. One of the rules for series circuits stated that current was the same at any given point. The equation $E = I \times R$ for each resistor will determine the voltage drop across each load. The following equations are for voltage drops:

- $E1 = 2A \times 3Ohms = 6V$
- $E2 = 2A \times 3Ohms = 6V$
- $E3 = 2A \times 6Ohms = 12V$

All of the circuit values have now been calculated. Verify each answer by using the Ohm's Law Circle.

Parallel Circuit

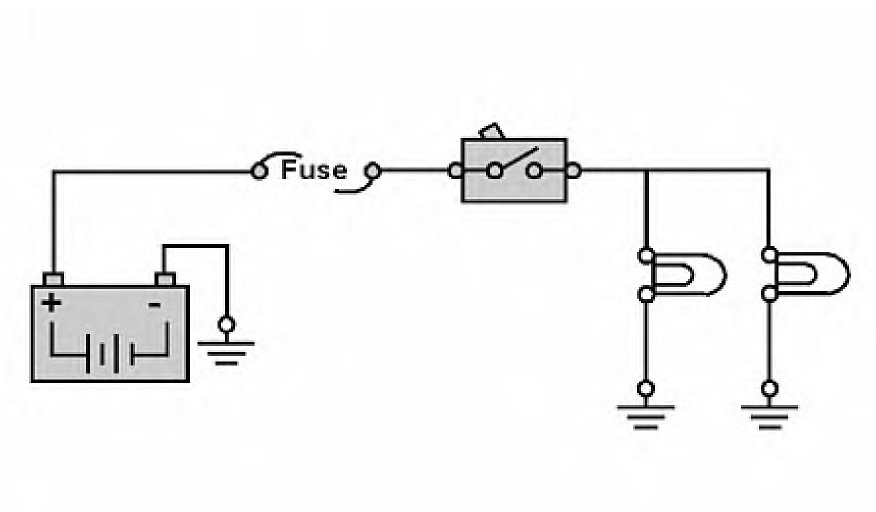

Illustration 3 g01071099

A parallel circuit is more complex than a series circuit because there is more than one path for current to flow. Each current path is called a branch. All branches connect to the same positive terminal and negative terminal. This causes the branches to have the same voltage. Each branch drops the same amount of voltage, regardless of resistance within the branch.

The current flow that is in each branch can be different. The difference depends on the resistance. Total current in the circuit equals the sum of the branch currents.

The total resistance is always less than the smallest resistance in any branch.

In the circuit shown in Illustration 3, current flows from the battery through a fuse and a switch. The current divides into two branches. Each branch contains a lamp. Each branch is connected to frame ground.

The following rules apply to parallel circuits:

- The voltage is the same in each parallel branch.
- The total current is the sum of each individual branch currents
- The equivalent resistance is equal to the applied voltage divided by the total current, and is always less than the smallest resistance in any one branch.

The following rules are for parallel circuits:

- Voltage is the same for all branches.
- Current is the sum of the individual branch currents.
- Equivalent resistance is smaller than the smallest resistance of any individual branch.

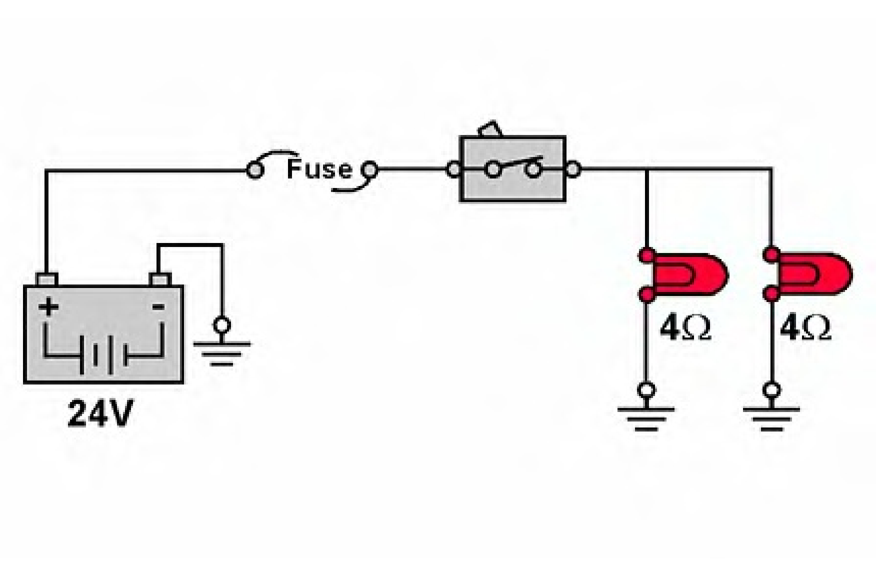

Illustration 4 g01070318

The circuit is made up of various devices and various components. This includes a 24 volt power source. The resistance of each lamp is given along with the value of source voltage. Before you apply the basic laws of parallel circuits, it will be necessary to determine an equivalent resistance in order to replace the two 4 ohm parallel branches.

The first step in developing an equivalent circuit is to apply the basic rules for determining the total resistance of the two parallel branches. The total resistance of the combined branches will be smaller than the smallest resistance of an individual branch. The circuit above has two parallel branches, each with a 4Ohms lamp, therefore, the total resistance will be less than 4Ohms.

The following equation is used to solve for total resistance.

$1/R_t = 1/R1 + 1/R2$

$1/R_t = 1/4 + 1/4$ or

$1/R_t = .25 + .25 = .50$ or

$R_t = 1/.50$ or $R_t = 2$ ohms

One of the rules for parallel circuits states that the voltage is the same in all parallel branches. With 24 volts applied to each branch, the individual current flow can be calculated by using Ohm's Law. The equation I = E/R is used to calculate the current in each branch as 6 amps. In this particular case, the current flow in each branch is the same because the resistance values are the same.

Solving Current Flow in a Parallel Circuit

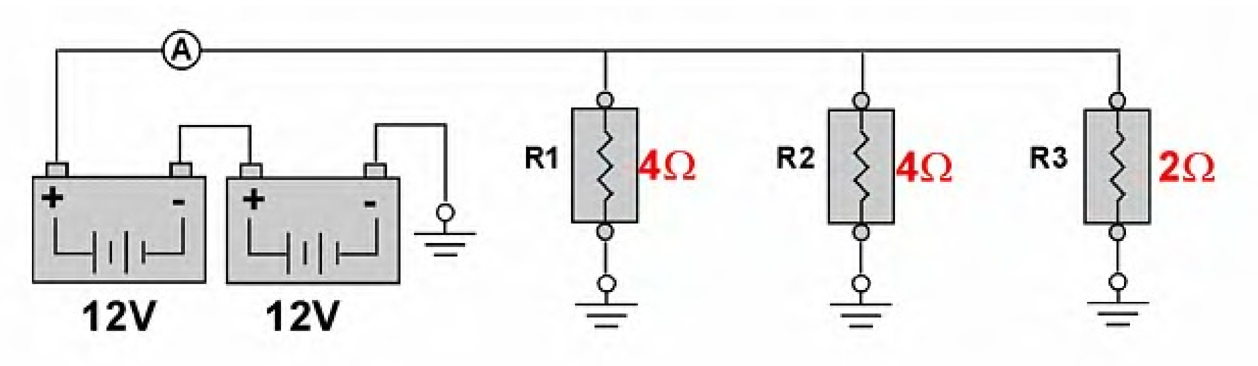

Illustration 5 g01070320

The circuit that is shown in Illustration 5 is a typical DC circuit with three parallel branches. The circuit also contains an ammeter connected in series with the parallel branches (all current flow in the circuit must pass through the ammeter).

Applying the basic rules for parallel circuits makes solving this problem very simple. The source voltage is given (24 volts) and each branch resistance is given (R1 = 4Ohms; R2= 4Ohms; R3 = 2Ohms). Applying the voltage rule for parallel circuits (voltage is the SAME in all branches) you can solve the unknown current value in each branch by using the Ohm's Law Circle, whereas, I = E/R.

I1 = E1/R1 or I1 = 24/4 or I1 = 6 amps

I2 = E2/R2 or I2 = 24/4 or I2 = 6 amps

I3 = E3/R3 or I3 = 24/2 or I3 = 12 amps

Since current flow in parallel branches is the sum of all branch currents, the equation for total current is I_t = I1 + I2 + I3 or 6+6+12 = 24 amp. With the source voltage given as 24 volts and the total current calculated at 24 amp, the total circuit resistance is calculated as 1 ohm. ($R_t = E_t/I_t$).

Series-Parallel Circuits

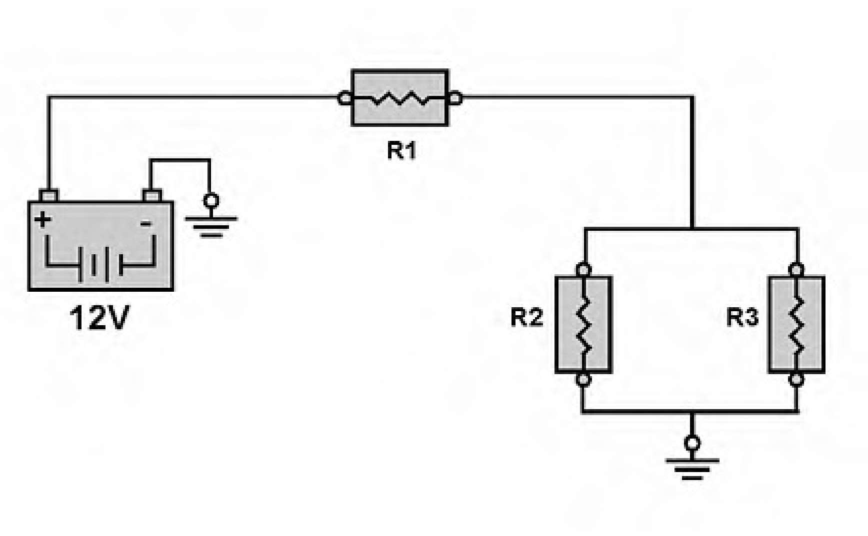

Illustration 6 g01070324

A series-parallel circuit is composed of a series section and a parallel section. All of the rules previously discussed regarding series circuits and parallel circuits are applicable in solving for unknown circuit values.

Although some series-parallel circuits appear to be very complex, the series parallel circuits are solved quite easily by using a logical approach. The following tips will make solving series-parallel circuits less complicated:

- Examine the circuit carefully. Then determine the path or paths that current may flow through the circuit before returning to the source.
- Redraw a complex circuit to simplify the appearance.
- When you simplify a series parallel circuit, begin at the farthest point from the voltage source. Replace the parallel resistor combinations one step at a time.
- A correctly redrawn series parallel (equivalent) circuit will contain only ONE series resistor in the end.
- Apply the simple series rules for determining the unknown values.
- Return to the original circuit and plug in the known values. Use Ohm's Law to solve the remaining values.

Solving a Series-Parallel Problem

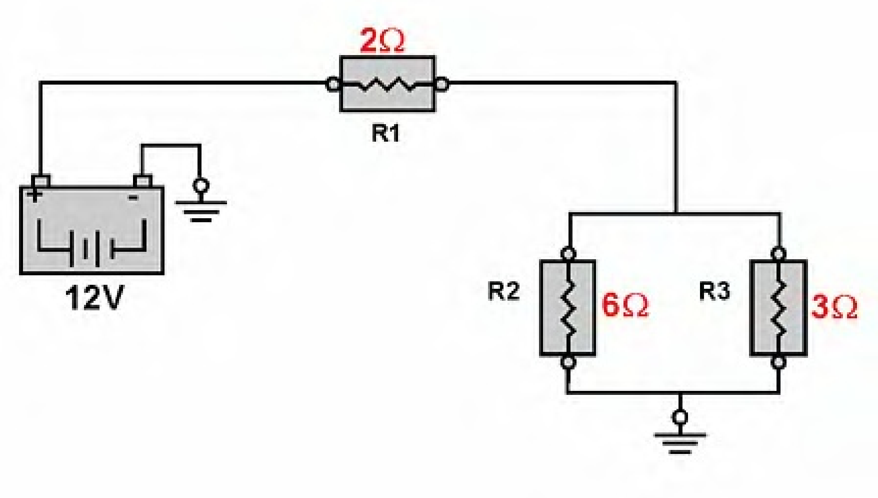

Illustration 7 g01070325

The series parallel circuit, as shown in Illustration 7, shows a 2Ohms resistor in series with a parallel branch that contains a 6Ohms resistor and a 3Ohms resistor. To solve this problem it is necessary to determine the equivalent resistance for the parallel branch. Using the following equation, solve for the parallel equivalent (R_e) resistance:

$1/R_e = 1/R_2 + 1/R_3$

$1/R_e = 1/6 + 1/3$ or

$1/R_e = .1666 +.3333 = .50$ or

$1/R_e = 1/.50$ or $R_e = 2$ ohms

Illustration 7 has been redrawn (See Illustration 8) with the equivalent resistance for the parallel branch. Solve circuit totals by using simple Ohm's Law rules for series circuits.

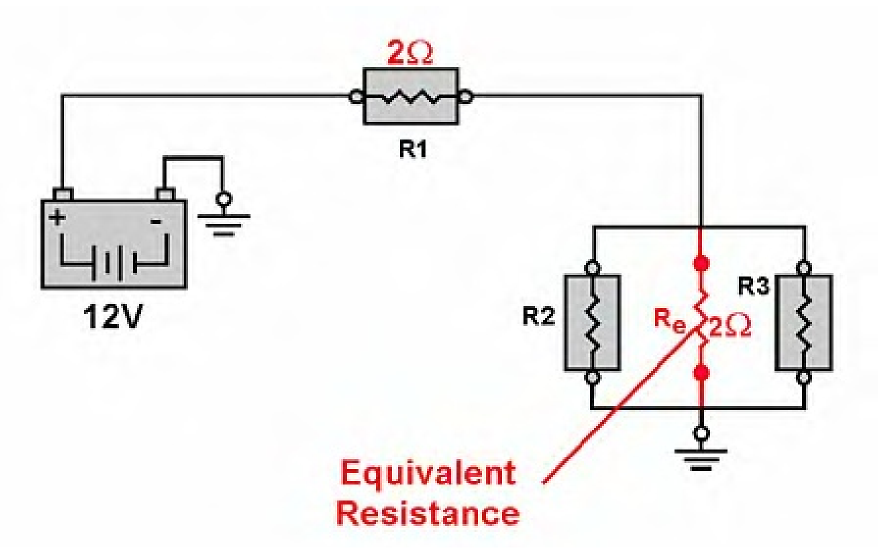

Illustration 8 g01070328

Using the rules for series circuits, the total circuit resistance can now be calculated by using the equation $R_t = R1 + Re$ or $R_t = 2 + 2$ or 4 ohms.

The remaining value that is unknown is current. Again, using Ohm's Law Circle, current can be calculated by the equation:

$I = E/R$ or

$I = 12/4$ or

$I = 3$ amp

Illustration 9 shows all the known values.

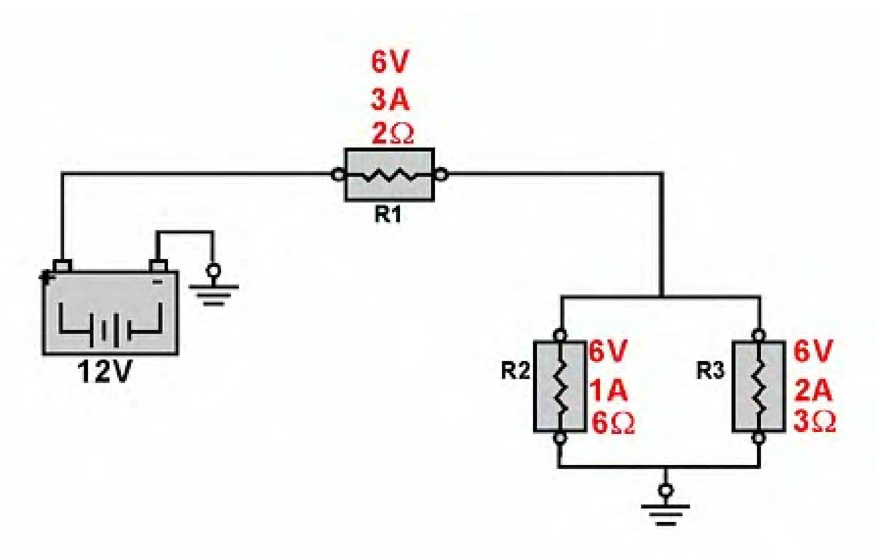

Illustration 9 g01070330

Circuit calculations indicate that the total current flow in the circuit is 3 amps. Since all current flow that leaves the source must return, you know that the 3 amps must flow through R1. It is now possible to calculate the voltage drop across R1 by using the equation $E = I \times R$, or $E = 3A \times 2Ohms$, or $E1 = 6$ volts.

If 6 volts is consumed by resistor R1, the remaining source voltage (6V) is applied to both parallel branches. Using Ohm's Law for the parallel branch reveals that 1 amp flows through R2 and 2 amps flow through R3 before combining into the total circuit current of 3 amps returning to the negative side of the power source.

Other Methods and Tips for Solving Complex Series Parallel Circuits

As stated earlier, complex circuits can be easily solved by carefully examining the path for current flow and then draw the circuit again. No matter how complex a circuit appears, drawing an equivalent circuit and reducing the circuit to the lowest form (series circuit) will provide the necessary information to plug into the original circuit.

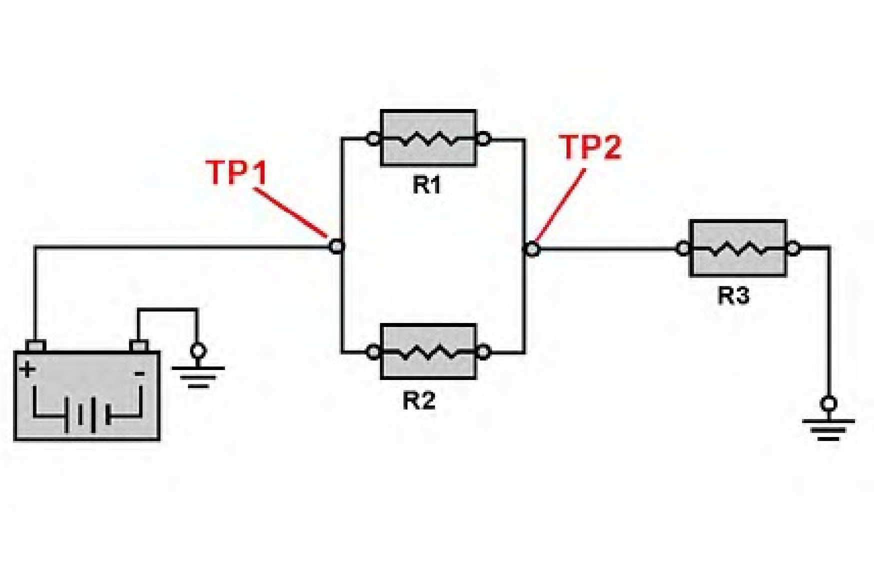

Illustration 10 g01070333

1. Trace current flow from the (+) side of the battery to the (-) side of the battery. All the current leaving the source is available at "TP1" (test point 1). At "TP1" the current is divided among the two parallel branches and then recombined at "TP2" before flowing through the series resistor "R3" and returning to ground. Now that you have identified the path of current flow, the next step is drawing an equivalent circuit for the parallel branches.

2. Use Ohm's Law to calculate the equivalent resistance for the parallel branch. There are two equations that are available for solving parallel branch resistances. The following equations are used to solve for resistances.

   - $1/R_e = 1/R1 + 1/R2$
   - $R_e = R1 \times R2/R1 + R2$

   The second equation is called product over sum method that is used for combining two parallel resistances. When the circuit contains only two branches the product over sum method is the easiest equation.

3. Redraw the circuit substituting the R_e value to represent the equivalent resistance. The circuit now has two resistors in series, shown as R_e and R3. Further reduce the circuit by adding R_e and R3 as a single resistance called R_t. The following circuits reflect those steps.

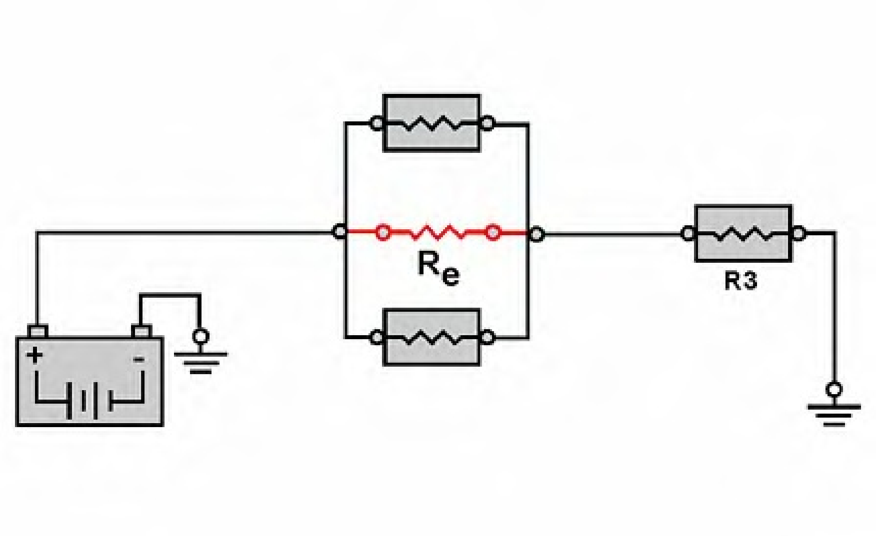

Illustration 11 g01070335

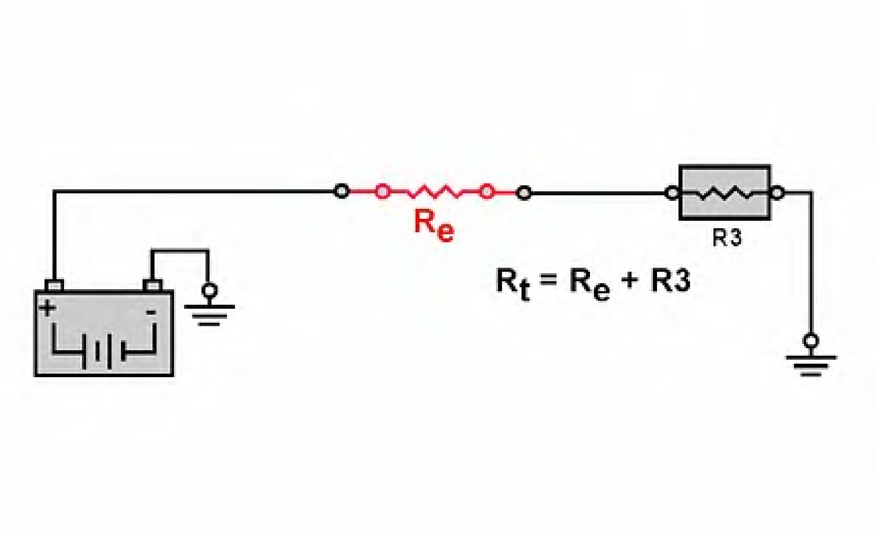

Illustration 12 g01070336

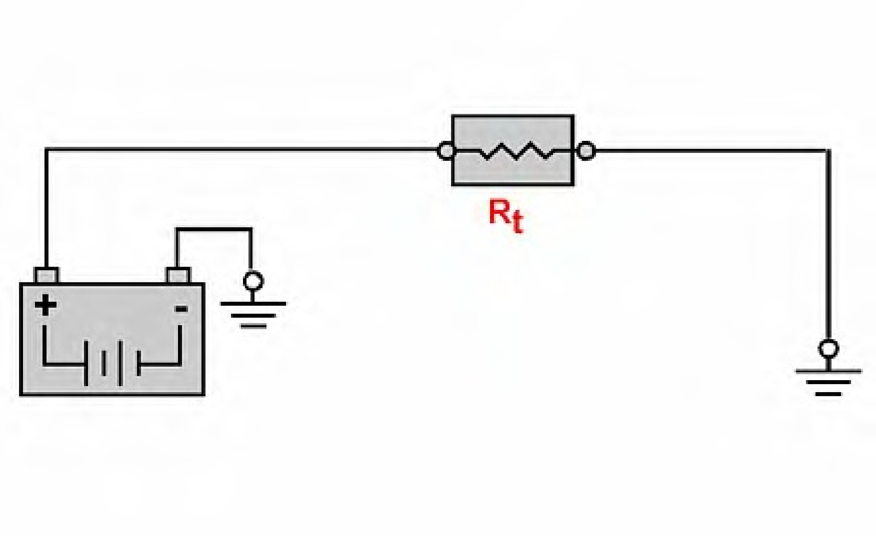

Illustration 13 g01070337

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Basic Electrical Components

SMCS - 1400; 1450

Introduction to Basic Electrical Components

There are many different types of components that are used in electrical circuits.

Wires

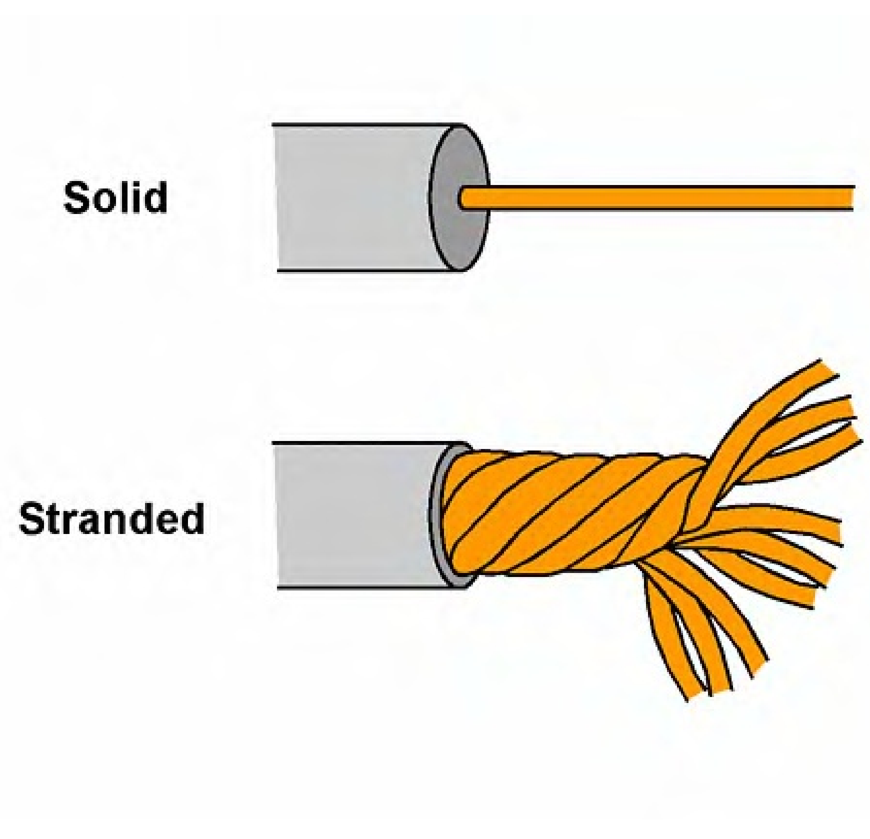


Illustration 1 g01072288

Wires are the conductors for electrical circuits. Wires are also called leads. Most wires are stranded. The stranded wires are made up of several smaller wires that are wrapped together and covered by a common insulating sheath.

The following wires are found in Caterpillar machines:

- Copper is the most common type of wire. Copper wires are usually stranded.
- Fusible Links are circuit protection devices that are made of smaller wire than the rest of the circuit that is protected.
- Twisted/Shielded Cable is a pair of small gage wires that are insulated against RFI/EMI. This cable is used for computer communication signals.

Illustration 2 g01072291

Many wires are bound together in groups with one or more common connectors on each end. These groups are called wire harnesses. A harness may contain wires from different circuits and systems. An example would be the harness that plugs into the headlight switch assembly. The headlight switch assembly contains wires for the following lights: parking lights, taillights, high beam headlights and low beam headlights.

Some harness wires are enclosed in a plastic conduit. These conduits are split lengthwise in order to allow easy access to the harness wires. Other harness wires are wrapped in tape. Clips (plastic) and clamps (metal) attach harnesses to the machine.

Caterpillar electrical schematics provide wire harness locations in order to help you easily locate a specific harness on a machine. The features of Caterpillar electrical schematics will be covered later in the lesson.

Wire Gage

WIRE SIZING

AWG	DIAMETER (mils)	OHMS PER 1000 FT
10	102.9	.9989
12	80.8	1.588
14	64.1	2.525
16	50.8	4.016
18	40.3	6.385
20	32.0	10.15
22	25.4	16.14
30	10.0	103.2
40	3.10	1049.0

Illustration 3 g01072292

Electrical circuits and electronic circuits are engineered with specific size and length of conductors in order to provide paths for current flow. The size of a wire determines how much current the wire can carry. Wire sizes can be rated in two different ways. American Wire Gage (AWG) size is usually referred to as simply the gage of the wire. Wire sizes can also be rated by metric size.

When you repair machine wiring or you replace machine wiring, it is necessary to use the correct size and correct length for the conductors. Illustration 3 shows the typical resistances for the various size of conductors.

When you use the AWG, remember that smaller gage numbers denote larger wire sizes, and larger gage numbers denote smaller wire sizes. Metric wire sizes refer to the diameter of the wire in millimeters, so larger metric sizes translate to larger wires.

Soldering

While an electrical connection might exist between two crimped wires, it might be incomplete or faulty. Soldering creates a solid and a dependable electrical connection.

The soldering process depends on the molten solder that flows into all the surface imperfections of the metals in order to be soldered. When two pieces of metal are soldered together, a thin layer of solder adheres between the metals and completes the electrical connection.

Solder is a mixture of tin and lead. Solder usually contains a solder flux. The function of solder flux, is to eliminate oxidation during the soldering process. Flux also lowers the surface tension of the molten solder. This allows the molten solder to flow and spread more easily. The flux most commonly used in electrical wiring repair is rosin. Rosin is noncorrosive, reasonably non-toxic, and readily liquefied by heat. Rosin core solder is the only kind that should be used in electronic wiring repair. Never use acid core or use other solders that contain corrosive flux. The flux will rapidly destroy the connection's ability to conduct current.

When you solder, follow these guidelines:

- The soldering tool is used to heat the terminal or the clip. This will transfer heat by conductance to the wires, which will become hot enough to melt the solder. Do not heat the solder directly.

- Make sure that there are solder fillets between the core (conductor) and the terminal or the clip, but not on the insulator.
- If you use a clip, make sure that the solder covers the exposed conductor, and all of the clip.
- If you solder around a terminal, make sure the solder covers the conductor. Also, make sure the solder does not extend past the conductor. It may be helpful to tilt the terminal end of the wire that is being repaired slightly up in order to prevent solder from flowing onto the terminal.
- Do not apply so much solder that the individual wire strands are not visible.
- Do not allow the soldering tool to burn the terminal or the insulation.
- Do not leave sharp points of solder. The sharp points can tear the tape that is used to insulate the repair.
- Do not allow individual wire strands to protrude from the repair. Also, do not allow the wire strands to protrude over the insulator.
- Do not solder wires in a live circuit. Always disconnect power from the wires and then make the repair.

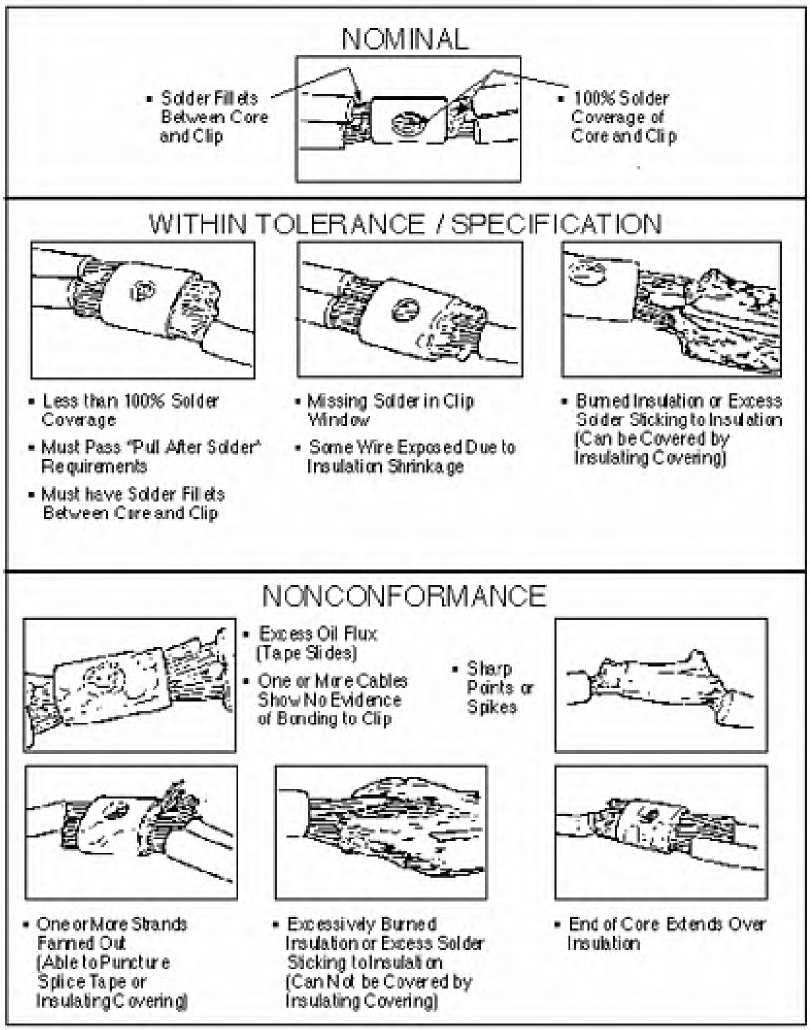


Illustration 4 g01072293

Soldering Tools and Preparation

Tools

The following tools are recommended for use when you prepare wires and connections. Also, when you solder wires or connections:

- Diagonal pliers, commonly called dikes, cutters or diagonals, are used for cutting soft wire and component leads. Diagonal pliers should not be used for cutting hard metals like iron or steel.
- Long nose pliers or needle-nose pliers are used for holding the wire so that the stripped end may be twisted around a terminal post or inserted into a terminal eye.

- A wire stripper, is used to remove insulation from the hookup wires. There are different types of strippers. These strippers range from the simple type found on diagonal pliers to the more automatic multisized strippers which can handle different wire diameters.

- A soldering iron is a standard tool in the industry that is used for connecting wires together. Soldering irons are rated by the amount of power the irons dissipate. So the soldering irons are rated indirectly by the amount of heat the irons can develop. One hundred watt guns and one hundred twenty five watt guns are the most popular sizes. The type of job determines which size iron should be used on the job.

- Heat sinks are used to prevent overheating during soldering. Heat sinks are used to prevent unsoldering of heat sensitive electronic parts. The heat sink is generally a clip that is attached to the lead between the body of the part and the terminal point at which the heat is applied. The heat sink absorbs heat. The heat sink reduces the amount of heat that is conducted by the component.

- When component leads are being removed from their holes, desoldering tools will simplify the job of cleaning solder from etched (pc) board solder holes. The holes must be free of solder before the terminals of a new component may be inserted.

Wire Preparation

Two or more wires that provide a conductive path for electricity must be electrically connected. This means that an uninsulated surface on one wire must be mechanically connected to an uninsulated surface on the other wire. To ensure that the wires will not separate, or the connection corrode, the wires are soldered at the junction.

Before wires may be connected and soldered the wires must be properly prepared. This involves stripping the insulation at the ends of the wire, providing terminal leads which may be connected to each other or to a terminal post or connector contact.

After you remove the insulation, examine the wire for nicks, cuts and discoloration. If the wire has a shiny look and is not nicked or damaged, no further preparation is needed. If the wire has a dull, dark appearance, the wire must be cleaned before soldering.

The final step before you solder the wire is to perform a task called tinning. If you use stranded wires, the wire should be twisted and placed on the tip of a heated soldering device. Heat the wire sufficiently so that the wire will melt the solder.

Mechanical Connections

Some of the more common connectors are posts, terminals and splices. Illustration 5 shows a connection to a terminal post. The wire should be secured to the post by preforming a three quarter turn to a full turn. Do not wind the wire around the post several times. It is inefficient and also causes problems if the connection needs to be desoldered.

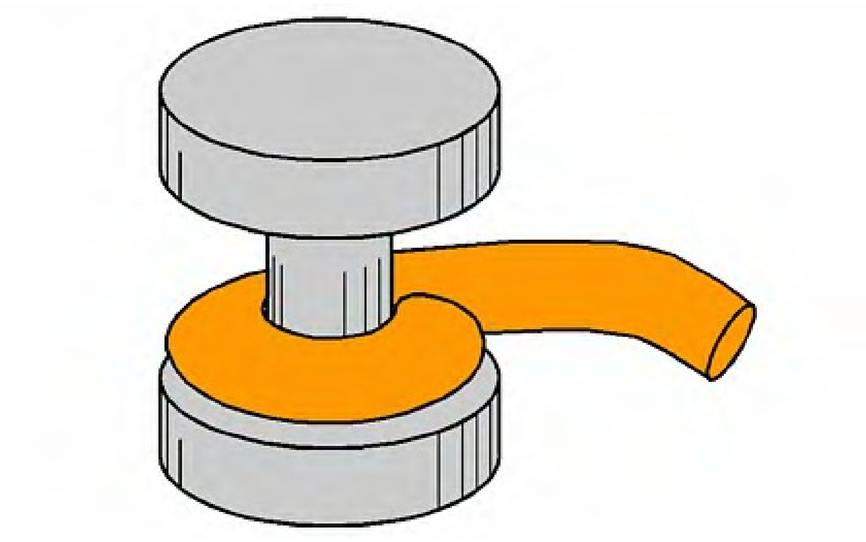


Illustration 5 g01072294

Illustration 6 shows a typical connection to a terminal strip. Twist the wire in order to form a hook. Then insert the hook into the opening on the terminal strip.

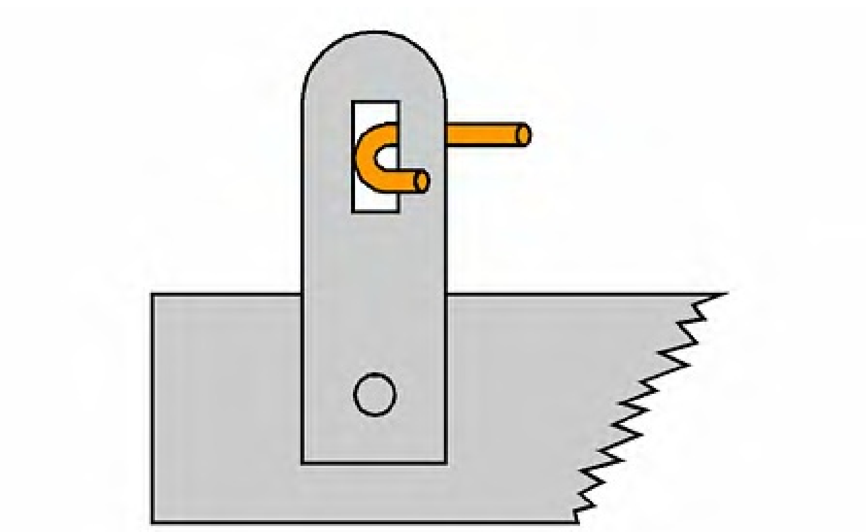


Illustration 6 g01072295

If two wires are will be spliced, the recommended procedure is to twist each wire in the form of a hook. Combine the two hooks and apply the solder to the joint. It is not necessary to twist the wires together before soldering. Illustration 7 shows a hook splice connection.

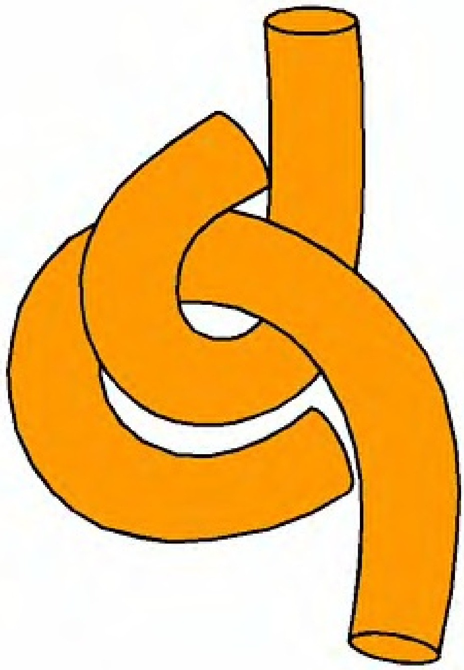


Illustration 7 g01072298

When you connect heat sensitive components to a terminal post or to a terminal strip, it is recommended that a heat sink device be used. Illustration 8 shows a heat sink that is connected between a diode and a terminal post. The heat sink acts as a heat load, and therefore reduces the heat transfer to the diode.

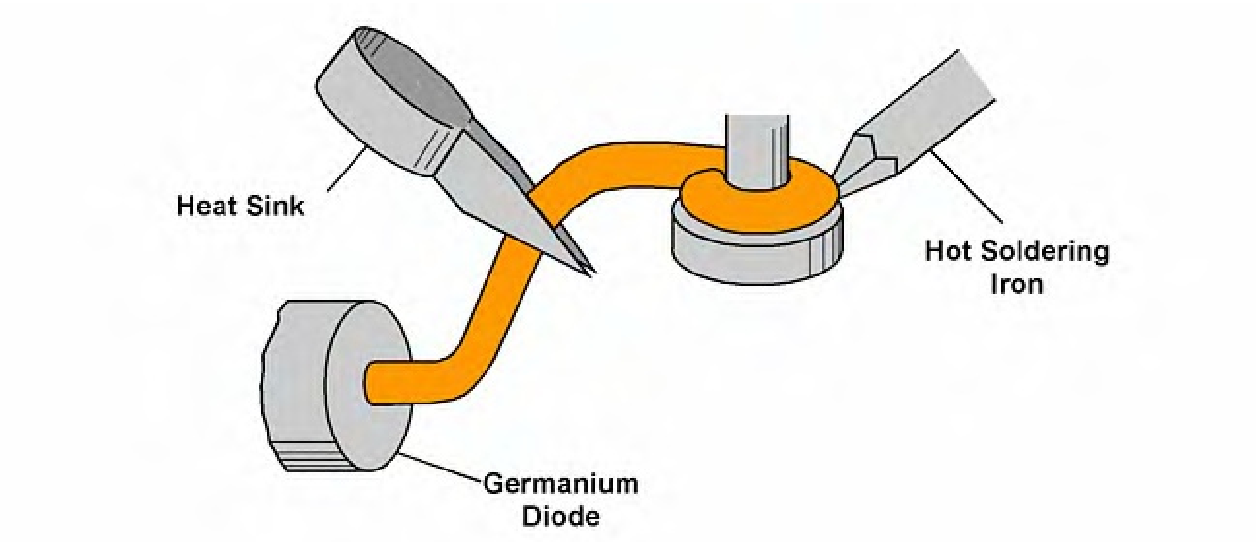


Illustration 8 g01072299

Safety Precautions

The soldering gun or the soldering iron operates at temperatures that are high enough to cause serious burns. Observe the following safety precautions:

1. Do not permit hot solder to be sprayed into the air by shaking a hot gun, an iron or a hot soldered joint.
2. Always grasp a soldering gun or a soldering iron by the insulated handle. Do not grasp the bare metal part.
3. Do not permit the metal part of a soldering gun or a soldering iron to rest or to come in contact with combustible materials. An iron should always rest on a soldering stand when the iron is not in use.

Helpful Hints

Good soldering is part of a technician's skills. Solder connections must be mechanically strong, so that the connections will not vibrate loose. Loose connections will cause intermittent problems. Electrically, solder contacts must have low resistance for providing proper signal transfer.

The following rules are for basic soldering:

1. The soldering tip must be tinned and clean.
2. Metals must be clean before the metals are connected.
3. Support the joint mechanically where possible.
4. Pretin large surfaces before you solder the surfaces together.
5. Apply the solder to the joint, not to the gun or to the iron tip. Solder must flow freely and have a shiny, smooth appearance.
6. Use only enough solder to make a solid connection.

7. When additional flux is used, apply to the joint. Only rosin flux should be used on electrical connections.

8. Solder rapidly and do not permit components or permit insulation to burn or to overheat.

9. Use rosin-core solder or an equivalent. Do not use acid core solder for any electrical connections.

Connectors

Illustration 9 g01072301

The purpose of a connector is to pass current from one wire to another. In order to accomplish this, the connector must have two mating halves (plug or receptacle). One half houses a pin and the other half houses a socket. When the two halves are joined, current is allowed to pass.

With the increased use of electronic systems on Caterpillar machines, servicing connectors has become a critical task. Increased usage of electronic systems causes an increase in maintenance on the wiring, connectors, pins, and sockets. Another important factor that contributes to increased repair is the harsh environment in which the connectors operate. Connectors must operate in the following extreme conditions: heat, cold, dirt, dust, moisture and chemicals.

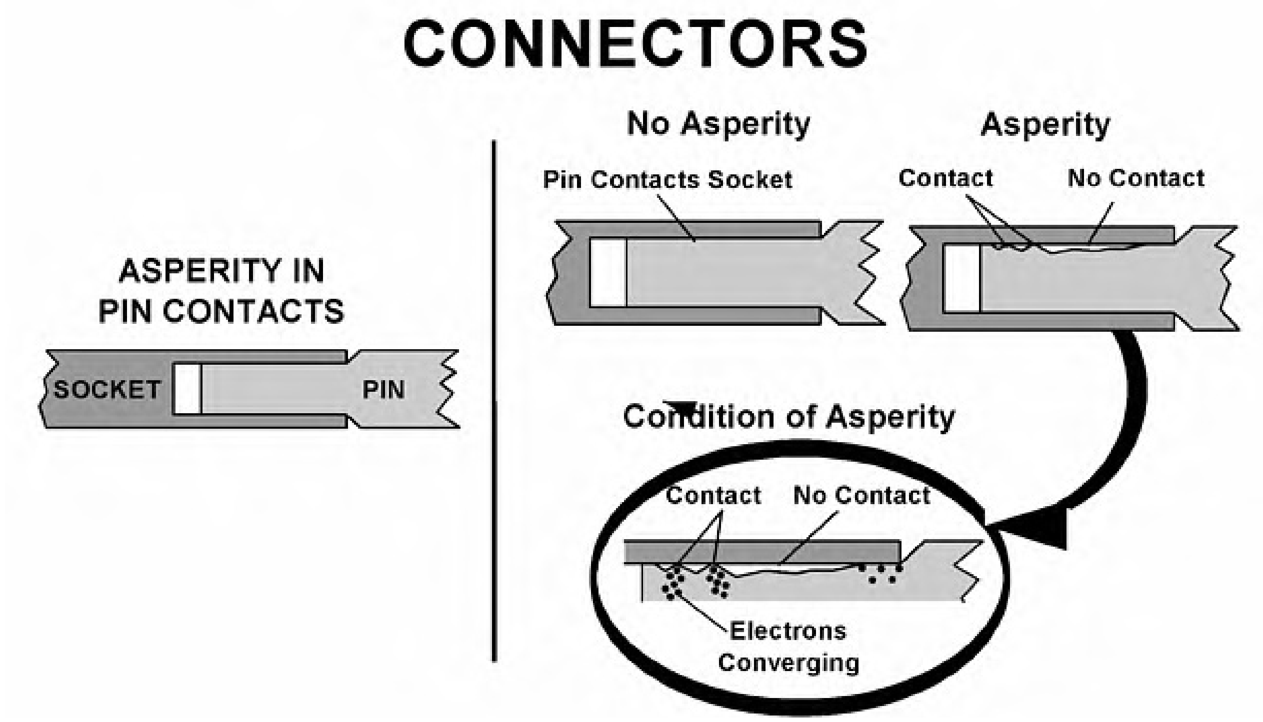


Illustration 10 g01072303

Pins and sockets have resistance and offer some opposition to current flow. Since the surface of the pins and sockets are not smooth (contain peaks and valleys) a condition known as asperity (roughness of surface) exists. When the mating halves are connected, approximately one percent of the surfaces actually contact each other.

The electrons are forced to converge at the peaks, thereby creating a resistance between the contact halves. Although this process seems rather insignificant to the operation of an electronic control, a resistance across the connector could create a malfunction in electronic controls.

Plating

In order to achieve a minimum resistance in the pins and the contacts, you need to be concerned with the finish, pressure and metal that is used in construction of the pins and the contacts. Tin is soft enough to allow for film wiping, but it has high resistivity. Copper has low resistivity, but it is hard. So in striving for minimum resistance and the reduction of asperity, low resistance copper contacts are often plated with tin.

Film wiping occurs when pins and contacts are plated with tin. When pins and contacts are mated together, the pins and contacts have a tendency to wipe together. Pins and contacts smooth out some of the peaks and valleys that are created by the asperity condition. Gold and silver are excellent plating material, but gold and silver are too costly to use.

Contaminants

Contaminants are one factor that contributes to resistance in connectors. Some harsh conditions that employ chemicals can cause malfunctions due to increased resistance.

Note: Connectors cause many diagnostic problems. It may be necessary to measure the resistance between connector halves when you are diagnosing electronic control malfunctions. Also, disconnecting and reconnecting connectors during the troubleshooting process can give misleading diagnostic information. Use breakout cables sparingly when you troubleshoot intermittent type electrical problems.

Types of Connectors

Several types of connectors are used throughout the electrical system and the electronic systems on Caterpillar machines. Each type of connector differs in the manner in which the connectors are serviced or are repaired.

The following types of connectors will be discussed in detail.

- Vehicular Environmental (VE) Connectors
- Sure-Seal Connectors
- Deutsch Connectors HD10 DT CE and DRC Series

VE Connectors

Illustration 11 g01072305

The VE connector was used primarily on earlier Caterpillar machine electrical harnesses when high temperatures, larger number of contacts, or higher current carrying capacities were needed.

The connector required a special metal release tool for removing the contacts that could damage the connector lock mechanism if the tool was turned during the release of the retaining clip.

Note: Do not use metal release tools that are listed in SEHS8038 for any other type of electrical connector.

After you crimp a wire to the contact, it is recommended that the contact be soldered in order to provide a good electrical contact. Use only rosin core solder on any electrical connection.

Specific information that relates to the process required for installing VE connector contacts (pins and sockets) is contained in the Special Instruction - Use of VE Connector Tool Group, SEHS8038.

This VE connector is no longer used on current product, but this connector may still require service by a field/shop technician.

Sure-Seal Connectors

Illustration 12 g01072308

Sure-Seal connectors are used extensively on Caterpillar machines. These connector housings have provisions for accurately mating between the two halves. Instead of using guide keys or keyways, the connector bodies are molded so that the connectors will not mate incorrectly.

Sure-Seal connectors are limited to a capacity of 10 contacts (pins and sockets).

Note: Part numbers for spare plug and receptacle housings and contacts are contained in the Special Instruction - Use of 6V3000 Sure-Seal Repair Kit, SMHS7531.

Use special tool 6V3001 for crimping contacts and stripping wires.

Sure-Seal Connectors require the use of a special tool 6V3008 for installing contacts. Use denatured alcohol as a lubricant when you install contacts. Special tooling is not required for removing pin contacts.

Any holes in the housings that are not used for contact assemblies should be filled with a **9G-3695** Sealing Plug . The sealing plug will help prevent moisture from entering the housings.

Deutsch Heavy Duty Series Connectors HD10

Illustration 13 g01072309

The HD10 connector is a thermoplastic cylindrical connector that utilizes crimp type contacts that are quickly and easily removed. The thermoplastic shells are available in nonthreaded and threaded configurations that use insert arrangements of 3, 5, 6 and 9 contacts. The contact size is no. 16 and accepts no. 14, no. 16 and no. 18 AWG wire.

The HD10 uses crimp type, solid copper alloy contacts (size no. 16) that feature an ability to carry continuous high operating current loads without overheating. The contacts are crimp terminated using a Deutsch Crimp Tool, **1U-5805** Wire Removal Tool part number .

Deutsch termination procedures recommend no soldering after properly crimped contacts are completed.

The procedure for preparing a wire and crimping a contact is the same for all Deutsch connectors and is explained in the Special Instruction - Servicing DT connectors, SEHS9615. The removal procedure differs from connector to connector and will be explained in each section.

DeutschTransportation (DT) Series Connectors

Illustration 14 g01072432

The DT connector is a thermoplastic connector that utilizes crimp type contacts that are quickly and easily removed. These connectors require no special tooling. The thermoplastic housings are available in configurations that use insert arrangements of 2, 3, 4, 6, 8 and 12 contacts. The contact size is no. 16 and accepts no. 14, no. 16 and no. 18 AWG wire.

The DT uses crimp type, solid copper alloy contacts (size no. 16) or stamped and formed contacts (less costly) that feature an ability to carry continuous high operating current loads without overheating. The contacts are crimp terminated with a Deutsch Crimp Tool, Caterpillar part number 1U5804.

The DT connector differs from other Deutsch connectors in both appearance and construction. The DT is either rectangular or triangular shaped and contains serviceable plug wedges, receptacle wedges and silicone seals.

The recommended cleaning solvent for all Deutsch contacts is denatured alcohol.

Note: For a more detailed explanation on servicing the DT connector, consult Special Instruction - Servicing DT Connector, SEHS9615.

Caterpillar Environmental Connectors (CE)

Illustration 15 g01072310

The CE connector is a special application connector. The CE Series connector can accommodate between 7 and 37 contacts. The 37 contact connector is being used on various electronic control modules.

The CE connector uses two different crimping tools. The crimping tool for no. 4 thru no. 10 size contacts is a 4C4075 Hand Crimp Tool Assembly, and the tool for no. 12 thru no. 18 contacts is the same tool that is used on the HD and DT Series connectors 1U5804 .

Note: For a more detailed explanation on servicing the CE connectors, refer to the Special Instruction - Use of CE/VE Connector Tools, SEHS9065.

Deutsch Rectangular Connector (DRC)

Illustration 16 g01072311

The DRC connector features a rectangular thermoplastic housing. The DRC connector is completely environmentally sealed. The DRC is best suited to be compatible with external and internal electronic control module.

The connector is designed with a higher number of terminals. The insert arrangements that are available are 24, 40, and 70 contact terminations. The contact size is no. 16 and accepts no. 16 and no. 18 AWG wire.

The connector uses crimp type, copper alloy contacts (size no. 16) or stamped and formed contacts (less costly) that feature an ability to carry continuous high operating current loads without overheating. The contacts are crimp terminated using a Deutsch Crimp Tool, **1U-5805** Wire Removal Tool part number.

The connector contains a clocking key for correct orientation and is properly secured by a stainless steel jackscrew. A 4 mm (5/32 inch) "HEX" wrench is required to mate the connector halves. The recommended torque for tightening the jackscrew is 25 inch pounds.

Note: The DRC uses the same installation and removal procedures as the HD10 series.

Switches

Illustration 17 g01072313

A switch is a device that is used to complete or to interrupt a current path. Switches are placed between two conductors (wires).

Some of the more common switches that are used on Caterpillar machines are listed below:

- Single-pole single-throw (SPST)
- Single-pole double throw (SPDT)
- Double-pole single-throw (DPST)
- Double-pole double-throw (DPDT)

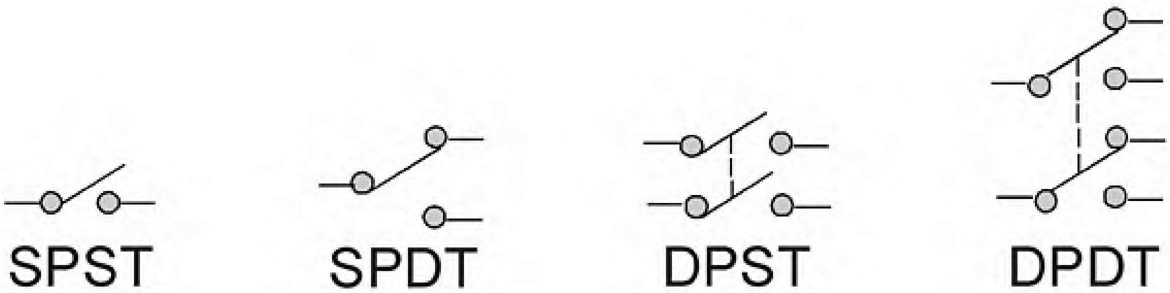


Illustration 18 g01072314

There are many ways of actuating switches. The switches that are shown above are mechanically operated by moving the switch lever or the toggle. Sometimes, switches are linked so that the switches always open and close at the same time. In schematics, this is shown by connecting linked switches with a dashed line.

Other mechanically operated switches are limit switches and pressure switches. The switch contacts are closed or opened by an external means. A lever may actuate a limit switch or pressure may actuate a limit switch.

Some of the more common switches that are used on Caterpillar machines are listed below:

- Toggle
- Push-On
- Key Start
- Rotary
- Pressure
- Limit
- Rocker
- Magnetic
- Cutout

Some switches are more complex than other switches. Caterpillar machines use magnetic switches for measuring speed signals. Caterpillar electronic switches contain internal electronic components, such as transistors to turn remote signals on or off.

An example of a more complex switch that is used on Caterpillar machines is the key start switch. Illustration 19 shows the internal schematic of the "Key Start Switch". This type of switch controls the following functions: an accessory position "ACC", a run position "RUN", a start position "START" and an off position "OFF". This type of switch can control other components. Also, the Key Start Switch can deliver power to several components at the same time.

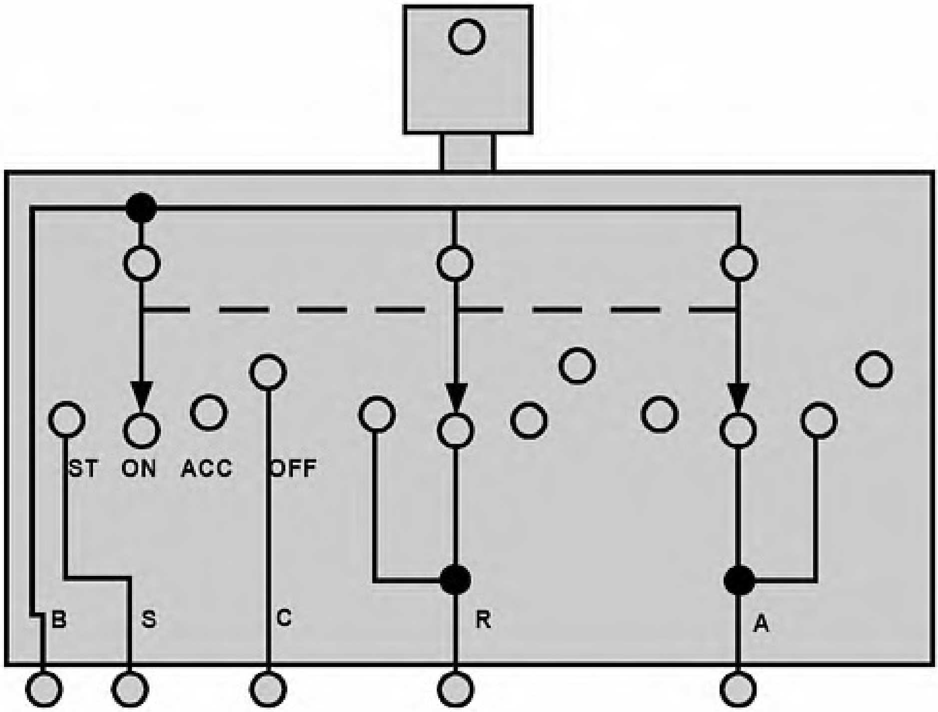


Illustration 19 g01072316

Circuit Protectors

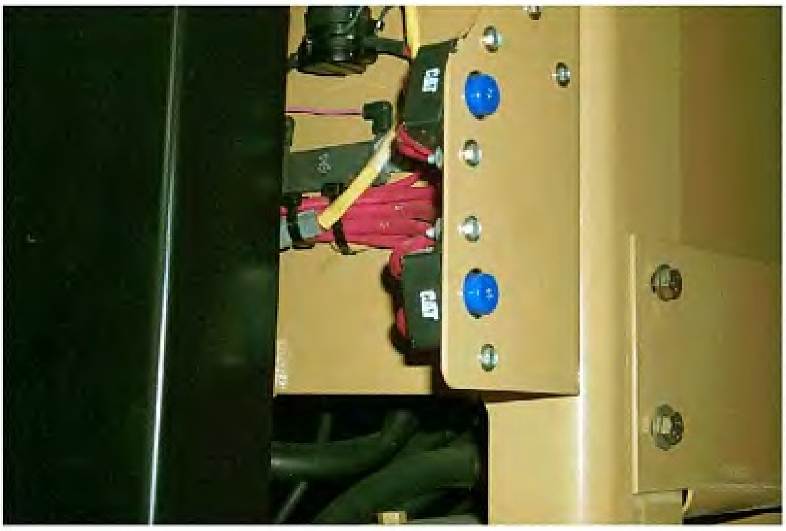


Illustration 20 g01072317

Fuses, fusible links, and circuit breakers are circuit protectors. Excess current in a circuit causes heat. The heat, not the current, causes the circuit protector to open before the wiring can be damaged. This has the same effect as turning a switch "OFF".

Note: Circuit protectors are designed to protect the wiring and not necessarily other components.

Fuses and circuit breakers can help you diagnose circuit problems. If a circuit protector opens repeatedly, there is probably a more serious electrical problem that needs to be repaired.

Fuses

Illustration 21 g01072319

Fuses are the most common circuit protectors. A fuse is made of a thin metal strip or wire inside a holder made of glass or plastic. When the current flow becomes higher than the fuse rating, the metal melts and the circuit opens. A fuse must be replaced after the circuit opens.

Fuses are rated according to the amperage that the fuse can carry before the fuse opening. Plastic fuse holders are molded in different colors in order to signify fuse ratings. Fuse ratings are also molded into the top of the fuse.

A fusible link (not shown) is a short section of insulated wire that is thinner than the wire in the circuit that the link protects. Excess current causes the wire inside the link to melt. Like fuses, fusible links must be replaced after the fuse has blown.

You can tell if a fusible link is blown by pulling on the two ends. If it stretches like a rubber band, the wire must have melted and the link is no longer good. The insulation of a fusible link is thicker than regular wire insulation. The thicker insulation to contains the melted link after it blows.

Note: When you replace a fusible link, never use a length longer than 225 mm (9 inch).

Circuit Breakers

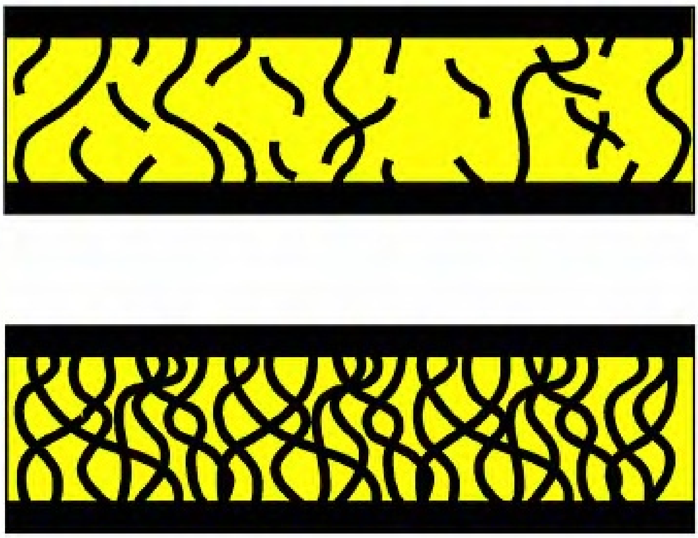


Illustration 22 g01072321

A circuit breaker is similar to a fuse. High current will cause the breaker to trip. This will open the circuit. The breaker can be manually reset after the overcurrent condition has been eliminated.

Some circuit breakers are automatically reset. These circuit breakers are called cycling circuit breakers. Circuit breakers are built into several Caterpillar components. An example of one component is the headlight switch.

There are also noncycling circuit breakers. This type operates with a heated wire that opens contacts until current flow is removed.

A cycling circuit breaker contains a strip that is made of two different metals. Current that is higher than the circuit breaker rating makes the two metals change shape unevenly. The strip bends, and a set of contacts is opened in order to stop current flow. When the metal cools, the metal returns to its normal shape. This closes the contacts. Current flow can resume. Automatically resetting circuit breakers are also called cycling circuit breakers. The circuit breaker cycles open and closed until the current returns to a normal level.

A PTC (for Positive Temperature Coefficient) is a special type of circuit breaker called a thermistor or a thermal resistor. PTCs are made from a conductive polymer. This material is in the form of a dense crystal, with many carbon particles that are packed together. The carbon particles provide conductive pathways for current flow. When the material is heated, the polymer expands, pulling the carbon chains apart. In this expanded state, there are few pathways for current.

A PTC is a solid state device. A PTC has no moving parts. When the PTC is tripped, the device remains in the open circuit state as long as voltage remains applied to the circuit. The PTC resets only when voltage is removed and the polymer cools.

Resistors

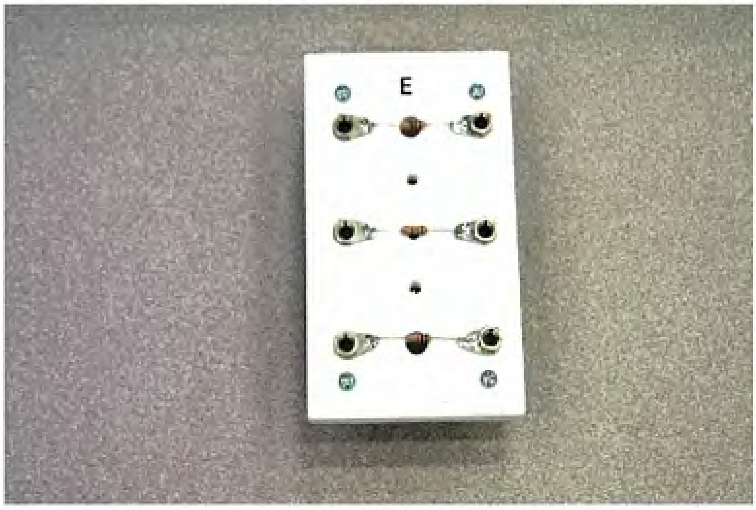
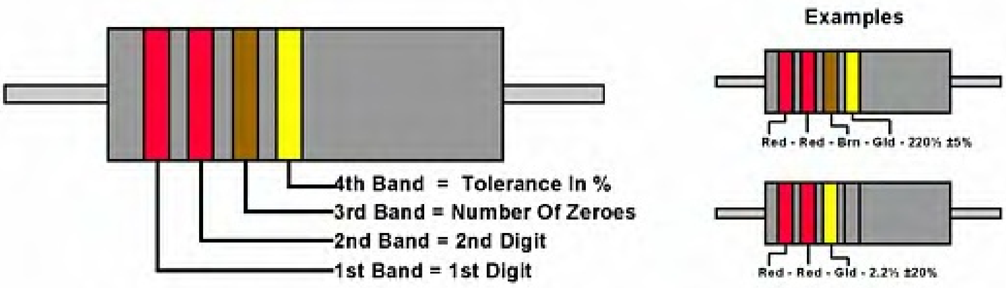


Illustration 23 g01072322

Sometimes it is necessary to reduce the amount of voltage or current at a specific point in a circuit. The easiest way to reduce the voltage or the current that is supplied to a load is to increase the resistance. This is done by adding resistors. Resistors come in two types: variable and fixed. Common uses for resistors in electrical circuits are the audio system and the climate control circuit. These components use several resistors that are wired to vary voltage.

Resistors are rated in ohms for the amount of resistance the resistors provide the circuit. Resistors are rated in watts for the amount of heat the watts can dissipate.



1st Band	Transfers Directly Into Numbers
2nd Band	Transfers Directly Into Numbers
3rd Band	Place Decimal Point (number Of Zeroes After 2nd Digit) If Gold, Divide By 10 If Silver, Divide By 100
4th Band	Designates Tolerance In %

Band 1, 2, 3	
Black	-0
Brown	-1
Red	-2
Orange	-3
Yellow	-4
Green	-5
Blue	-6
Violet	-7
Gray	-8
White	-9

4th Band	
Brown	±01%
Red	±02%
Gold	±05%
Silver	±10%
No Band	±20%

Illustration 24 g01072454

Illustration 24 shows the color code chart for identifying resistors. The rating of a resistor can be determined by looking at the bands of color on the resistor. The bands should be closer to one end of the resistor than the other end. The end with the color bands should be on your left as you read the bands. The bands are read from left to right.

The last color band indicates the resistor tolerance. This refers to how much the actual resistor value can vary from the specified rating. This rating is given as a percentage of the total rating. Some resistors have no band in this last position. Such a resistor has a tolerance of 20% of the resistance value.

Some circuits are designed with very precise resistance values and will not operate properly otherwise. For this reason, you should never replace a resistor with one of a higher tolerance.

Resistors and Wattages

Because a resistor resists current flow, electrical friction builds up. This creates heat that the resistor must be able to dissipate. Too much heat could change a resistor so that the rating and tolerance are no longer in the designed range.

Wattage is the amount of power that can be consumed by a resistor. The larger the wattage is, the more heat a resistor can withstand. Illustration 25 shows examples of resistor wattages.

Resistor Wattages

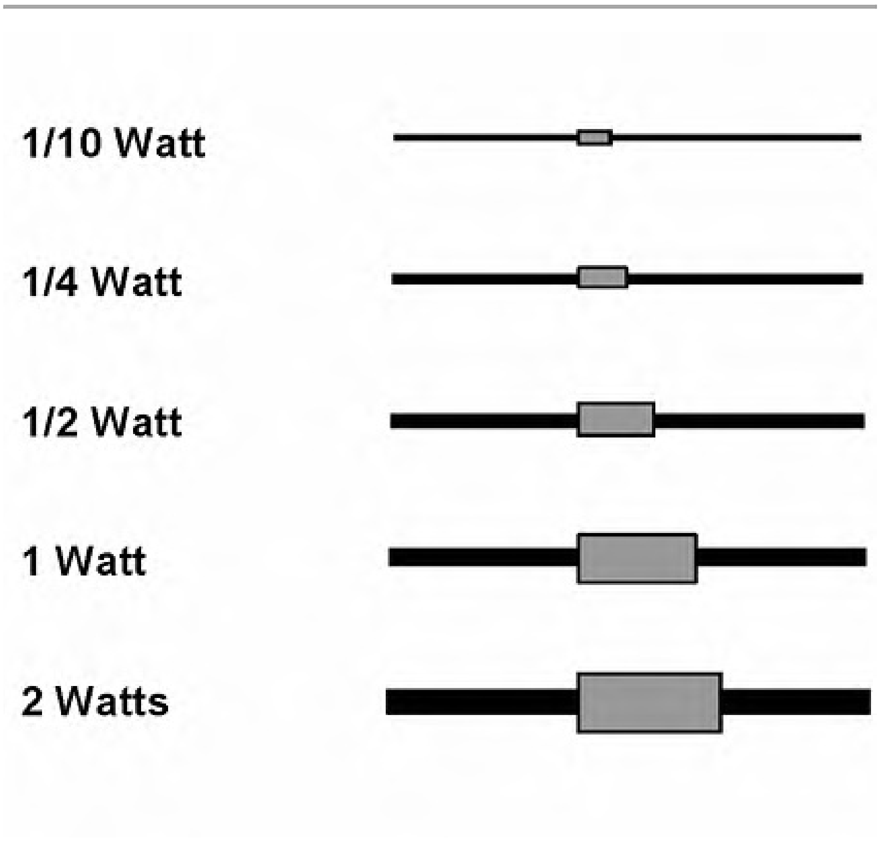


Illustration 25 g01072324

In order for a circuit to function properly, the resistors must have the correct wattage rating as well as the correct resistance rating. The resistors and other components could be damaged by additional current flow and heat if the resistance or wattage ratings are incorrect.

You can identify the wattage of a carbon-composition resistor by the size. The most common ratings are 1/10 watt, 1/4 watt, 1/2 watt, 1 watt, and 2 watts.

Variable Resistors

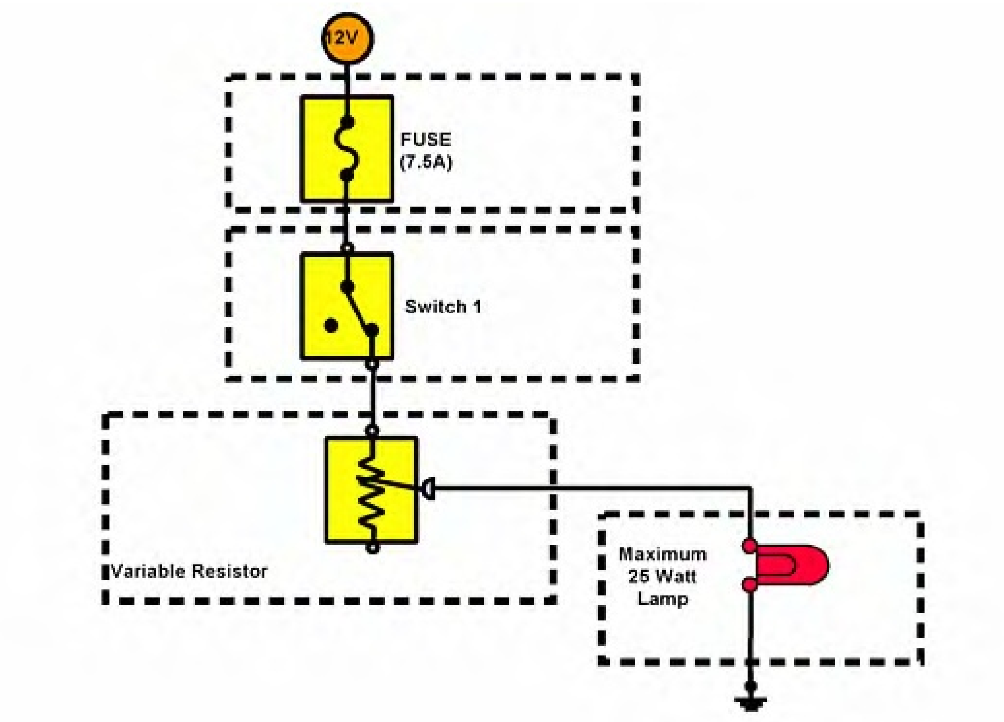


Illustration 26 g01072325

The kinds of resistors that have been discussed so far are fixed. This means that the resistors rating cannot be adjusted. Other resistors are variable (Illustration 26). This means that the resistor resistance can be changed by adjusting a control. The control moves a contact over the surface of a resistance. As current flows through a greater length of resistor material, the current decreases. As current flows through less resistor material, current increases.

The amount of variance and the number of resistance positions depend on how the variable resistor is constructed. Some variable resistors have only two different resistance values. Other variable resistors have an infinite range between the minimum values and their maximum values.

Variable resistors can be linear or non-linear. The resistance of a linear resistor increases evenly. When the control is set at one fourth of the travel, resistance increases to one fourth of the maximum. When the control is set to half of travel, resistance increases to half of its maximum.

There are many kinds of variable resistors. Some variable resistors are called rheostats, potentiometers or thermistors. Illustration 27 shows a schematic symbol for a rheostat.

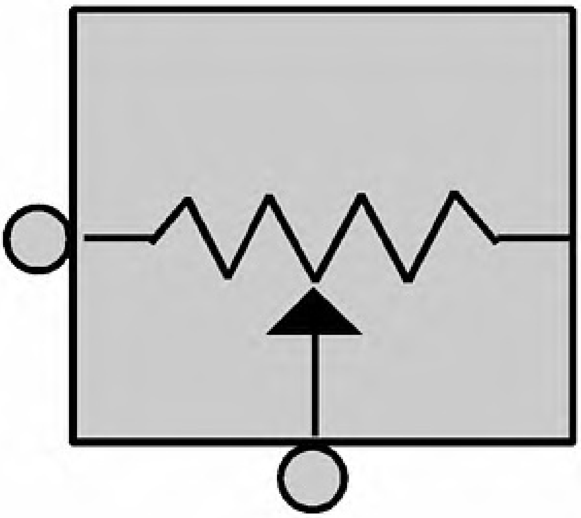


Illustration 27 g01072326

A rheostat typically has two terminals. A rheostat allows current flow in one path. On Caterpillar machines, a rheostat is used to control the brightness of the instrument lights.

Another type of variable resistor is the potentiometer. The potentiometer allows two paths for current flow. The potentiometer can be controlled manually or controlled mechanically. Illustration 28 shows a potentiometer that is from a fuel system. The fuel sender measures a specific system resistance value which corresponds to a specific system condition. The output resistance is measured at the main display module and the value corresponds to the depth of fuel in the tank.

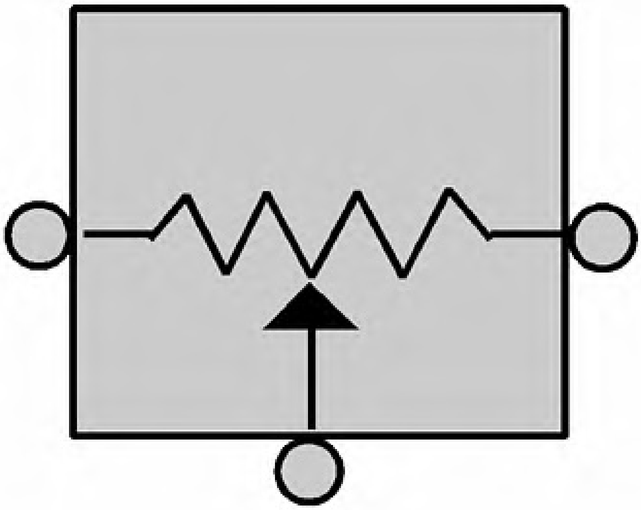


Illustration 28 g01072327

A potentiometer (pot) has three terminals and works by dividing the voltage between two of the terminals. Potentiometers can also be designed to work as rheostats.

Thermistors

Thermistors (thermal resistors) are a type of variable resistor that operate without human control. A thermistor is made of carbon. The resistance of carbon decreases instead of increasing at higher temperatures. This property can be useful in certain electrical circuits. Thermistor elements are used extensively in sensors on Caterpillar machines for measuring system temperatures.

Failed Resistors

Fixed resistors either work or do not work.. Fixed resistors work by passing the proper amount of current. A fixed resistor that has failed, will not allow current to pass or will allow too much current to pass.

Variable resistors, on the other hand, can exhibit a flat spot where the moving parts brush against one another and cause wear. This can become evident as lack of response through a portion of the resistor's travel.

Capacitor

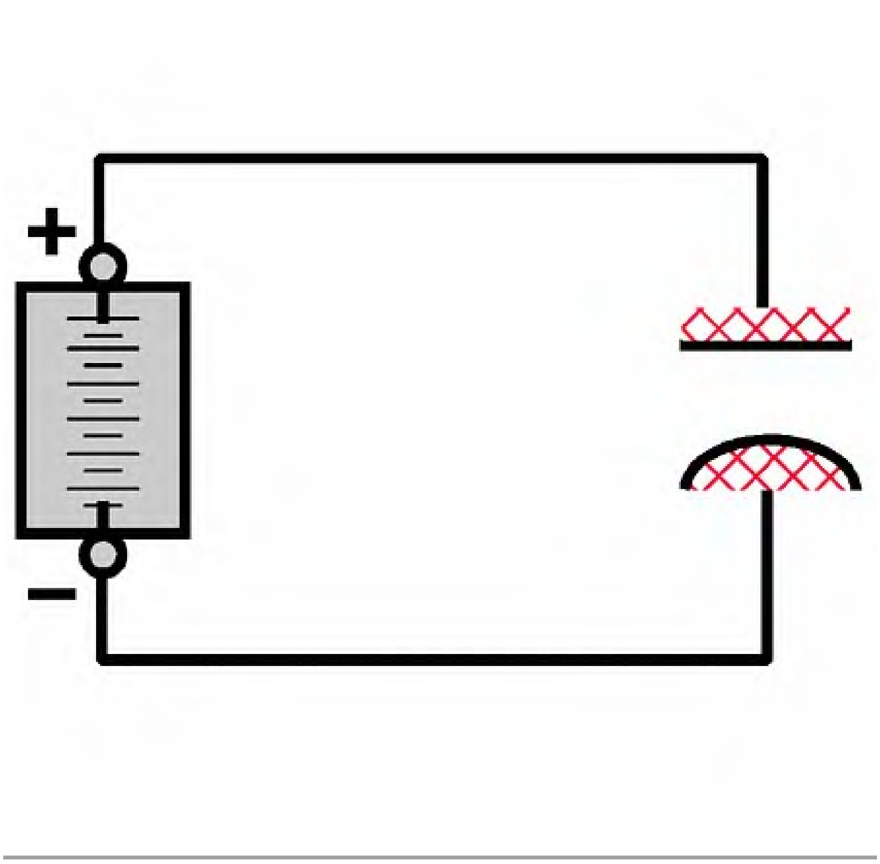


Illustration 29 g01072328

A capacitor is a device that can store an electrical charge. A capacitor creates an electrical field that can store energy. The measurement of this energy storing ability is called capacitance. In Caterpillar electrical systems, capacitors are used for the following functions:

- To store energy
- As timer circuits

- As filters

Construction methods vary. A simple capacitor can be made from two plates of conductive material that are separated by an insulating material that is called a dielectric. Typical dielectric materials are air, paper, plastic, and ceramic.

Capacitor Energy Storage

In some circuits, a capacitor can take the place of a battery. If a capacitor is placed in a circuit with a voltage source, current flows in the circuit briefly while the capacitor charges. That is, electrons accumulate on the surface of the plate that is connected to the negative terminal. Electrons move away from the plate that is connected to the positive terminal. This continues until the electrical charge of the capacitor and the voltage source are equal. How fast this happens depends on several factors, including the amount of voltage that is applied and the size of the capacitor.

When the capacitor is charged to the same potential as the voltage source, current flow stops. The capacitor can then hold the charge when the capacitor is disconnected from the voltage source. With the two plates separated by a dielectric, there is no where for the electrons to go. The negative plate retains the accumulated electrons, and the positive plate still has a deficit of electrons. This is how the capacitor stores energy.

A charged capacitor can deliver stored energy just as a battery would. It is important to note that, unlike a battery, a capacitor stores electricity, but the capacitor does not create it. When a capacitor is used to deliver a suitable small current, a capacitor has the potential to deliver voltage to a circuit for as long as a few weeks.

Capacitor Measurements

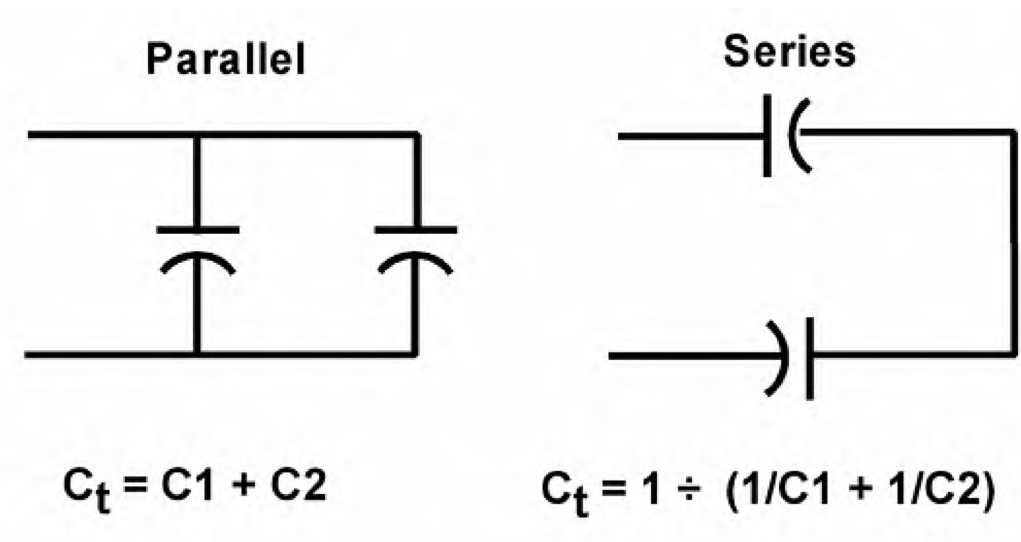


Illustration 30 g01072329

Capacitors are rated in units of measurement called Farads. Farads are represented by the symbol F. These specify how many electrons the capacitor can store. The farad is a very large number of electrons. In the systems you use, you will see capacitors that are rated in microfarads (µF). A microfarad is one millionth of a farad.

In addition to being rated in farads, capacitors are also rated according to the maximum voltage that the capacitor can handle. When you replace a capacitor, never use a capacitor with a lower voltage rating.

Three factors combine to determine the capacitance of a given capacitor:

- The area of the conductive plates
- The distance between the conductive plates
- The material that is used as the dielectric.

Calculating Total Capacitance

The total capacitance of a circuit is dependent on how the capacitors are designed in the circuit.

When capacitors are in parallel, total capacitance is determined by the following equation:

- $C_t = C1 + C2 + C3$

When capacitors are in series, total capacitance is determined by this equation:

- $C_t = 1/ (1/C1 + 1/C2)$

Note: Always short across the terminals of a capacitor before you connect the capacitor to a circuit or meter. This discharges any residual charge that might be stored.

CATERPILLAR®

Systems Operation - Fundamentals
Electrical System for All Caterpillar Products
Media Number -SEGV3008-01 **Publication Date -01/06/2004** **Date Updated -28/06/2004**

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Battery

SMCS - 1400; 1401; 1450

Introduction to Battery

The battery stores energy for the complete electrical system. The battery produces current upon demand for the machine electrical devices.

Batteries

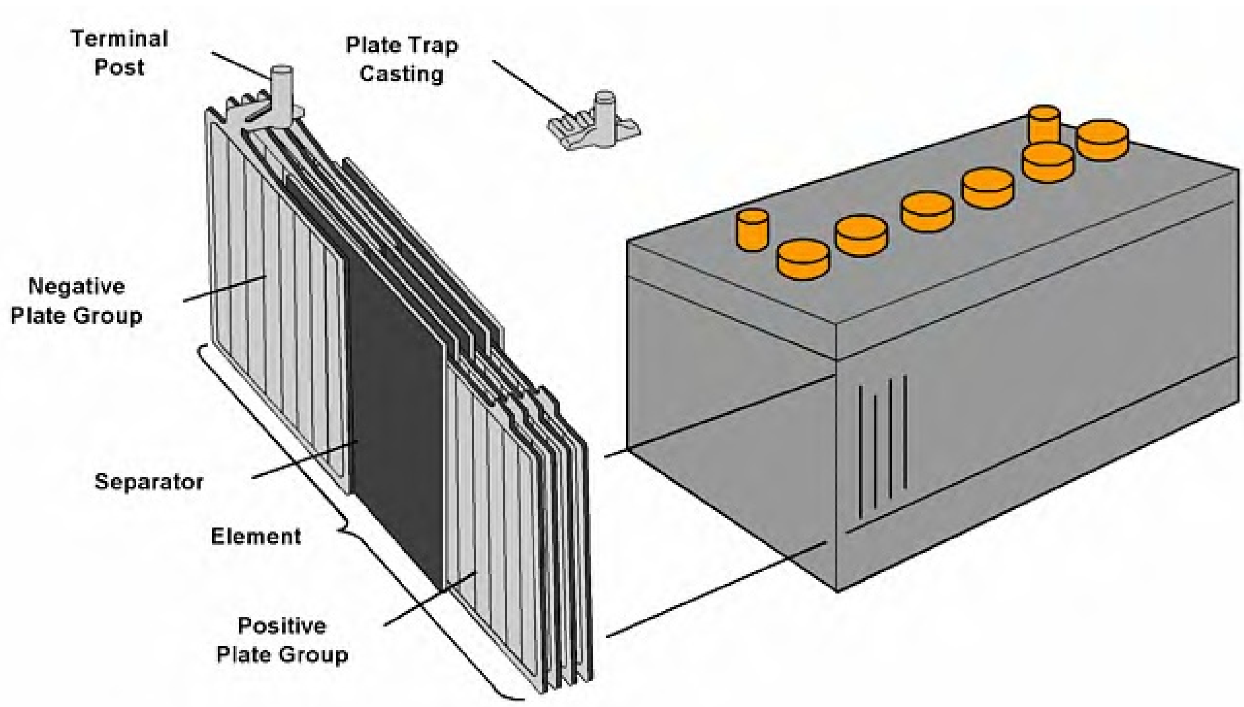

Illustration 1 g01072957

A battery stores electrical energy in chemical form to be released as electrical energy for the machine electrical system. This includes the starting, charging, and accessory circuits. This battery current is produced by a chemical reaction between the active materials of the battery plates and the sulfuric acid in the electrolyte. The battery is a voltage stabilizer for the system. The battery acts as an accumulator or a reservoir of power.

After a period of use, the battery becomes discharged and will no longer produce a flow of current. The battery can be recharged with direct current, in the opposite direction that current flows out of the battery. In normal operation, the battery is kept charged by current input from the alternator.

For good operation, the battery must do the following:

- Supply current for starting the engine.
- Supply current when the demand exceeds the output of the charging system.
- Stabilize the voltage in the system during operation.

Battery Construction

A battery is made up of a number of individual elements in a hard rubber case or plastic case. The basic units of each cell are positive and negative plates, as shown in Illustration 1. Negative plates have a lead surface, which is gray in color, while the positive plates have a lead peroxide surface which is brown in color. The negative plates and positive plates are connected into plate groups. In some batteries, there is always one more plate in the negative group than in the positive group. This allows the negative plates to form two outsides when the groups are interconnected. Other batteries have the same number of positive plates and negative plates.

Each plate in the interlaced group is kept apart from a neighbor by porous separators, which allow a free flow of electrolyte around the active plates. The complete assembly is called an element. Elements in different cells are connected in series in order to increase voltage. The cells are separate from one another, so there is no flow of electrolyte between the cells. Each cell will produce approximately 2.2 volts. So if 6 cells are connected together in series, the battery will produce approximately 13.2 volts.

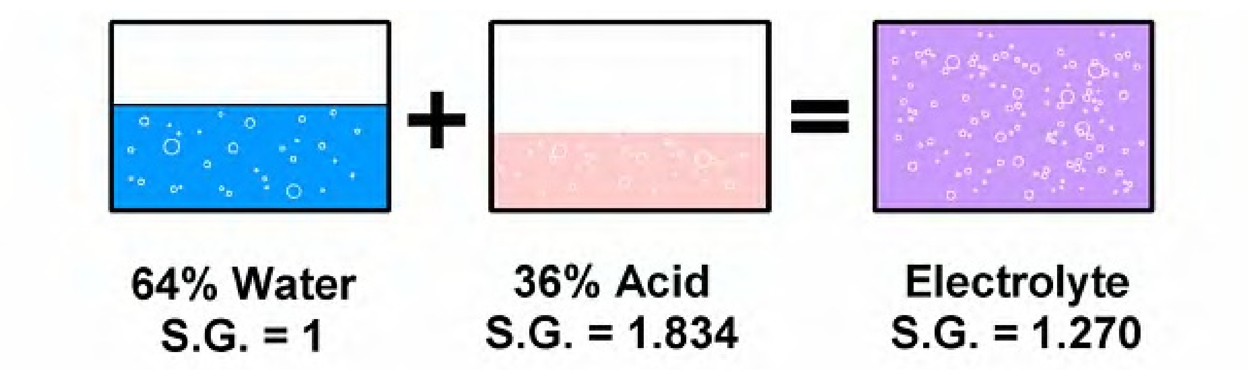

Illustration 2 g01072958

The electrolyte in a fully charged battery is a concentrated solution of sulfuric acid in water. The electrolyte has a specific gravity of about 1.270 at 27 °C (80 °F), which means the electrolyte weighs 1.270 times more than water. The solution is about 36% sulfuric acid H_2SO_4 and 64% water H_20.

Battery Water

The necessity for pure water in batteries has always been a controversial subject. It is true that water with impurities affects the life and performance of a battery. Whether or not the effect of impure water is truly significant will depend on how high the mineral content of your water supply is. Generally, you do not have to use distilled water rather than tap water, but it will be better for the battery if you do use distilled water.

Battery Terminals

Batteries have negative posts and positive posts. The positive post is larger in order to help prevent the battery from being connected in reverse polarity. The positive terminal has a (+) marked on the top and the negative post a (-) marked on the top. Other identifying marks that are on or near the posts, are "POS" and "NEG". There are colored plastic rings that are placed on the posts, red for positive and black for negative.

Battery Vent Caps

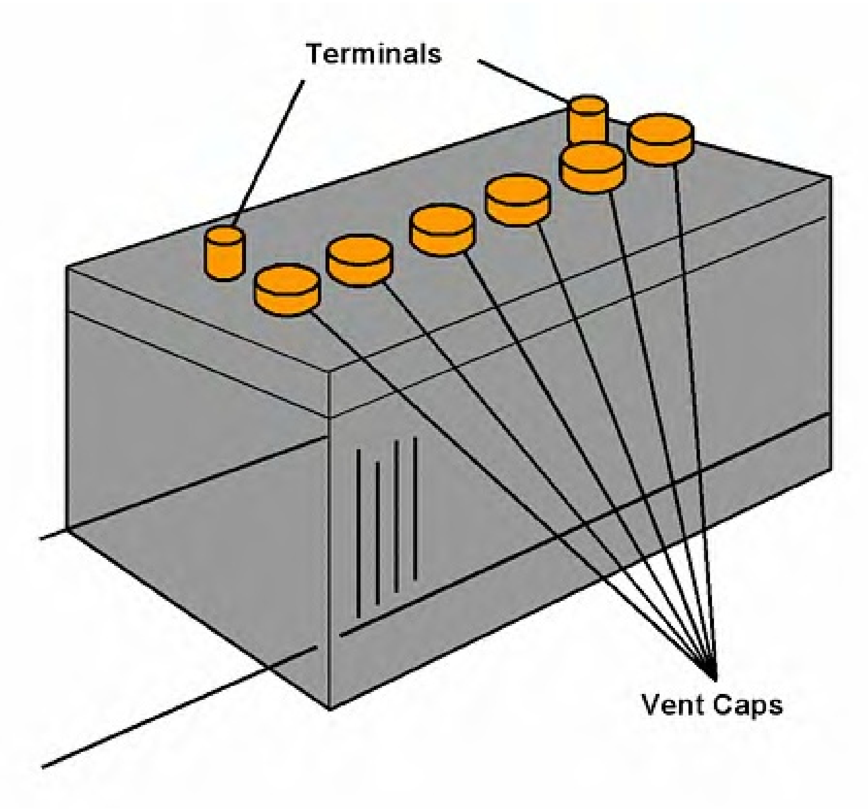

Illustration 3 g01072960

Vent caps are located in each cell cover. Some batteries have individual vent caps for each cell. Some batteries have gang units which connect three cell vents together in a single unit. Vent caps cover access holes through which the electrolyte level can be checked and water added. The access holes provide a vent for the escape of gases that are formed when the battery is charging.

Battery Potential

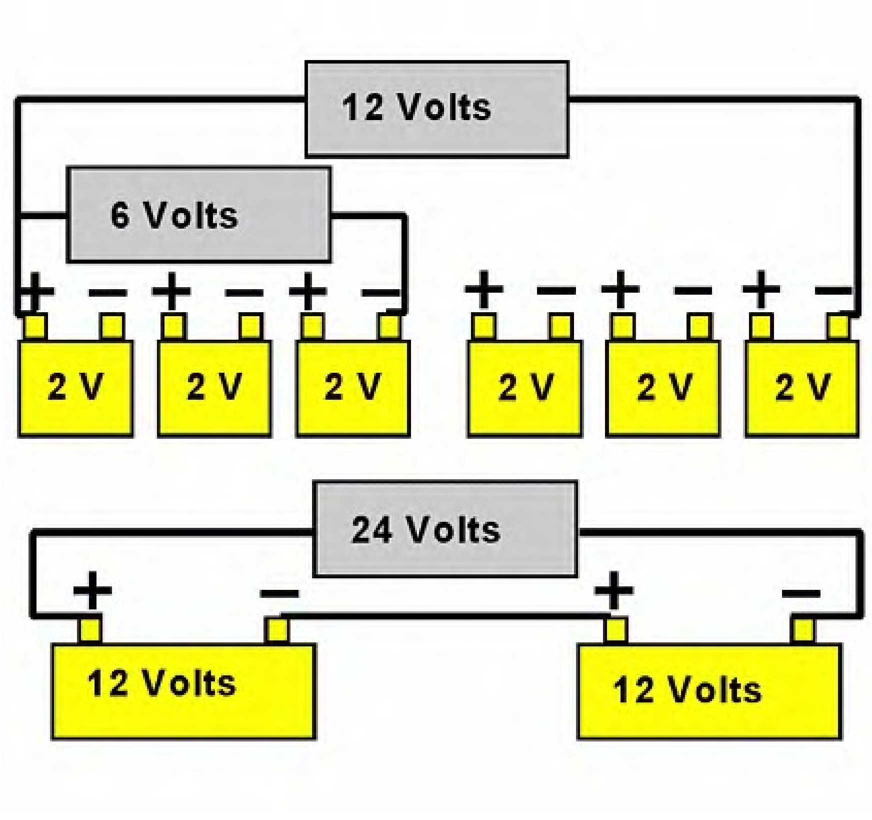

Illustration 4 g01072962

Each cell in a storage battery has a potential of about 2 volts. Six volt batteries contain three cells that are connected in series. Twelve volt batteries contain six cells in series (Illustration 4, top diagram). For higher voltages, combinations of batteries are used. Illustration 4 (bottom diagram) shows two twelve volt batteries that are connected in series in order to provide 24 volts.

How a Battery Works

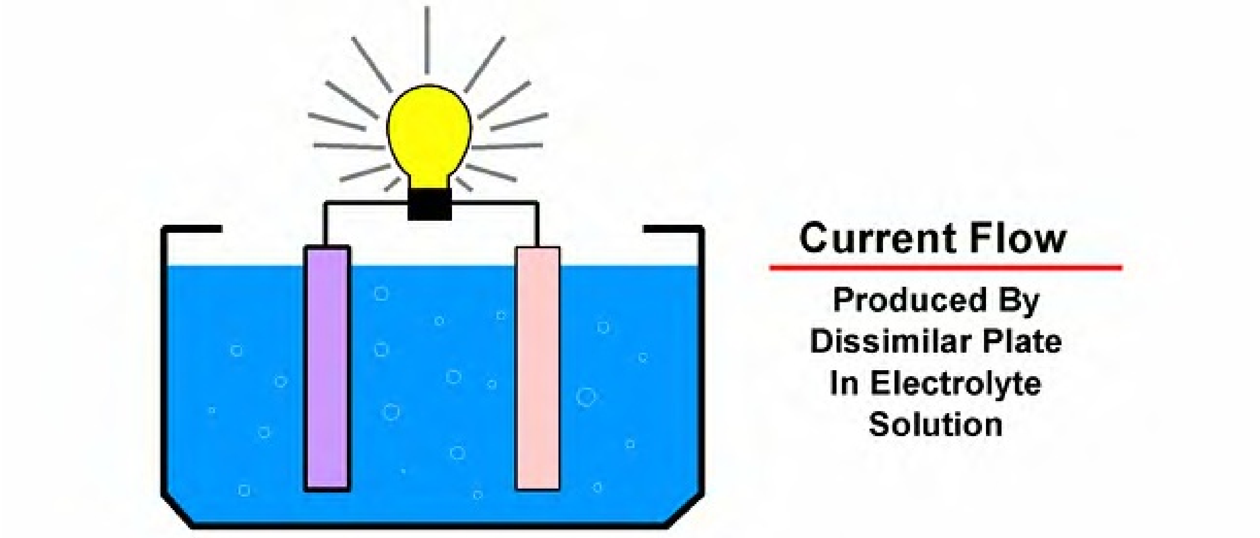

Illustration 5 g01072967

The battery produces current by a chemical reaction between the active materials of the unlike plates and the sulfuric acid of the electrolyte. While this chemical reaction is taking place, the battery is discharging. The battery is discharged after all of the active material have reacted. Then, the battery must be recharged before use.

Note that batteries of the same voltage can produce different amounts of current. The reason for this is that the amount of current a battery can produce is dependent on the number and size of the battery plates. The more plates there are, the more chemical reactions can take place between the electrolyte and the plates, therefore, the greater the amount of current produced. If two 12 volt batteries have a different number of plates, the battery with the greater number will supply more current flow and will have higher capacity.

Operating Cycles

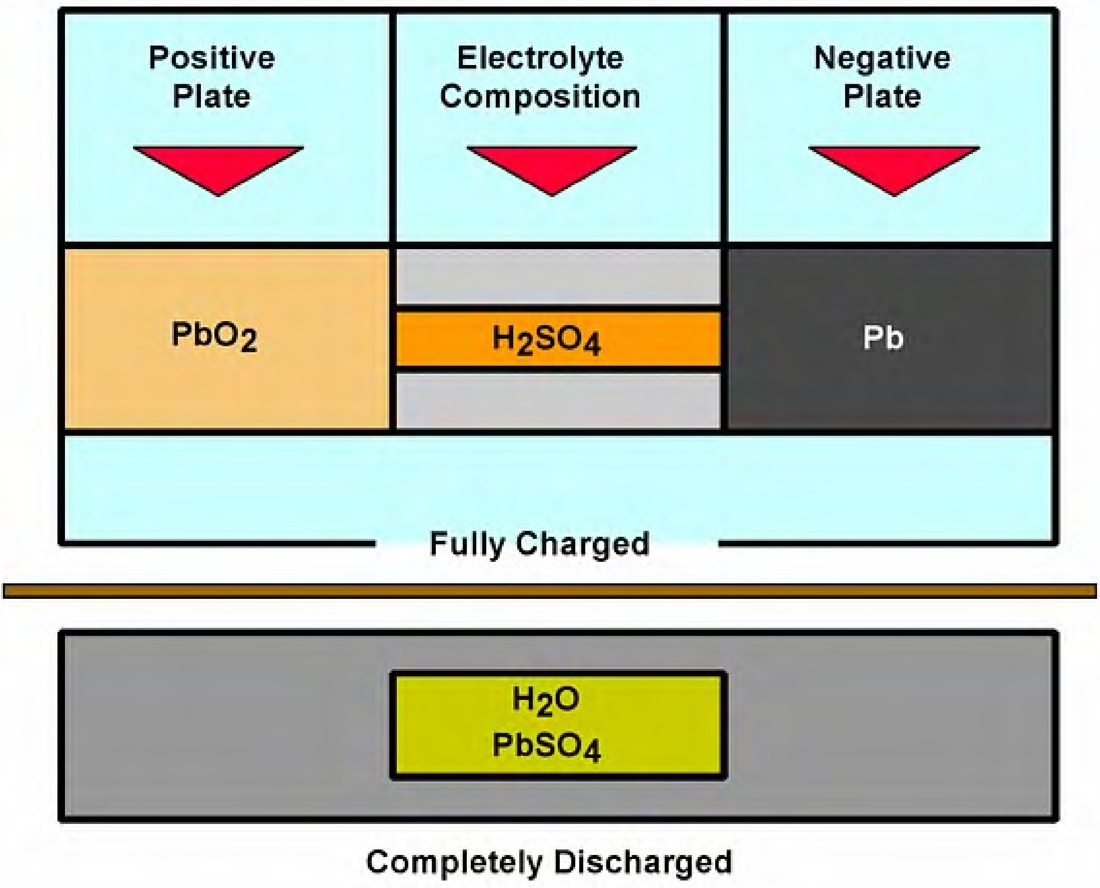

Illustration 6 g01072970

A battery has two operating cycles:

- Discharging
- Charging

Discharging Cycle

When a battery is supplying current, the battery is discharging. The chemical changes in a discharging battery are as follows:

- Positive plates are made of lead peroxide PbO_2. The lead PB reacts with the sulfated radical SO_4 in the electrolyte H_2SO_4 to form lead sulfate $PbSO_4$. At the same time the oxygen O_2 in the lead peroxide joins with the hydrogen H in the electrolyte to form water H_20.
- Negative plates are made of lead PB. The lead also combines with the sulfated radicals in the electrolyte to form lead sulfate $PbSO_4$.
- In the discharging process, lead sulfate forms on both the positive plates and negative plates making the two plates similar. These deposits account for the loss of cell voltage, because voltage depends on the positive and negative plates being different. As the battery progressively discharges, more lead sulfate is formed at the plates and more water is formed in the electrolyte. Note that although SO_4 radical leaves the electrolyte, it never leaves the battery. Therefore, never add any additional sulfuric acid H_2SO_4 to a battery. The extra SO_4 would only

cause the battery to selfdischarge at a higher than normal rate. Water is the only substance in a battery that must be replaced.

Charging Cycle

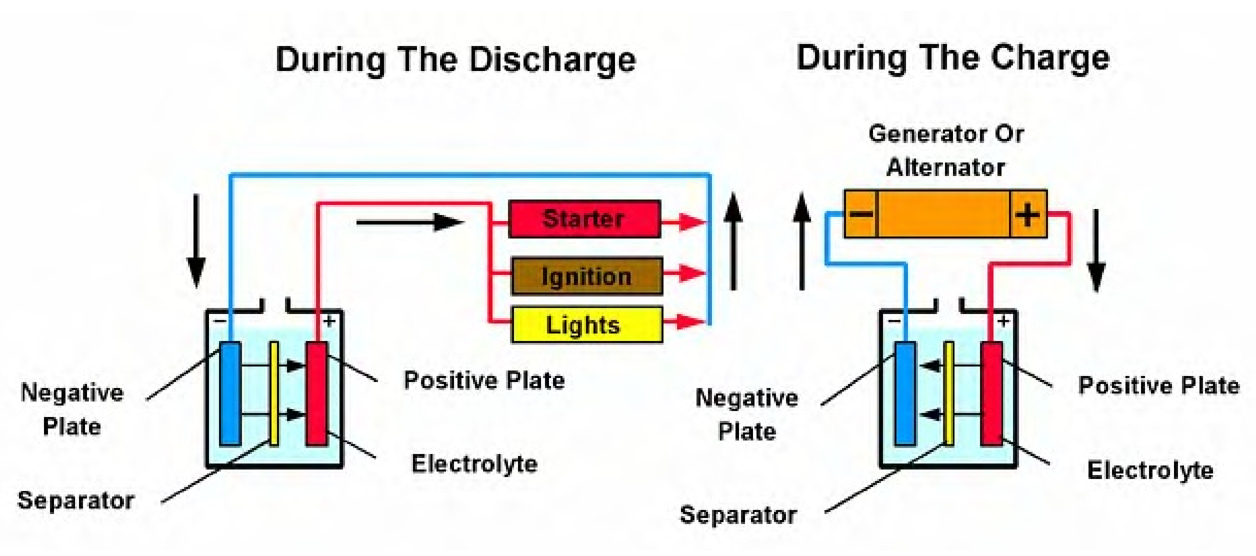

Illustration 7 g01072971

The chemical reactions that take place in the battery cell during the charging cycle (Illustration 7), are essentially the reverse of those which occur during the discharging cycle. The sulfate radical leaves the plates and goes back to the electrolyte. This replenished the strength of the sulfuric acid. Oxygen from the water in the discharged electrolyte joins with the lead at the positive plate to form lead peroxide.

The Battery and the Charging Circuit

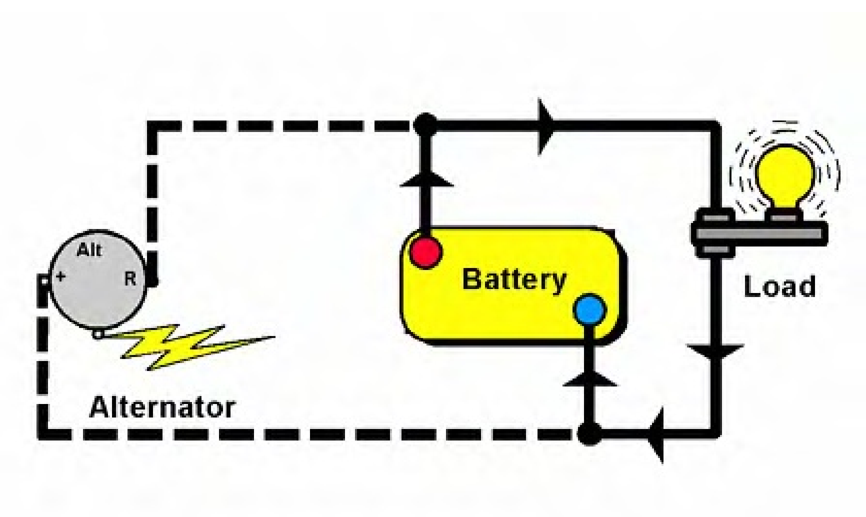

Illustration 8 g01072972

Batteries operate in a charging circuit with an alternator. The battery supplies current to the circuits and the battery becomes discharged. The alternator sends current to the battery in order to recharge it. Operation of the charging circuit varies with the engine speed. When the engine is shut off, the battery alone supplies current to the accessory circuits. At low speeds, both the battery and the alternator may supply current. At higher speeds, the alternator should take over and supply enough current in order to operate the accessories. The alternator will also recharge the battery. The voltage regulator limits the voltage from the alternator to a safe value which does not overcharge the battery at high speeds.

Electrolysis

Illustration 9 g01072977

When an electric current flows through water, the water molecules split into their component parts: hydrogen and oxygen. These two gases bubble to the surface and evaporate into the air. The water level goes down correspondingly. This process is called electrolysis. Electrolysis occurs whenever you charge a battery. When the current flows through an electrolyte, electrolysis takes place and the water level decreases.

Variation in Battery Efficiency or Terminal Voltage

Battery voltage is not constant. A 12 V battery does not deliver 12 V at all times. The main factors which affect the terminal voltage of a battery include temperature and operating cycle.

Temperature

A battery produces current by chemical reactions through sulfuric acid that is acting in the positive plates and the negative plates. At lower temperatures, the chemicals do not react as fast. Therefore, the battery has a lower voltage. Temperature will affect the terminal voltage of the battery. As temperature goes down, the battery becomes less efficient, while the cranking requirements of the engine will increase. At 27 °C (80 °F) a battery is 100 percent efficient. The battery has full cranking power. At -30 °C (-22 °F) a battery is only 30 percent efficient.

Types of Batteries

There are basically two types of batteries that are used in automotive equipment and heavy equipment applications:

- Conventional
- Maintenance free.

Conventional Batteries

Conventional batteries may be dry-charged or wet-charged. A dry-charged battery contains fully charged elements, but the dry-charged battery contains no electrolyte. Once the dry-charged battery is activated by being filled with electrolyte, the dry-charged battery is essentially the same as a wet-charged battery. A dry-charged battery retains a full state of charge as long as moisture is not allowed to enter the cells. If the dry-charged battery is stored in a cool, dry place, the battery will not lose part of the charge on the shelf prior to being used.

The activation of a dry charged battery is usually done at the warehouse where the battery is purchased by the dealer. To make sure the correct electrolyte is used and the battery is properly activated, many manufacturers furnish a packaged electrolyte for their dry charged batteries along with instructions for activation. These instructions must be carefully followed.

Wet-charged batteries contain fully charged elements and are filled with electrolyte at the factory. A wet-charged battery will not maintain a state of charge during storage. A wet-charged battery must be recharged periodically. During storage, even though a battery is not active, a slow reaction takes place between the electrolyte and the plates that causes the battery to lose the charge. This reaction is called self discharge. The rate at which self discharge occurs varies directly with the temperature of the electrolyte.

A fully-charged battery that is stored at a temperature of 38 °C (100 °F) will be completely discharged after a storage period of 90 days. The same battery that is stored at 15 °C (59 °F) will be slightly discharged after 90 days. Wet-charged batteries should be stored in the coolest place possible, without being so cold that the electrolyte freezes.

Note that a wet-charged battery which is kept fully-charged will not freeze unless the temperature goes below -60 °C (-76 °F), whereas a discharged battery with a specific gravity of 1.100 will freeze at -8 °C (17 °F). Wet-charged batteries which are stored for a long period of time without recharging may be permanently damaged by the formulation of hard, dense lead sulfate crystals on the plates. In order to prevent the crystals from forming, wet-charged batteries that are in storage should be brought to full charge every 30 days.

Maintenance-Free Batteries

Illustration 10 g01072981

The maintenance-free battery was developed in an effort to reduce battery maintenance, and to make batteries more dependable and longer lasting. A maintenance-free battery is similar in shape to a conventional battery, but the maintenance-free battery has no filler caps, so the electrolyte is completely sealed inside. Some of these batteries contain a state of charge indicator.

The indicator is a built in hydrometer that has a small green ball. This ball floats when the specific gravity of the electrolyte is 1.225 or higher. The indicator can also be used as a quick, easy way of telling if the battery is charged or discharged. The indicator must be read according to the manufacturer recommendations.

Characteristics of Maintenance-Free Batteries

Since the electrolyte is sealed in, the battery has a lifetime supply. The battery level does not have to be checked. Problems of over filling or under filling the cells are eliminated. Gases are produced during the discharge and the charging process. The gases that rise to the top of the case are trapped by the liquid gas separator. The gases cool and condense, and then the gases drain back into the electrolyte reservoir. Internal pressure that may occur is released through a small vent hole in the flame arrester vent located in the side cover.

Maintenance-free batteries and coventional batteries have plate groups, but the groups are constructed differently. Another difference is that the plates are enclosed in envelopes that act as the separators. These envelopes collect sediment as the plates come apart with age. The envelopes are bonded together. The envelopes permit the element to be placed on the bottom of the case.

In contrast, the element that is in a conventional battery is raised in the case to give room for sediment to collect without touching the plates. Having the element rest on the bottom of the tank allows for more electrolyte to cover the plates. The battery efficiency is improved.

Another important design difference in maintenance-free batteries is the material that is used to construct the grid for each cell plate. In a conventional battery the grid is made from lead antimony. In a maintenance-free battery, the grid is made from lead calcium. It is this difference in grid material that gives the maintenance-free battery the characteristic of not using water. The lead calcium grid significantly reduces the gassing and subsequent loss of water that is compared to a battery with lead antimony plates.

Deep Cycle Battery

A variation of the standard automotive and heavy equipment type lead acid battery is the deep cycle battery. This is also a lead acid battery, but the battery is specially constructed for use in applications that may not incorporate a charging system to support the electrical system and keep the battery charged.

A deep cycle battery is also used in applications where the battery is used to operate electrical systems when the engine is not running, such as in a motor home.

The deep cycle battery has a denser active material and thicker plates. This helps keep the active material in the grid during repeated deep discharge and recharge cycles. Glass separators may be used to reinforce the plates, reduce vibration damage, or shedding of the active material from the grid. The deep cycle battery can be discharged fully and recharged many times without harm. A standard automotive and heavy equipment battery would soon break down under these deep cycle conditions.

Battery Ratings

The following factors influence battery capacity (the amount of current a battery can produce):

- The number, size and thickness of the plates.
- The quality and strength of the electrolyte.

Batteries used the ampere hour rating method for many years until new capacity ratings for batteries were adopted in 1971 by the Society of Automotive Engineers (SAE) and the Battery Council International (BCI).

Three current methods that are used for rating automobile size batteries are cold cranking performance, cranking performance and reserve capacity.

Cold Cranking Performance

The basic job of a battery is to start an engine. This involves a high discharge rate in amperes for a short period of time. It is more difficult for a battery to deliver power when the battery is cold. The engine requires more power to turn over when the engine is cold. The following definition is for the cold cranking rating:

- The discharge load in amperes which a new, fully charged battery at -18 °C (-0 °F) can continuously deliver for 30 seconds and maintain a voltage of 1.2 volts per cell.

Many low cost batteries can deliver only 200 amps, while more powerful batteries will deliver up to 1000 amps under the same conditions. The cold cranking performance of the battery must match the power requirements of the engine it has to start. If an engine under cold conditions required 400 amps to start, obviously the cheaper battery delivering only 200 amps would be inadequate.

Cranking Performance

Cranking performance at 0 °C (32 °F), is a new rating recently recognized by BCI. Cranking performance is the discharge load in amperes which a new, fully charged battery at 0 °C (32 °F) can continuously deliver for 30 seconds and maintain a voltage of 1.2 volts per cell.

Reserve Capacity

Reserve capacity is defined as the ability of a battery to sustain a minimum machine electrical load in the event of a charging system failure. It is also a comparative measure of the battery's ability to provide power for machines that have small parasitic electrical loads for long periods of time, and still have enough capacity to crank the engine. The reserve capacity rating is defined below:

- The number of minutes which a new, fully-charged battery at 26.7 °C (80 °F) can be continuously discharged at 25 amperes and maintain a terminal voltage equal to or greater than 1.75 volts per cell.

Battery Use and Replacement

Be sure to replace the battery with another battery that is equal in capacity to the original. A smaller battery, although it may initially seem to be adequate, will eventually fail as a result of excessive cycling which shortens battery life. A larger battery than the original may be needed if accessories such as an air conditioning unit are added to the vehicle's electrical circuit.

A high output alternator may be needed in cases where electrical loads are excessive. This high output alternator will help keep the battery charged and will increase the battery service life.

Battery Charging

Illustration 11 g01072982

When a battery is in use the battery will alternate between fully-charged and fully-discharged. When you test a battery and determine that the battery requires charging, you will have to decide how the battery is to be recharged.

Battery Chargers

While an engine is running, the battery charge is maintained by the charging system. Occasionally, the battery charge may wear down. If not attended to, the battery will not have enough power to start the engine. When a battery's state of charge is low, the battery should be recharged. Recharging can be done on the battery, while the battery is in the vehicle or after the battery has been removed. There are a number of different battery chargers.

Constant Current Chargers

A constant current charger supplies a constant or a set amount of current to the battery. The recommended charging rate is 1 amp per positive battery plate per cell. For example, if a battery has five positive plates per cell, the battery should be charged at 5 amps. Most batteries which are slow charged with a constant current charger will take 5 to 6 amps.

Constant Voltage Chargers

A constant voltage charger supplies the battery with a constant voltage during the charging period, for example, 15 volts for a 12 volt battery. This charger will charge the battery at a fairly high amperage when the battery is low. As the battery builds up charge, the amperage tapers off almost to nothing as the battery becomes fully-charged. Constant voltage chargers are much more common than constant current chargers.

Charging Conventional Batteries

Time is usually the main factor when you decide whether to fast charge or to slow charge a battery. Obviously, it is better to slow charge a battery, because you get a more thorough charging job. However, you do not always have the time (24 to 48 hours) to do a slow charge and in such cases fast charges must be done.

Constant Current Slow Chargers

A slow charger can be either constant current or constant voltage (constant voltage is more common). The maximum amount of voltage that a charger will produce is printed on the charger. For example, a 60 volt charger could be used for five 12 volt batteries (total 60 volts) or ten 6 volt batteries (total 60 volts).

The term slow charging refers to a charge rate of 10 Amps or less. When there are a number of batteries of different sizes on the charger, average out the charge rate. On some of the new chargers, you do not have to bother counting or averaging out the new positive plates. These chargers have a yellow, green and red band on the charge rate indicator, and it is recommended the control be set in the green range.

To connect a constant current charger, start with the black lead (negative) from the charger and connect the lead to the positive post of the last battery. Using good jumpers, connect the batteries, positive to negative to complete the series circuit.

Recheck all the connections by turning the connections slightly on the posts. Finally, turn the charger on and adjust the charger to the correct charge rate.

The state of charge of a battery that is being charged should be checked with a hydrometer twice a day, when possible. The total charging time will vary depending on the strength of the charge. At the end of 48 hours batteries should be fully-charged. If a battery becomes fully-charged and the specific gravity is 1.275 or over before 48 hours are up, remove it.

Constant Voltage Slow Chargers

Constant voltage chargers are connected to the batteries in parallel. The maximum number of batteries a charger can handle will be marked on the charger.

The voltage control is set at a specified voltage, such as 15 volts for a 12 volt battery. The charge rate is automatically sensed by the charger. The charge rate will be high when the discharged battery is first connected to the charger. The charge rate will gradually taper off as the battery becomes fully charged. When connecting batteries in parallel to a constant voltage charger, start with the black lead (negative) from the charger and connect it to the negative (-) post of the first battery. Using good jumper cables, connect the batteries negative to negative and positive to positive.

As with a constant current charger, check the specific gravity of the charging batteries twice a day and remove the batteries when they are fully charged.

Fast Chargers

Fast chargers will give a battery a high charge for a short period of time, usually no more than one hour. Fast chargers are portable in contrast to slow chargers. Slow chargers are usually mounted to a wall or sit in a permanent position on a bench. Portable fast chargers can charge a battery while the battery is still in the machine. Generally, only one battery at a time is charged on a fast charger. Many modern fast chargers also have a capacity to slow charge a battery.

Precautions When Fast Charging

Whenever a battery is charged, especially fast charged, never allow the electrolyte to exceed 51 °C (123 °F).

Watch the color of the electrolyte when you are fast charging batteries. As a battery, ages the electrolyte will become discolored by sediment. During a fast charge the sediment is stirred up. The sediment can get trapped between the plates. This can cause a short. Check the color of the electrolyte during charging with the hydrometer. If sediment begins to appear, reduce the charging rate.

Correct Battery Charging Practice

Before you connect conventional batteries to a charger make sure that the battery tops are clean and the electrolyte is up to the correct level.

All chargers need 110 V alternating current supply.

Always make sure that the charger is turned OFF before you connect the charger to a battery.

When you connect any charger, observe the correct polarity. Always be sure to connect negative to negative and positive to positive. Most chargers are polarity protected.

Check the charger voltage settings before you turn the charger ON. On a constant voltage slow charger, set the voltage to match the number of volts in the batteries that you are charging. On a constant current charger, set the voltage for 6 or 12 V depending on which battery you are charging.

Charging Time

When you are slow charging a battery, do a specific gravity check twice a day to see if the battery is fully charged. Do not continue to charge a battery if tests indicate that the battery has reached full charge. Set the fast charge time for no longer than one hour. Watch the battery to make sure that the battery does not overheat.

Always turn the charger off before you disconnect the charger in order to prevent any sparks from accidentally igniting explosive hydrogen gases that are given off during charging. Never charge a battery in a place where there may be any chance of sparks, such as in an area where welding or grinding is done.

Charging Maintenance-Free Batteries

Maintenance-free batteries are charged by using conventional battery charging equipment. The fast and slow charging rates for maintenance-free batteries are lower and the times of charging are proportionately longer.

Jump Starting

Illustration 12 g01072983

When a charger is not available, a common practice to start a vehicle with a dead battery, is to use jumper cables and a battery pack. Before you connect jumper cables, be sure all the electrical accessories such as lights, radio and wipers are OFF.

Observe battery voltage when you are jump starting a vehicle. Jump a 6 volt battery with a second 6 volt battery or jump a 12 volt battery with a second 12 volt battery. This is important because of the danger of arcing when you connect the jumper cables which could cause a battery to explode.

On heavy duty starting systems that use two 12 volt batteries in series to provide 24 volts for cranking, special precautions must be observed to prevent damage to the electrical components while you are jump starting. Check the Service Manual recommendations before you attempt to jump start any machine with this battery. You will require two sets of jumper cables and two 12 volt batteries.

Identify polarity before you connect jumper cables. Connect the jumper cables negative to negative and positive to positive (since you are just replacing the existing power source).

Connect the jumper cables in the following order:

1. Connect one cable clamp to the positive terminal of the dead battery.

2. Connect the other end to the positive terminal of the booster battery.

3. Connect the second clamp to the negative terminal of the booster battery.

4. Then, connect the other end to the engine block of the vehicle with the dead battery.

When you remove the cables, reverse the procedure for connecting the cables. Keep the clamps separated until the cables are disconnected from the source in order to prevent arcing.

Battery Maintenance

The battery is the heart of the electrical system. No accurate tests can be performed on any part of the electrical system unless the battery is properly serviced and fully charged.

Battery Testing

In order to determine what is wrong with a battery, you have to test it. Preform the following tests on batteries:

- Specific gravity (chemical test)
- Load test

Specific Gravity Test Conventional Battery

Specific gravity is the weight of a liquid that is compared to water. When you perform a specific gravity test on a battery you are determining the state of charge in the battery that is based on the percentage of acid to water in the electrolyte. The strength of the electrolyte varies directly with the state of charge of each cell. The higher the specific gravity, the greater the capability of the battery to produce an electrical potential. Specific gravity tests are done by using a hydrometer.

Hydrometer

Illustration 13 g01072984

Hydrometers are calibrated in order to measure specific gravity correctly at an electrolyte temperature of 27 °C (80 °F). To determine a corrected specific gravity reading when the temperature of the electrolyte is other than 27 °C (80 °F): Add to the hydrometer reading four gravity points (0.004) for each 5.5 °C (41 °F) above 27 °C (80 °F). Subtract four gravity points (0.004) for each 5.5 °C (41 °F) below 27 °C (80 °F). This compensates for expansion and contraction of the electrolyte above or below the standard.

The specific gravity of each battery cell should be tested by using the hydrometer. If water has been recently added to a battery, a hydrometer will not give an accurate reading of the battery's state of charge. Charge the battery long enough to ensure complete mixing of the water and electrolyte. Then check the battery cells with the hydrometer.

Fully charged specific gravity varies in different types of batteries. Typical readings are as follows:

Table 1

State of charge	Specific Gravity
100%	1.280
75%	1.250
50%	1.220
25%	1.190
0%	1.130

The electrolyte should be clear. A cloudy brown color indicates that plate material is shedding and that the battery is failing.

When the specific gravity reading is below 1.250, the battery may be in satisfactory condition but the state of charge is low. Charge the battery before making further tests.

When the specific gravity reading is above 1.280, the battery may be in satisfactory condition but the battery is above full charge. In use, the specific gravity should return quickly to the normal range. Make further tests in order to determine the battery's condition.

The amount of variation in the specific gravities of the cells should be within 30 to 50 points (0.030 to 0.050). If cell variation exceeds this amount, an unsatisfactory condition is indicated. This may be due to unequal consumption of electrolyte in the cells that are caused by an internal defect, short circuit, improper activation, or deterioration from extended use. The battery should normally be replaced, however, a battery should not be condemned based on specific gravity readings alone. Further testing should be done.

Specific Gravity Test Maintenance Free Battery

Look at the state of charge indicator (if equipped) that is on the battery in order to decide whether the battery needs charging before testing.

Green dot visible

If the green dot on the battery's state of charge indicator is visible, the battery charge and fluid level are within range. On some occasions, after prolonged cranking, the green dot may still be visible, but the battery will not have sufficient cranking power. Should this occur, charge the battery.

Green dot not visible

Charge the battery according to the manufacturer's specifications.

Yellow indicator

On some occasions, the test indicator may turn light yellow which indicates a low electrolyte level. In this instance the battery should not be tested, charged or jump started because, there is a very real possibility that the battery may explode.

Using a digital voltmeter, check battery voltage at the battery terminals. If the battery voltage is below 12.0 volts, charge the battery.

Use a battery load tester to remove the battery surface charge. Adjust the load tester to 50 percent of the battery's cold cranking amps (CCA) for five seconds. Allow the battery to rest for 5 minutes before testing.

Check the battery voltage at the battery terminals. Voltage must be over 12.4 V (which indicates at least 75% charge) before a load test can be performed. If the voltage is under 12.4 V (which indicates below 75% charged), charge the battery and test it again.

Battery Load Test

Illustration 14 g01079627

A load test gives the best indication of a battery's condition. If the state of charge is 75% or better, a load test (capacity test) can be done on the battery. If, however, that state of charge is below 75%, you should charge the battery.

Typical load test procedures:

1. Connect the tester's ammeter and voltmeter leads to the appropriate post on the battery. The load control knob must be in the Off position.

2. Turn the control knob clockwise until the ammeter reading is one-half the cold cranking rate of the battery or as specified by the battery manufacturer.

3. Maintain the load for 15 seconds, then note the voltmeter reading and turn the control knob back to OFF position.

If the voltmeter reading is within the green band, 9.6 volts for a 12 volt battery or 4.8 V for a 6 V battery or is higher, the battery has good output capacity. However, although the battery may pass the load test, it may still require some charging to bring it back up to peak performance.

When cold, a battery has a lower discharge capacity. If a cold battery fails to pass the capacity test, let it stand until 27 °C (80 °F), then retest.

Open circuit voltage test

The open circuit voltage test can be used on maintenance free batteries to indicate state of charge if the battery does not have a state of charge indicator. To perform this test the battery must not have been heavily discharged or charged recently.

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Charging System

SMCS - 1400

Introduction to the Charging System

The charging system converts mechanical energy from the engine into electrical energy in order to charge the battery. The charging system supplies current in order to operate the electrical systems of the machine.

AC and DC Charging Circuits

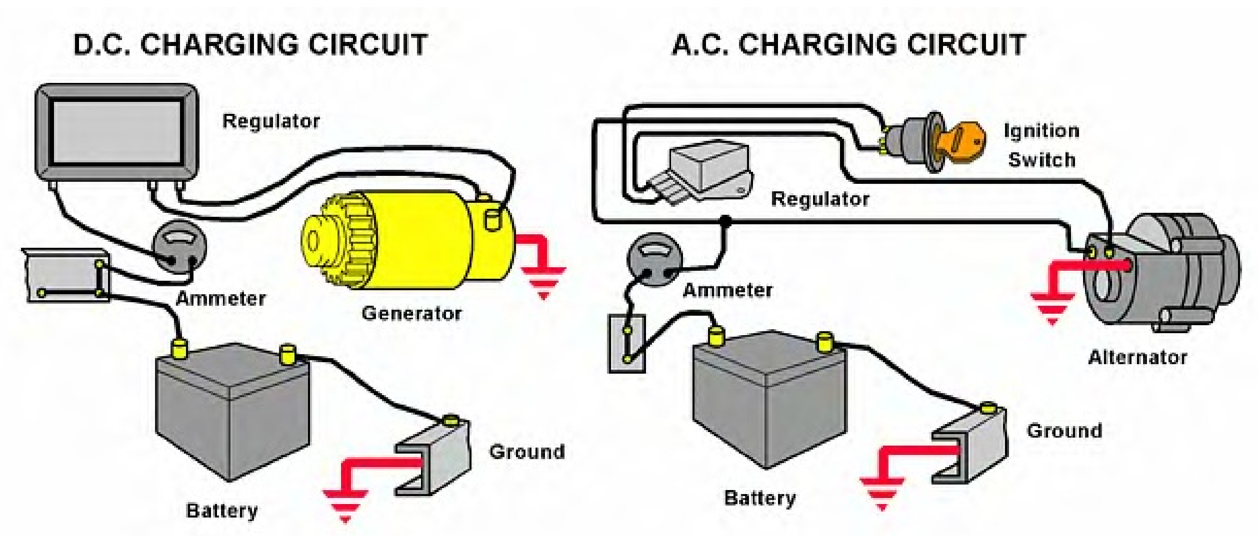

Illustration 1 g01073297

The charging system recharges the battery and generates current during operation. There are two kinds of charging circuits:

- DC charging circuits that use generators.

- AC charging circuits that use alternators.

Both circuits generate an alternating current (AC). The difference in the circuits are in the way the circuits rectify the AC current to direct current (DC). DC charging circuits have a generator and a regulator.

The generator supplies the electrical power. The generator rectifies the current mechanically by using commutators and brushes.

The regulator has three functions:

- The regulator opens the charging circuit. The regulator closes the charging circuit.
- The regulator prevents the battery from overcharging.
- The regulator limits the generators output to safe rates.

AC charging circuits include an alternator and a regulator. The alternator is really an AC generator. The alternator produces AC current, like the generator, but rectifies the current by using diodes. Alternators are generally more compact than generators of equal output. Alternators supply a higher current at low engine speeds.

The regulator in AC charging circuits limits the alternator voltage to a safe preset level. Transistorized models are used in many of the modern charging circuits.

Charging Circuit Operation

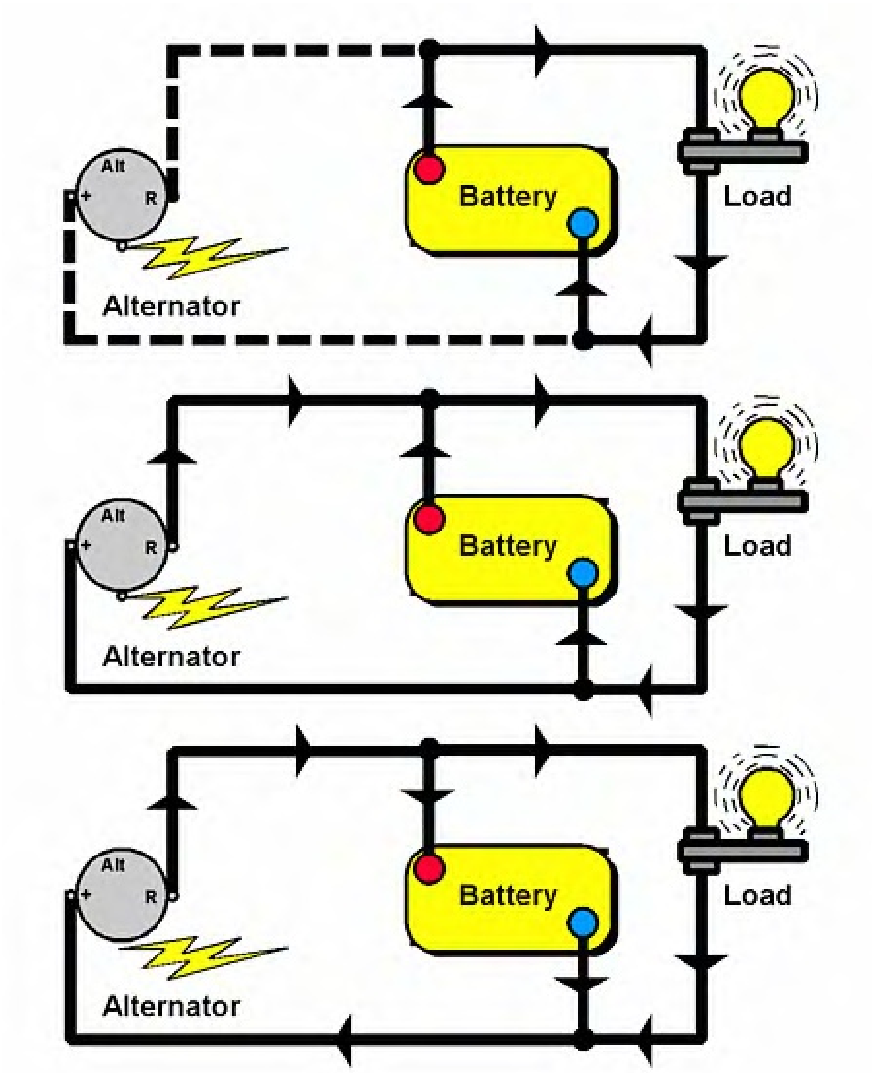

Illustration 2 g01073299

Charging circuits operate in three stages:

- During starting, the battery supplies all the load current
- During peak operation, the battery helps the generator (or alternator) supply current
- During normal operation, the generator (or alternator) supplies all current and recharges the battery

In both charging circuits, the battery starts the circuit when the battery supplies current to the starting motor in order to start the engine (Illustration 2, top diagram). The engine then drives the generator (or alternator). This produces current to take over the operation of the ignition, lights, and accessory loads in the whole system.

The center diagram (Illustration 2) shows that the battery supplies current during peak operation when the electrical loads are too high for the generator (or alternator).

Once the engine is started, the generator (or alternator) provides the current to the machine electrical systems (Illustration 2, bottom diagram). The generator supplies current as long as the engine is running above the idle speed. When the engine is at idle or stops, the battery takes over part or all of the load. However, an alternator will continue to supply current during engine idling.

Generators

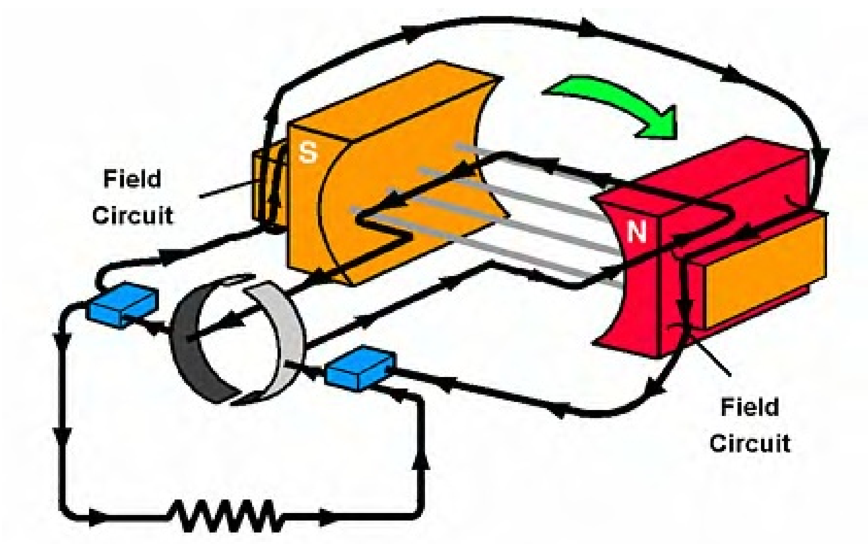

Illustration 3 g01073301

Generators in DC charging circuits will be covered briefly. The generator is still found on some older machines. To service this equipment, you should have a working knowledge of how the charging system functions. The majority of this lesson will focus on AC charging circuits, which have replaced DC charging circuits in the late model machines.

The generator produces electrical energy by using electromagnetic induction. Electromagnetic induction is used to generate electricity in the charging system. Electromagnetic induction occurs when there is relative movement between a conductor and a magnetic field. As the conductor cuts through the field a voltage is induced in the conductor. This voltage causes current flow when the conductor is connected to a circuit. The amount of output depends on the strength of the magnetic field, the speed at which the magnetic field is cut, and the number of conductors cutting the field.

The basic generator has two components:

Armature - a rotating wire loop (conductor)

Magnetic poles - stationary magnetic field

As the armature rotates through the magnetic field of the poles, voltage is generated. The ends of the armature loop are connected to a split ring that is called a commutator. Brushes contact the commutator and wires connect the brushes to a load. Current will flow since the circuit is complete. To ensure a strong current and proper flow, wires are wound around the magnetic poles and the wires are attached to the brushes. The wiring is called the field circuit of the generator.

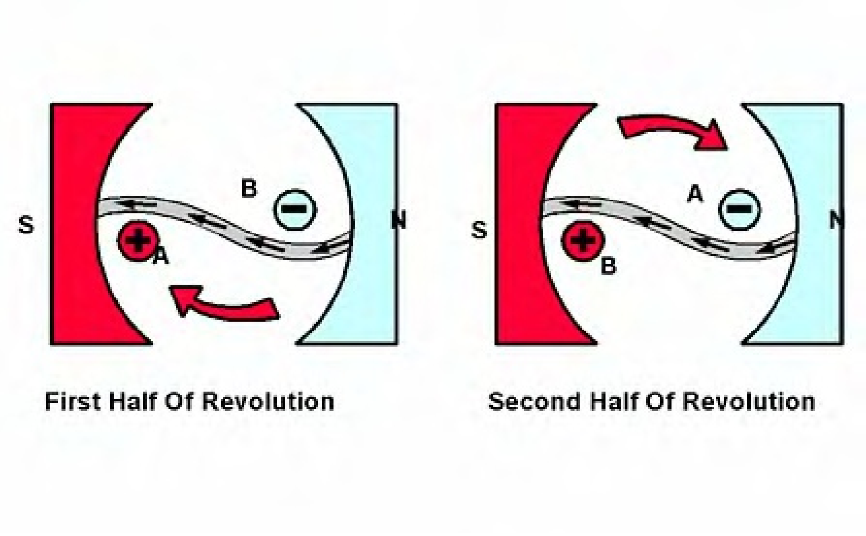

Illustration 4 g01073303

The basic generator produces an alternating current when the armature rotates. The armature reverses the polarity of the current on each side of the loop.

During the first half of the revolution, the top of the armature side (A) cuts through the magnetic field first, while the bottom of side (B) is first to cut through the field. Current flows toward side (A) and away from side (B). The conventional theory (+ to -) gives the polarities shown (+) for (A) and (-) for (B) .

During the second half of the revolution, the top of side (B) is the leading edge, while the bottom of side (A) is leading. Now (B) is (+) while (A) is (-). The armature loop ends reverse polarity during each revolution. The result is alternating current.

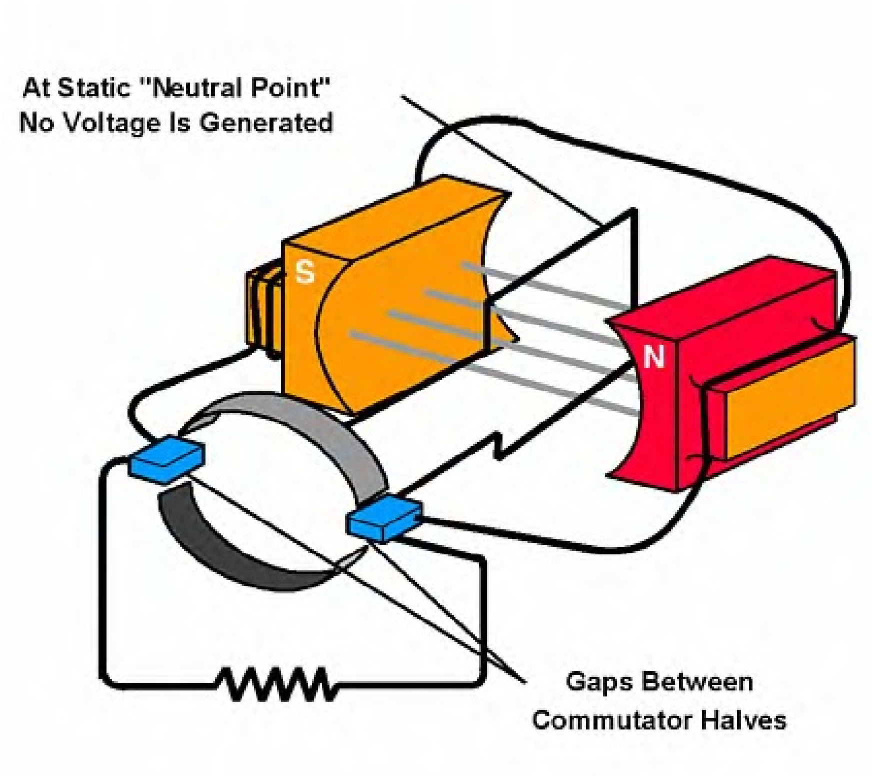

Illustration 5 g01073305

The commutator and brushes allow the AC current to flow to the load in the same direction. Twice during each rotation, the armature is vertical to the magnetic field. The armature loop is not passing through the field and no voltage is generated at this point. This is the static neutral point.

The commutator is split into two parts with the open areas matching the neutral point of the armature. This means that there is an air gap as the commutator passes the brushes. The other half of the commutator contacts the brushes past this point. Since the coil is in the same relative position as during the preceding one half revolution, current flow to the brush stays in the same direction. This results in direct current.

Illustration 6 g01073307

Direct current systems will automatically provide more field current as generator output increases. This increase in field current will result in an increase in generator output. If the current is left unregulated, the continuous increase will result in current and voltage levels that will destroy the generator, other electrical circuits, and the battery.

The generator cannot control the amount of voltage that is produced. Therefore, an external unit that is called a voltage regulator is used in the field circuit. A voltage regulator has a shunt coil and contact points to control the strength of the magnetic field. The result is limiting the voltage that is generated.

Alternator

An alternator operates on the same principle as a generator. An alternator converts mechanical energy into electrical energy. The alternator could be called an AC generator. The difference between the generator and alternator is the way the alternator rectifies AC current to DC current. The alternator rectifies current electronically by using diodes.

Alternators are generally more compact than generators. Alternators can supply a higher current at low engine speeds. Since late model machines include many electrical accessories, the alternator can best supply the current output for the increased electrical loads.

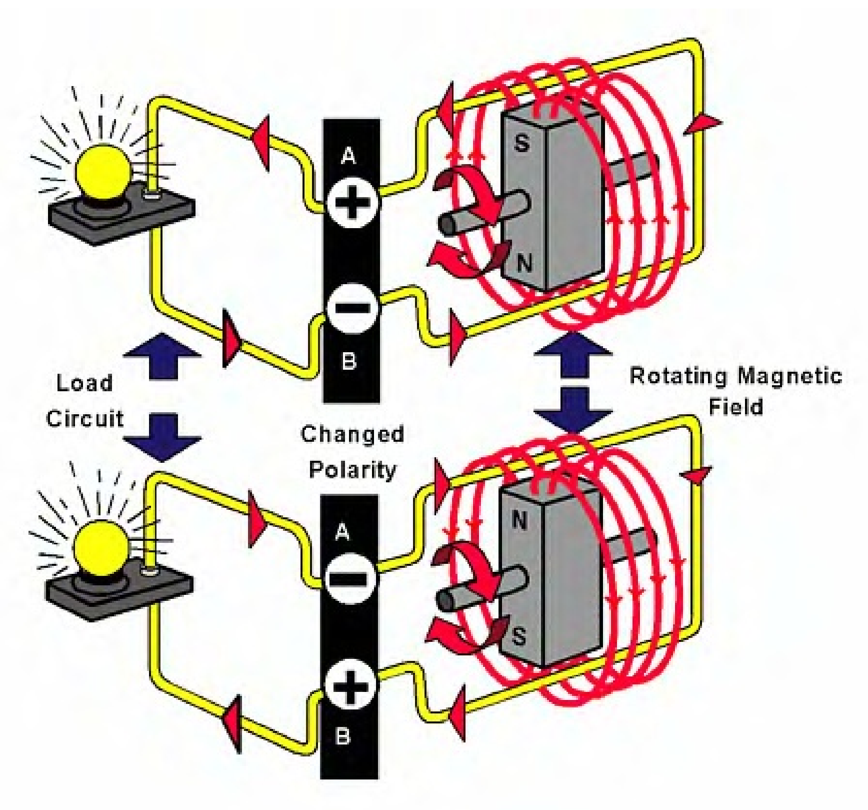

Illustration 7 g01073308

In the alternator, the magnetic field rotates inside the wire loop. This rotating magnetic field is generated by a rotor. The wire loop, which is stationary, is the conductor.

Magnetic lines of force move across the conductors. Magnetic lines induce current flow in the lines. Since the conductors are stationary, the conductors can be directly connected instead of using brushes. This reduces heat and wear.

Voltage will be induced in a conductor when a magnetic field is moved across the conductor. For example, consider a bar magnet with the magnetic field rotating inside a loop of wire. When the magnet is rotating, and with the (S) pole of the magnet is directly under the top portion of the loop and the (N) pole is directly over the bottom portion, the induced voltage will cause current to flow in the circuit in the direction shown. Since current flows from positive to negative through the external or load circuit, the end of the loop of wire that is marked (A) will be positive polarity and the end that is marked (B) will be negative polarity.

After the bar magnet has moved through one half revolution, the (N) pole will have moved directly under the top conductor and the (S) pole will have moved directly over the bottom conductor. The induced voltage will now cause current to flow in the opposite direction. The end of the loop wire that is marked (A) will become negative polarity, and the end that is marked (B) will become positive polarity. The polarity of the ends of the wire has changed. After a second one half revolution, the bar magnet will be back at the starting point where (A) is positive and (B) is negative.

Consequently, current will flow through the load or through the external circuit first in one direction and then in the other direction. This is an alternating current, which is developed internally by an alternator.

How Voltage is Induced

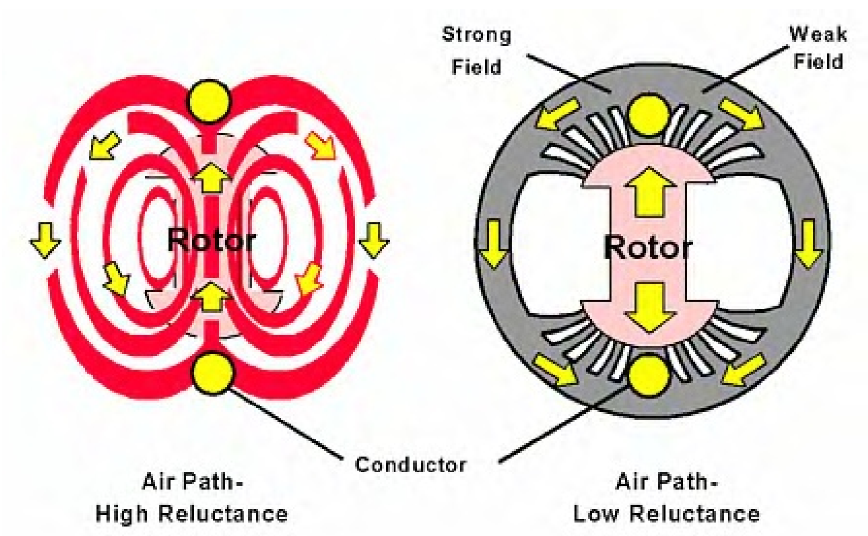

Illustration 8 g01073309

Very little voltage and current are produced with a bar magnet that is rotating inside a single loop of wire. When the loop of wire and the magnet are placed inside an iron frame, a conducting path for the magnetic lines of force is created. Since iron conducts magnetism very easily, adding the iron frame greatly increases the number of lines of force between the (N) pole and the (S) pole.

A large number of magnetic lines of force are at the center of the tip of the magnet. Therefore, a strong magnetic field exists at the center of the magnet and a weak magnetic field exists at the leading and trailing edges. This condition results when the air gap between the magnet and field frame is greater at the leading and trailing edges than at the center of the magnet.

The amount of voltage that is induced in a conductor is proportional to the number of lines of force which cut across the conductor in a given length of time. The voltage will also increase if the bar magnet turns faster because the lines of force cut across the wire in a shorter time period.

The rotating magnet in an alternator is called the rotor and the loop of wire and frame assembly is called the stator.

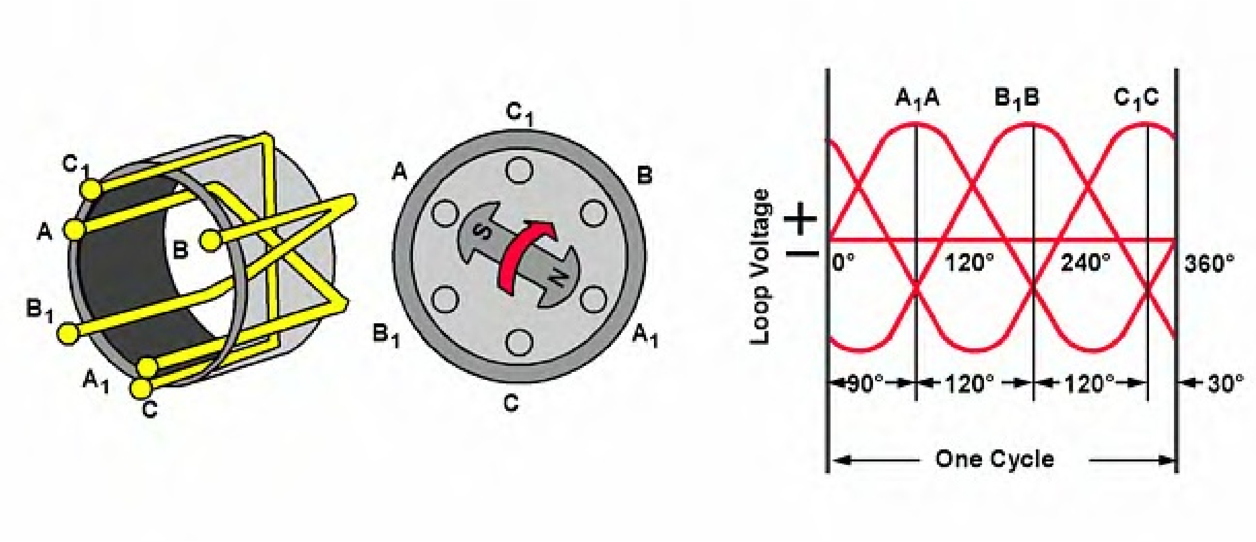

Illustration 9 g01073310

In Illustration 9 the single loop of wire acting as a stator winding and the bar magnet acting as a rotor illustrate how an AC voltage is produced in a basic alternator. When two more separate loops of wire, spaced 120 degrees apart, are added to the basic alternator, two more separate voltages will be produced.

When the (S) pole of the rotor is directly under the (A) conductor, the voltage at (A) will be maximum in magnitude and positive in polarity.

After the rotor has turned through 120 degrees, the (S) pole will be directly under the (B) conductor and the voltage at (B) will be maximum positive. Also 120 degrees later, the voltage at (C) will be maximum positive. The peak positive voltages at (A) , (B), (C) in each loop of wire occur 120 degrees apart. These loop voltages are also shown in Illustration 9.

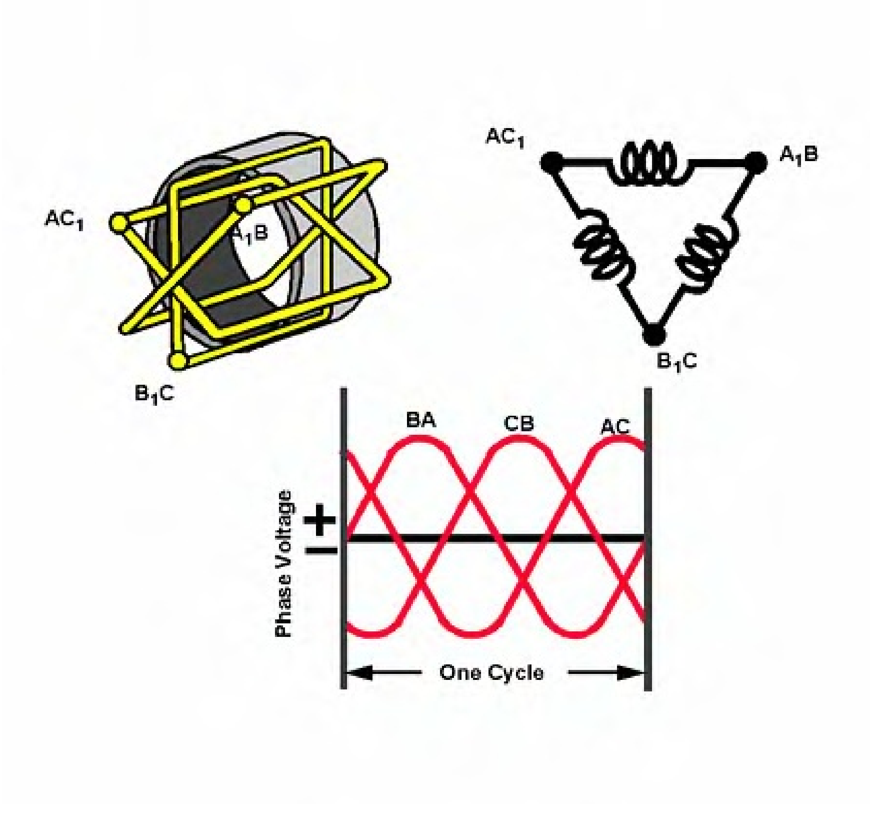

Illustration 10 g01073311

When the ends of the loops of wire marked (A1), (B1) and (C1) are connected to the ends marked (B), (C), and (A) respectively, a basic three-phase delta wound stator is formed (Illustration 10). The three AC voltages ((BA), (CB) and (AC)) available from the delta wound stator are identical to the three voltages previously discussed.

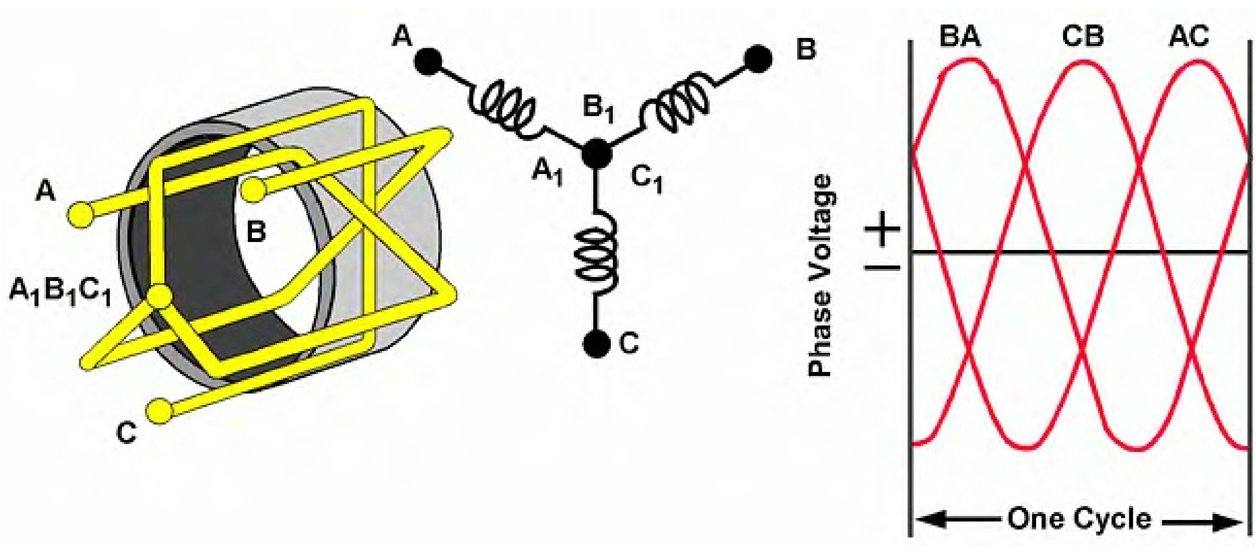

Illustration 11 g01073312

When the ends of the loops of wire marked (A1), (B1) and (C1) are connected together, a basic three-phase Y wound stator is formed (Illustration 11). Each of these voltages consist of the voltages in two loops of wire that are added together. Three AC voltages that are spaced 120 degrees apart are available from the Y stator.

In delta windings, each of the individual windings is connected to the end of another winding (Illustration 10). This creates parallel connections in the delta stator, which generally allows for higher current output than the Y wound stator. In the Y wound stator the windings are connected in order to form pairs of series connections (Illustration 11). The series connections generally provide higher voltages but lower current output than the delta wound stators.

The following modifications are used to increase the output of the alternator:

- Increase the number of conductors in each of the phase windings.
- Increase the strength of the magnetic fields.
- Increase the speed of rotation.
- Magnetic field generation

Current Rectification Using Y or Delta Wound Stators

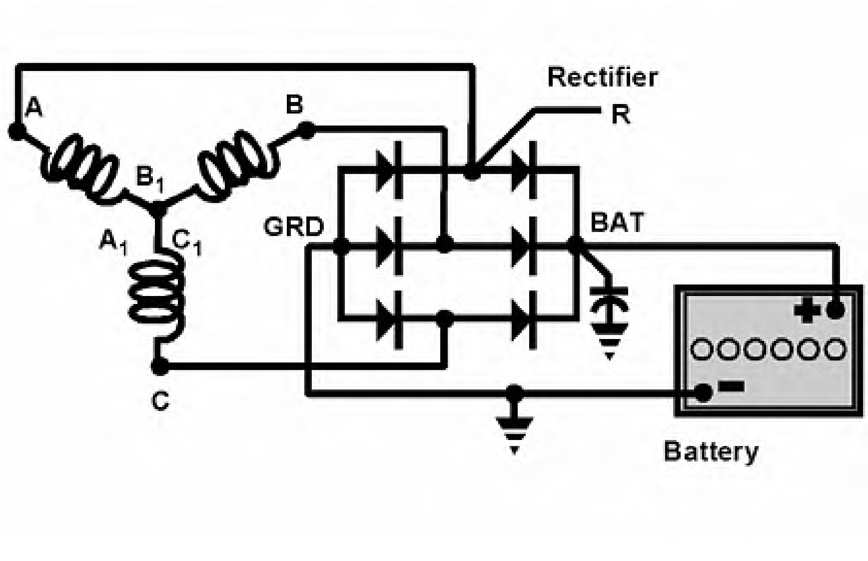

Illustration 12 g01073314

Even though the alternator seems complete, the current that is being generated from the alternator is still alternating. The electrical system requires direct current. In order for the output of the alternator to be of any value, the alternator must be converted from AC to DC.

The ideal device for this task is the diode. The diode is compact. The diode will conduct current in one direction only. The diode can be easily installed in the alternator housing.

Diodes are normally used in the alternator in two groups of three. Since there are three phases or windings in the alternator, three positive diodes and three negative diodes are required. In systems that require higher output, more diodes may be required.

A battery that is connected to the DC output terminal will have the energy restored as the alternator provides charging current. The blocking action of the diodes prevents the battery from discharging directly through the rectifier.

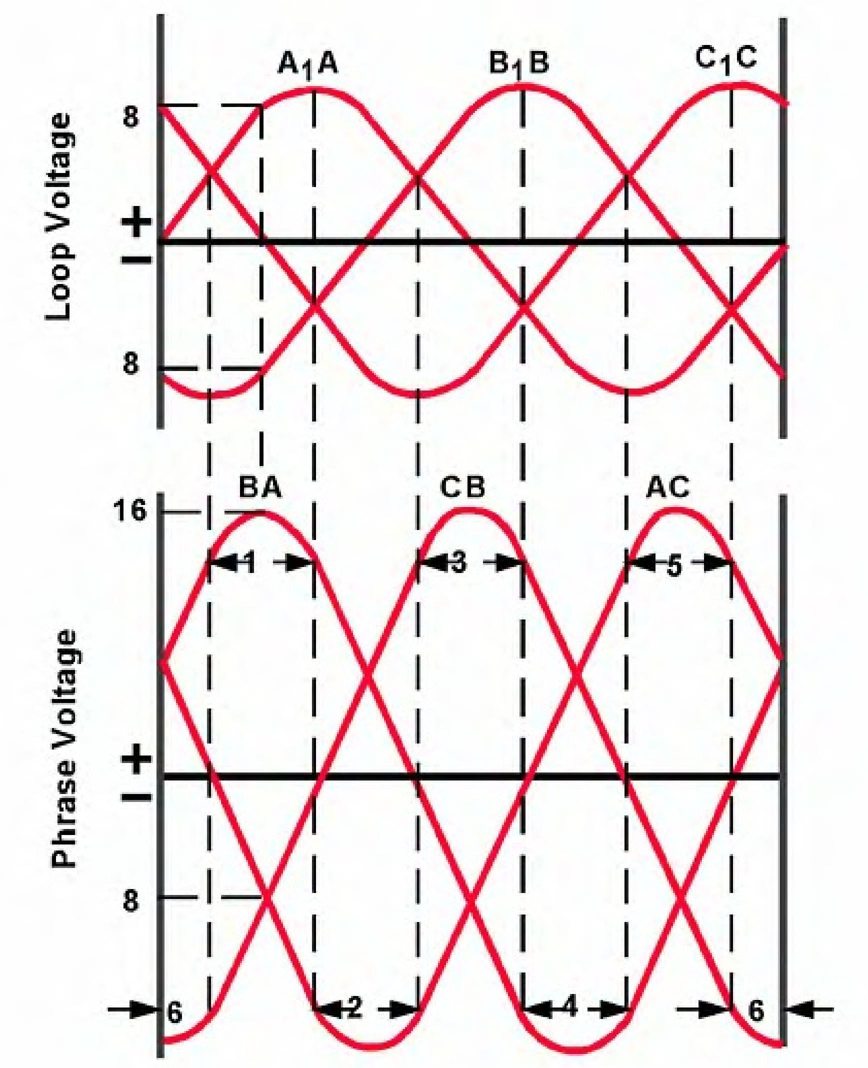

Illustration 13 g01073316

The three AC voltage curves that are provided by the Y type stator have been divided into six periods. These periods are shown in Illustration 13. Each period represents one sixth of a rotor revolution, or 60 degrees.

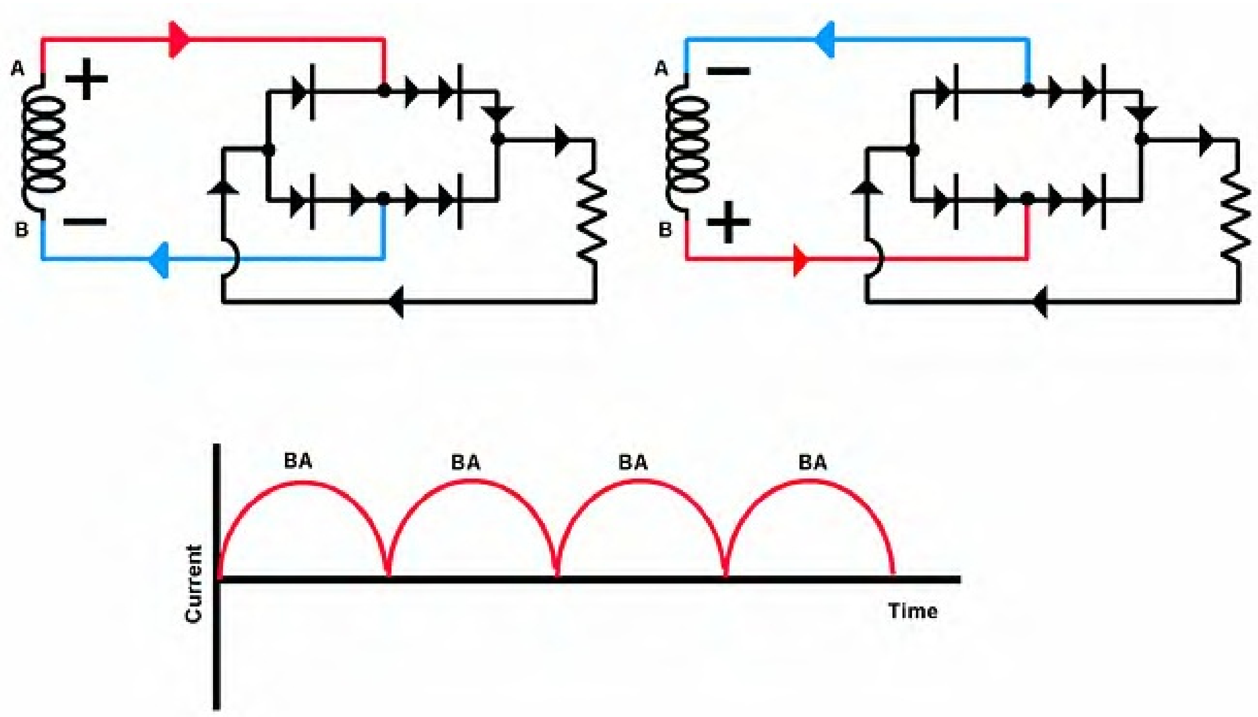

Illustration 14 g01073318

During period 1, the maximum voltage that is being induced appears across stator terminals (BA). This means the current flows from (B) to (A) in the stator winding during this period, and through the diodes as illustrated in Illustration 14.

The peak phase voltage that is developed from (B) to (A) is 16 volts. This means that the potential at (B) is 0 volts and the potential at (A) is 16 volts. From the voltage curves, the phase voltage from (C) to (B) at this instant is negative 8 volts. This means that the potential at (C) is 8 volts, since (C) to (B), or 8 to zero, represents a negative 8 volts. At this same time, the phase voltage from (A) to C is also negative 8 volts since (A) to (C), or 16 to 8, represents a negative 8 volts. The voltage potentials are shown in Illustration 13.

Only two of the diodes will conduct current, since these are the only diodes in which current can flow in the forward direction. The other diodes will not conduct current because these are reverse biased. The voltages that exist at the rectifier and the biasing of the diodes determine the current flow directions. These voltages are represented by the phase voltage curves in Illustration 13, which are the voltages that actually appear at the rectifier diodes. Following the same procedure for periods 2 through 6, the current flows can be determined.

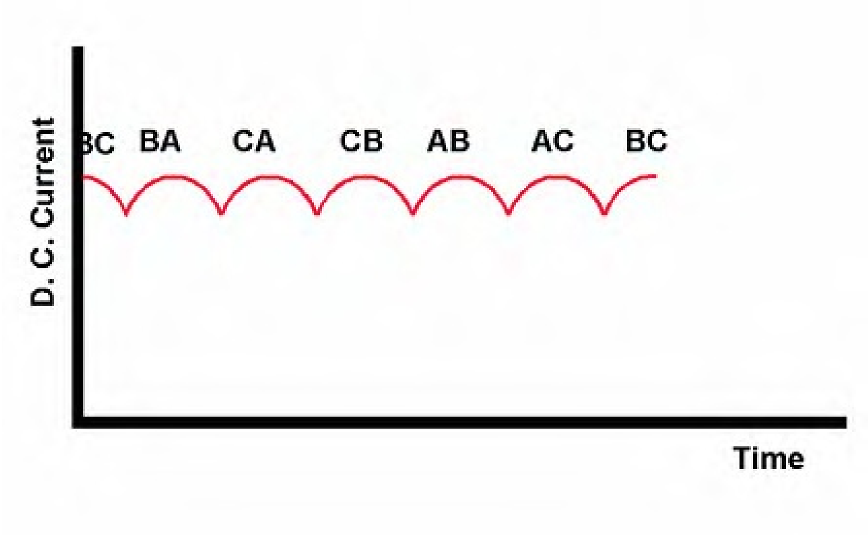

Illustration 15 g01073321

The voltage that is obtained from the stator-rectifier combination when connected to a battery is not perfectly flat, but is so smooth that the output may be considered to be a nonvarying DC voltage. Illustration 15 shows the voltage that is obtained from the phase voltage curves.

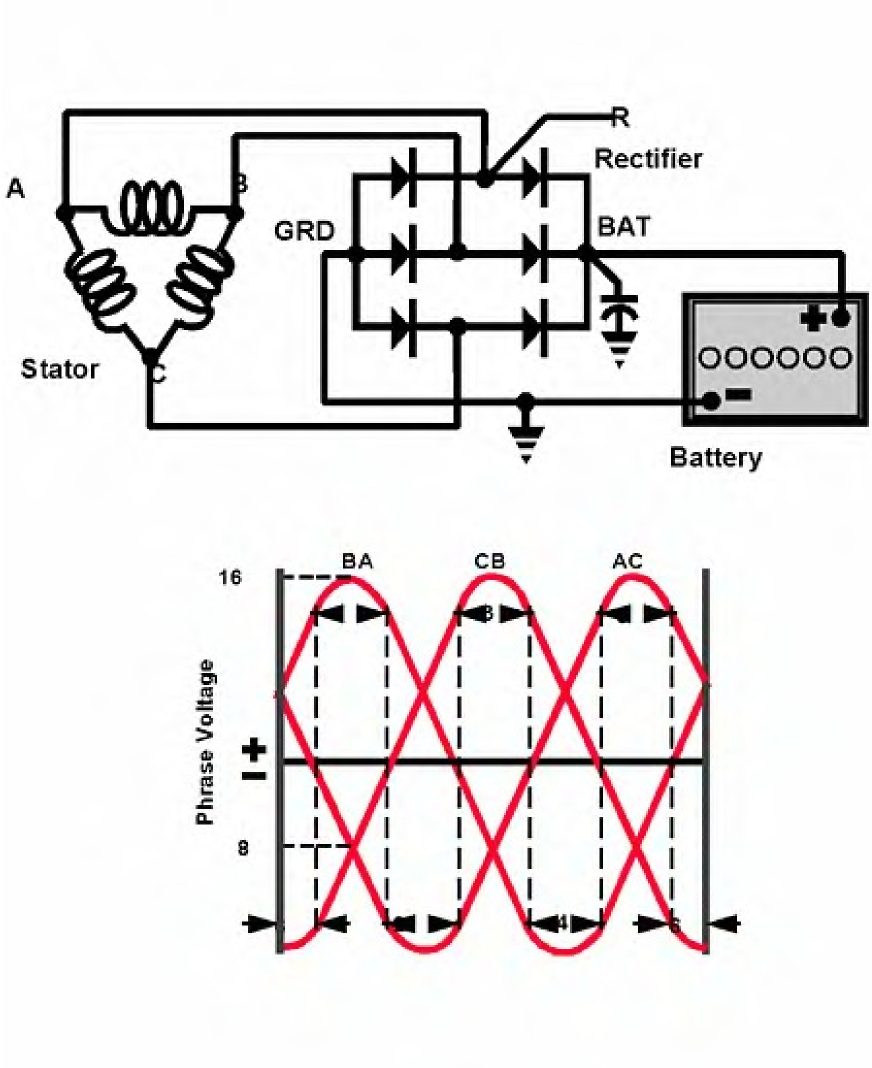

Illustration 16 g01073323

A delta type stator that is wound to provide the same output as a Y stator will also provide a smooth voltage and current output when the stator is connected to a six diode rectifier. For explanation purposes, the three-phase voltage curves that are obtained from the basic delta connection for one rotor revolution are reproduced here, and the curves are divided into six periods.

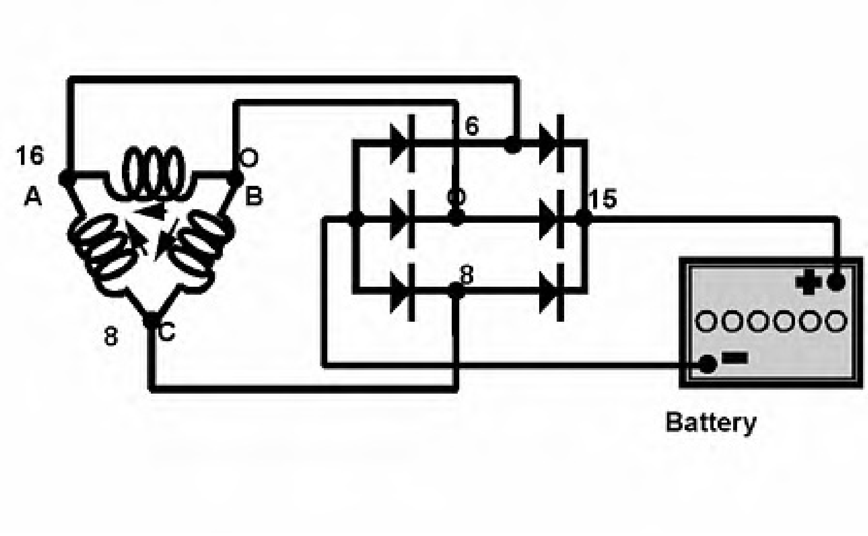

Illustration 17 g01073324

During period 1 (Illustration 17), the maximum voltage that is being developed in the Delta stator is in phase (BA). The current flow through the rectifier is exactly the same as for the Y stator since the voltage potentials on the diodes are identical. The difference between the Delta stator and the Y stator is that the Y stator conducts current through only two windings throughout one period. The delta stator conducts current through all three windings.

Phase (BA) is in parallel with phase (BC) and (CA). Since the voltage from (B) to (A) is 16, the voltage from (B) to (C) to (A) also must be 16 because 8 volts is developed in each of these two phases ((B) to (C) and (C) to (A). Following the same procedure for periods 2-6, the current flows can be determined.

Alternator Construction

Illustration 18 g01073327

When current is passed through the coil assembly, a magnetic field is created in each of the rotor pole pieces. One set of fingers will become north poles while the other set of fingers will become south poles.

Since the rotor fingers overlap each other, many individual flux loops will be formed between the alternator north and south poles. Instead of passing one magnetic field past each winding during one revolution of the rotor, many fields will pass the windings, which will increase the output of the stator.

Since the rotor must be supplied with current to create the magnetic field, the coil assembly inside the pole piece is connected to slip rings. These slip rings are provided so that brushes can be used to provide current to the moving field. Slip rings are pressed onto the shaft and insulated from the shaft. The coil conductors are soldered to the slip rings in order to form a complete circuit that is insulated from the shaft.

Because the rotor will be spinning at high speed, the rotor must be supported by bearings. The front end of the shaft has a bearing that is mounted in the drive end housing assembly (Illustration 18).

Note: Spacers are added to place the rotor in the correct position once the alternator is assembled. This will keep the fan from hitting the housing.

Since the generation of electricity creates heat, a fan is included in order to provide a flow of air through the assembly for cooling. A pulley is attached to the end of the rotor shaft. The pulley is driven by a belt.

Illustration 19 g01073328

The end housing supports the slip ring end of the rotor shaft. The end housing provides a mounting surface for the brushes, rectifier assembly, stator and regulator (if equipped). The drive end housing with the rotor and the slip ring end housing with the components are assembled as a unit. The stator is held in between. This assembly is held together with through capscrews.

The stator assembly is a laminated soft iron ring with three groups of coils or windings. One end of each stator winding is connected to a positive diode and a negative diode. The other ends of the stator windings can be connected in either a Y type stator configuration or a delta stator configuration.

The rectifier assembly converts the (AC) current to (DC) current. Three positive diodes and three negative diodes are mounted to the rectifier assembly.

The alternator is designed to provide minimal clearance between the rotor and stator, in order to maximize the effects of the magnetic field. The alternator is a compact assembly that is capable of generating high current flow in order to satisfy the needs of the electrical system.

The brushes are in contact with the copper slip rings in order to provide the necessary current for production of the magnetic field in the rotor. Since good contact is important for good conductivity, the brushes are held against the slip rings by small coil springs.

There are two brushes, which are usually contained in a brush holder assembly. This assembly can be easily attached to the slip ring end housing of the alternator.

Regulating the Alternator Output

Illustration 20 g01073329

If the alternator were allowed to operate uncontrolled, the alternator would produce voltages too high to be used in the machine. This would result in damage to the components. The regulator controls alternator output.

Current output is limited by the construction of the alternator. Current output is indicated as a maximum on the housing. For example, a housing may have a listing such as 12V 85A. This indicates that the maximum output is 85 amperes and the alternator is designed for a 12 volt system.

The regulation circuit controls the voltage output of the alternator by changing the strength of the magnetic field that is produced by the rotor. The regulator circuit does this by controlling the amount of current that flows through the brushes to the rotor coil.

The regulator is sensitive to the voltage of the battery. The regulator is sensitive to the electrical load that is being placed on the system. The regulator can then adjust the amount of current to the rotor in order to satisfy the demand.

If the battery voltage is low and the demand from electrical accessories is high, the voltage regulator will increase the output of the alternator to charge the battery. This provides sufficient current to operate accessories. When battery voltage is high and the electrical demands are low, the voltage regulator will reduce output from the alternator.

Alternator regulators can be of three different designs:

- Electro-mechanical (older machines)
- Electronic external regulators
- Electronic integral regulators

Electro-mechanical regulators can be found on some older systems. These regulators use relays to operate contact points. The double contact voltage regulator controls alternator output by regulating the amount of current flow to the rotor. Reducing current flow will reduce the strength of the magnetic field and result in lower output from the stator.

Electronic Voltage Regulators

Illustration 21 g01073331

Electronic voltage regulators perform the same function as the electro-mechanical regulators. In the electronic regulator, the field circuit is switched ON and OFF by electronic circuits. These circuits controll switching transistors. These electronic devices can be switched more quickly and carry more current than the contact points in the electro-mechanical regulators. Higher output from the alternator can be obtained because of greater current flow through the field circuit.

Electronic regulators use Zener diodes as part of the voltage sensing circuit. These special diodes allow current to flow in reverse of normal flow when a specific voltage across the diode is reached. When the current flows back through the Zener diode the field transistor is turned off and current flow is stopped in the field rotor. The electronic components can switch on and off several thousand times a second. This provides very smooth, accurate control of alternator output.

Most electronic regulators are not adjustable. If the regulators do not accurately control the output of the alternator, the regulator must be replaced.

Electronic Regulator Operation at Engine Start-Up

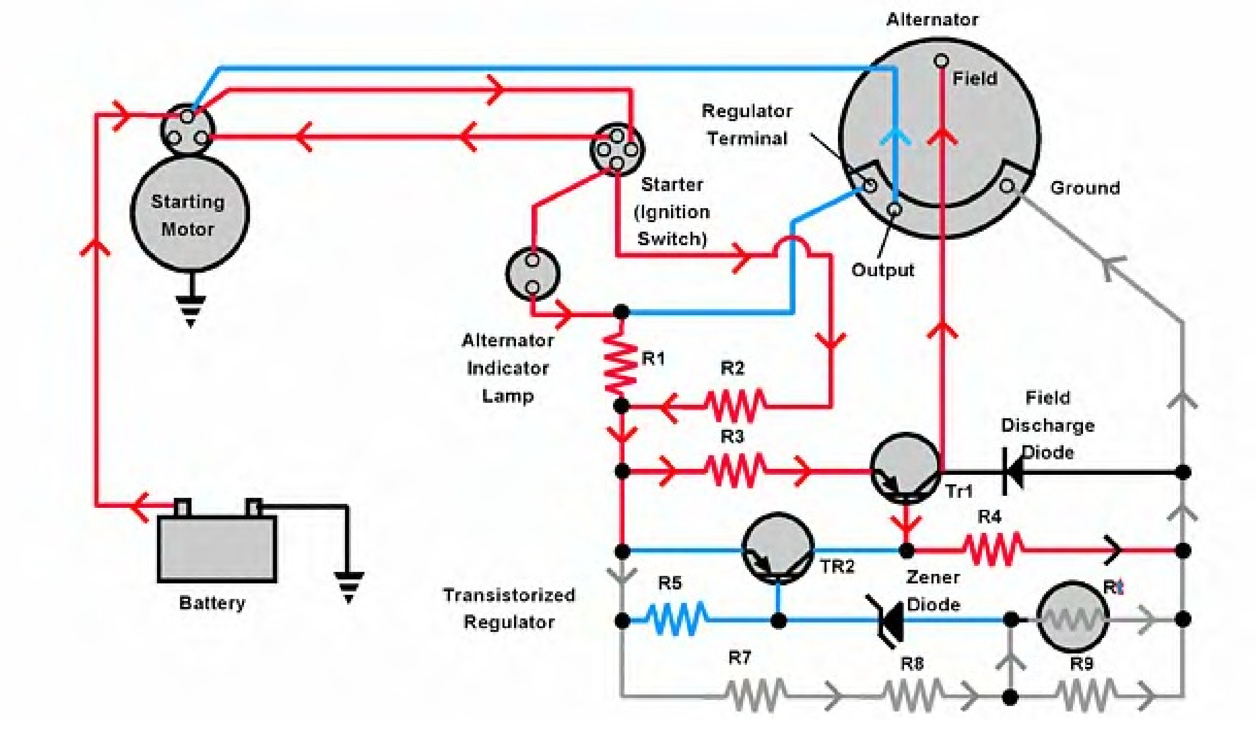

Illustration 22 g01073332

When the starter switch is turned ON, the circuit is completed (Illustration 22). Battery current flows to the starter solenoid and the starter key switch, as shown by the red lines. The key start switch directs current flow to the alternator indicator lamp and the regulator.

As the current flows into the regulator, different voltage values govern the course of the current. The voltage across resistors (R7) and (R8) is below the Zener diode critical or below the breakdown voltage. Therefore, the voltage that is felt at the base of (TR2), is the same as the voltage at the emitter. So the current cannot flow through (TR2) (as shown by the blue lines).

Thus the voltage difference in the emitter base circuit of (TR1) allows current to flow from the emitter through the base and collector. The collector current then goes on to excite the alternator field (vertical red line). At the same time, a slight amount of current flow travels to the alternator ground.

Regulator Operation During Engine Operation

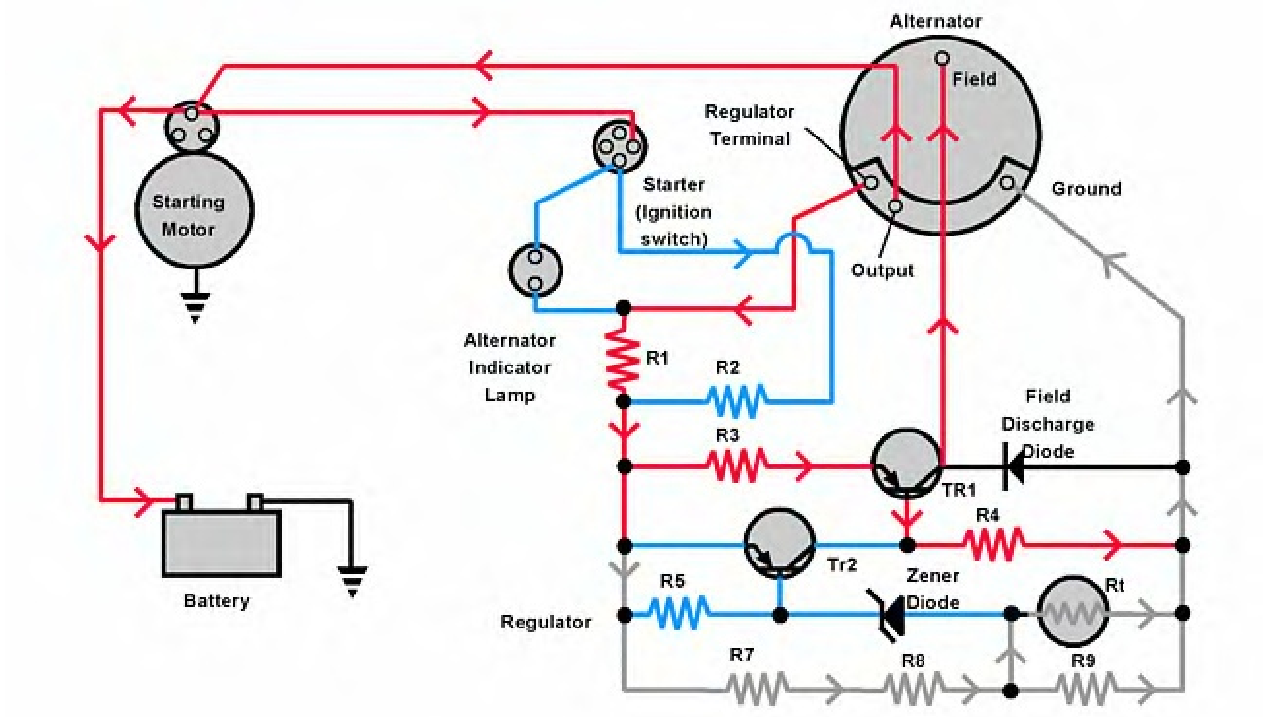

Illustration 23 g01073333

Regulator operation at the beginning of engine operation (Illustration 23) is similar to the engine start -up period, except that as the engine speeds up the alternator field around the rotor generates voltage in order to supply electrical loads.

However, the voltage values are still the same and transistor (TR1) still conducts the current to the alternator field as shown by the vertical red line.

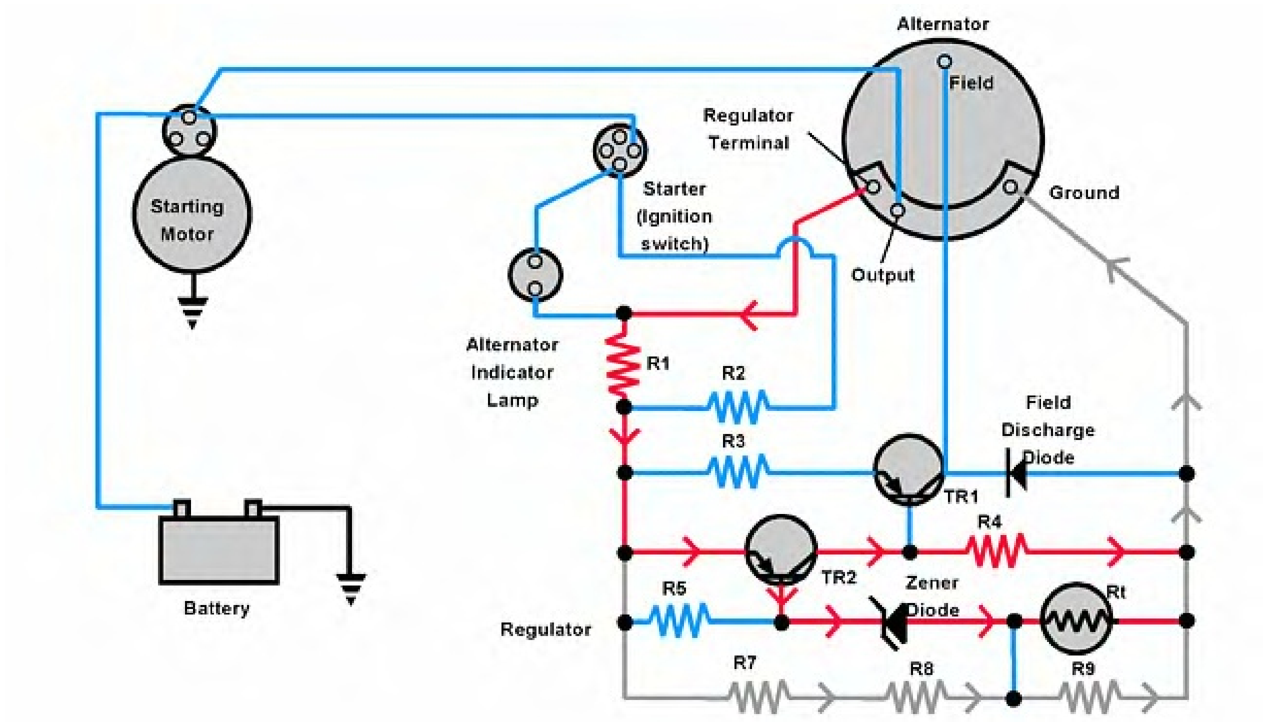

Illustration 24 g01073334

As the engine operates and load requirements begin to decrease, the alternator voltage increases (Illustration 24). This causes the voltage across the resistors to also increase. Then the voltage across (R7) and (R8) becomes greater than the Zener diode critical voltage. The Zener diode immediately breaks down allowing current to flow in the reverse direction. This turns on transistor (TR2) and current is able to flow through (TR2's) emitter, base and collector. When current flows through (TR2), the voltage at the base of (TR1) is equal to or greater than the emitter, which prevents current from flowing though (TR1) to the alternator field. The field collapses,alternator output is reduced and the circuit is protected.

The system voltage then drops below the critical voltage of the Zener diode. The Zener diode stops conducting. This turns off (TR2) and turns off (TR1). Current again flows to the alternator field. This operation is repeated many times a second. The two transistors act as switches that control the voltage and alternator output.

When (TR1) turns off, the alternator field current cannot drop immediately to zero, because the rotor windings cause the current to continue to flow. Before the current reaches zero, the system voltage and the regulator start current flow again. However, the decreasing field current flow induces a high voltage which can damage the transistor.

The field discharge diode that is shown in Illustration 24 prevents damage to transistor (TR1) .

Internal electronic regulators

Illustration 25 g01073337

Internal alternator regulators are mounted either inside or outside of the slip ring end housing of the alternator. This type of regulator eliminates the wiring harness between the alternator and regulator simplifying the system. This type of regulator is usually much smaller than other types and uses electronic circuits known as integrated circuits or ICs. ICs are miniaturized electronics with much of the circuit on one small chip. Integral regulators perform the same function as the external electronic regulators.

Some alternators with integral regulators have only one wire that is going to the regulator. This wire is the alternator output wire. The ground circuit is completed through the housing to the engine block. Current for the integral regulator is fed from the stator through a diode trio. The alternator starts charging by using the small amount of permanent magnetism in the rotor. This small amount of output is fed back into the field which increases the output. This continues until full output that is determined by the regulator is reached.

Regulator Circuits

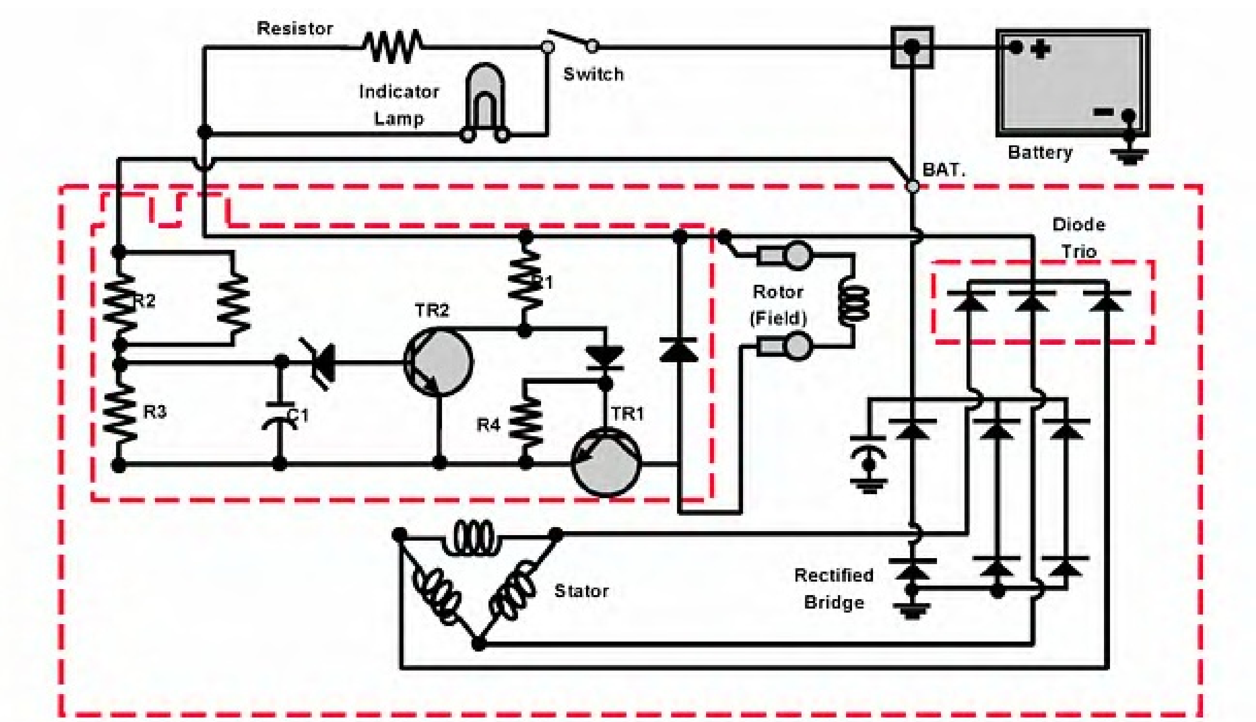

Illustration 26 g01073339

There are two basic field circuit connections for an alternator A circuit and B circuit.

An A type circuit alternator (Illustration 26) uses two insulated brushes in the alternator. One brush is connected directly to the battery, while the other brush is connected to ground with the regulator and ignition switch or relay in series. The regulator is located after the field, between the field and the alternator ground or negative diodes. Full alternator output is obtained by grounding the field windings. Some alternators have a tab in a test hole so that the field is grounded by placing a screwdriver against the tab end and the alternator frame. This type of circuit is used with integral regulators and some external electronic regulators.

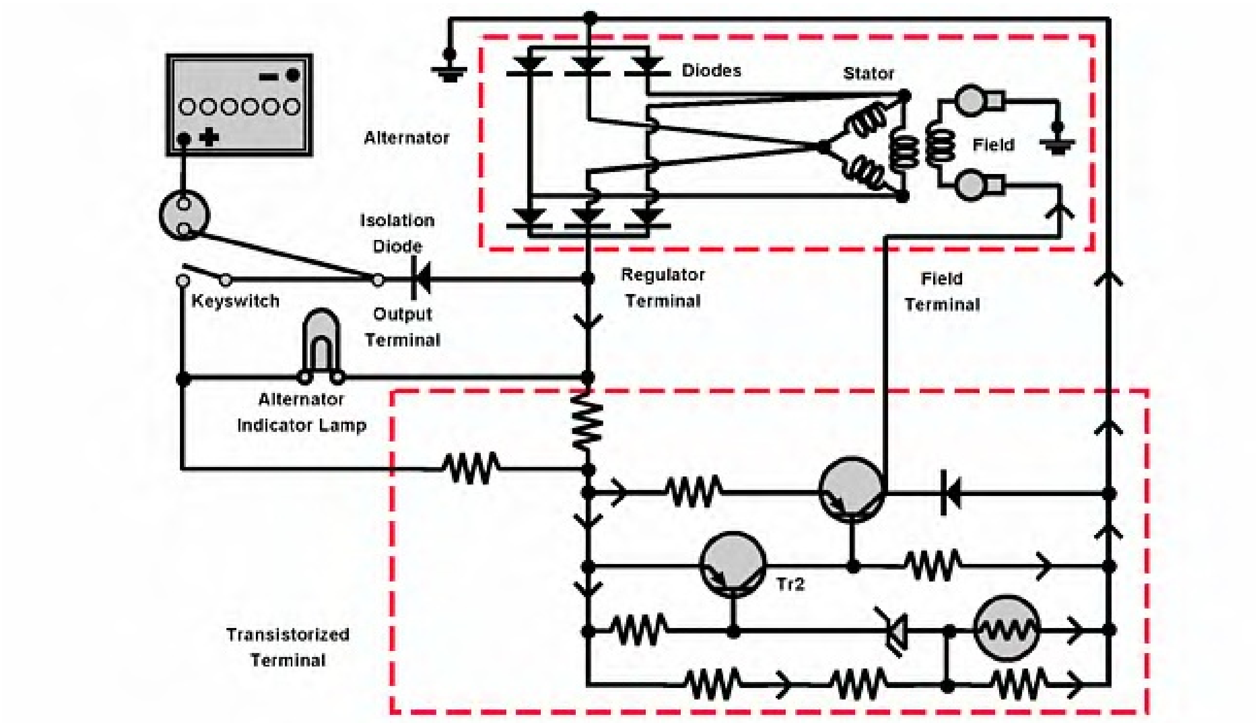

Illustration 27 g01073340

B type circuits use a brush that is grounded inside the alternator (Illustration 27). The other brush is connected to the battery in series with the regulator and the ignition switch or the relay. In a B circuit alternator the regulator is located before the field. The current flow is usually from the regulator terminal of the alternator to the regulator. After the regulator, the current flows to the field coil in the rotor, then to ground, and finally to the negative or return diode assembly. Full alternator output is obtained by connecting the field terminal to the regulator terminal or the output terminal.

Charge Indicators

Illustration 28 g01073341

Charge indicators may be an ammeter, a voltmeter or a charge indicator light. Ammeters may be installed in series if the ammeters are full current, shunt type, or in parallel if the ammeter is the nonshunt type.

Voltmeters are more commonly used because they more accurately indicate the operation of the system. Voltmeters can be easily installed in parallel with the charging system. Voltmeters provide information on both the operation of the charging system and condition of the battery.

Charge indicator lights show general system operation. Charge indicator lights will not indicate high alternator output or high voltage conditions, but will show low output.

Charging System Testing

Accurate testing of charging systems begins with an understanding of how the system functions. If your knowledge of the operation is complete, you can logically determine the fault through visual inspection and electrical testing.

Repair of the system may require replacement or repair of any of the items that are included in the system from the battery to the alternator.

All repairs should begin with a study or a review of the service manual for the machine upon which you are working.

When you test any electrical system a systematic approach will lead to quicker repairs. Charging systems require the same troubleshooting approach. Parts replacement without proper troubleshooting is not an acceptable method of finding and repairing system faults.

Verify the Complaint

Determine exactly what the complaint is, then verify that the fault is occurring. The following conditions are some of the common problems that occur in charging systems:

- The battery is discharged and the charging system is producing no charge or a low charge.
- The battery is charging and the charging system is overcharging.
- The alternator is noisy.
- The charge indicator light stays on or the light fails to come on.

Define the problem

Begin with a thorough visual inspection. Check for any of the following problems:

- Loose terminals or corroded battery terminals
- Loose connections or damaged ground connections at the engine and body
- Loose, dirty connections at the alternator and regulator
- Burnt fuse links or burnt wires
- Damaged, crimped, broken or cut wires

- Evidence of shorts or grounds
- Physical damage to the alternator or regulator
- Damage to belts and pulleys
- Odor of burnt electrical components

Determine whether the problem is electrical or mechanical. Alternators are belt driven. These drive belts must be inspected for tension, wear, and damage in order to make sure that the belts are doing the job. Inspect the belt for damage by checking the inside and outside surfaces for cracking, chipping, glazing or missing pieces.

Inspect the alternator pulley for wear and any other pulleys that the belt runs over. Premature belt failure is often caused by worn pulleys. Inspect all pulleys for alignment. Usually a visual inspection will show that the belts are not lined up correctly, but you may have to check with a straight edge against the pulley. Test the belt for proper tension. When you are adjusting belts or checking belt tension make sure that you are not over tightening or under tightening the belt. Incorrect tension will cause damage.

Noisy operation can be caused by worn belts, worn bearings, or internal problems. Some of these problems are, the rotor rubbing on the stator, the fan blades hitting the alternator, or defective diodes or stators.

Mechanical problems can be corrected by replacing the faulty components or repairing the defective unit as necessary. Electrical problems will require more detailed testing.

Continue your inspection by performing a complete battery service. Battery service and testing is covered in Lesson 1. A charging system will not function efficiently if the battery is defective.

Isolate the Problem

Once you have defined what the problem is, you must isolate the cause so that you can accurately make the necessary repairs. Mechanical faults can be located by inspecting or listening. Electrical faults require testing to locate the cause.

Charging System Tests

On machine charging system tests should be performed first in order to determine whether the alternator must be removed and tested further.

On machine tests include the following tests:

- Alternator output test
- Regulator test

Bench tests will determine if the alternator must be repaired or replaced.

Bench tests include include the following tests:

- Rotor field winding tests
- Stator tests

- Rectifier tests
- Brush tests

Systems Operation - Fundamentals
Electrical System for All Caterpillar Products
Media Number -SEGV3008-01 Publication Date -01/06/2004 Date Updated -28/06/2004

i02100236

Circuit Voltage

SMCS - 1400; 1450

Circuit Faults

The following information will describe the circuit malfunctions of series, parallel, and series parallel circuits.

Circuit Malfunctions

There are several ways that a circuit can malfunction. Most electrical malfunctions are caused by the following conditions: opens, shorts, grounds, high resistance, or intermittents.

Opens

An open in any part of a circuit is an extremely high resistance that results in no current flow in the circuit. An open can be caused by any of the following components that have failed:

- Switch
- Fuse
- Broken wire
- Connector
- Component (load)

The physical location of the open determines how the circuit will react. In a series circuit, any open connection will result in no current flow in the circuit. Illustration 1 shows an open in a series circuit. The switch acts as an open. Therefore, no current will flow through the two loads when the switch is open.

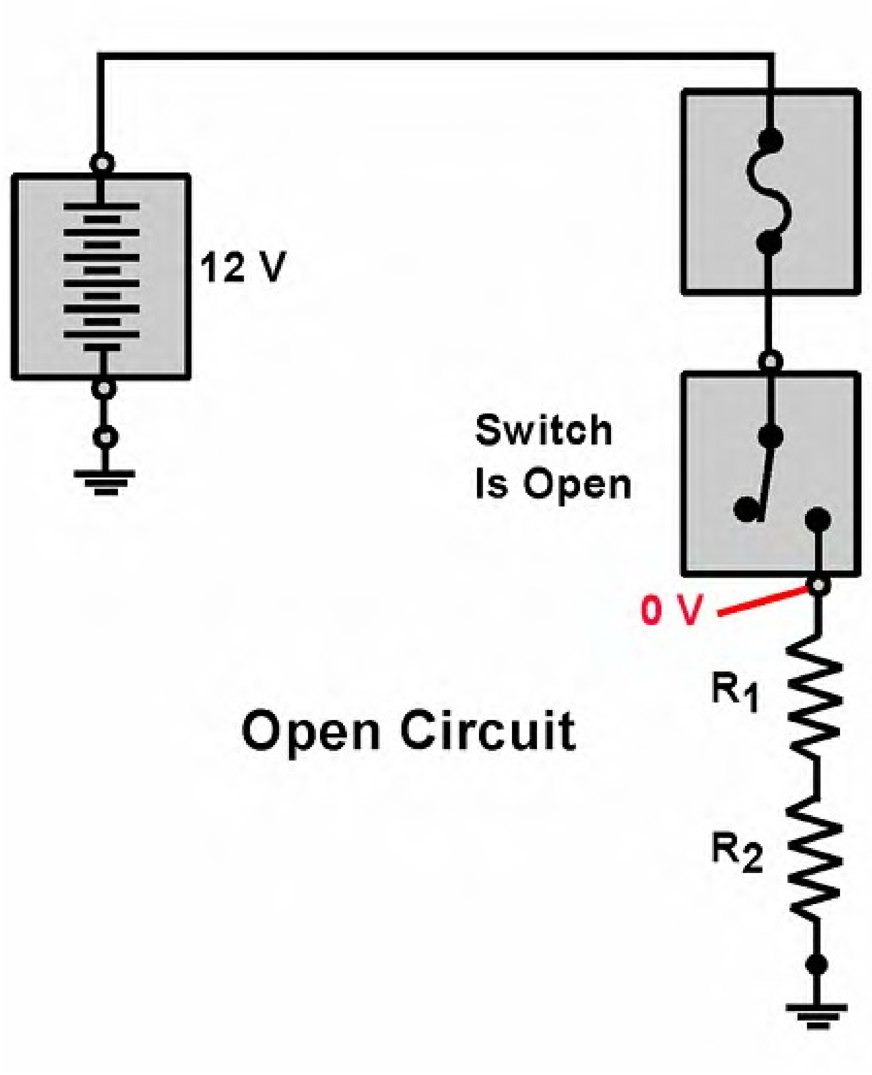

Illustration 1 g01070634

Troubleshooting an open circuit is easily accomplished by using a multimeter and by measuring the source voltage. If source voltage is available at the connection ahead of the switch and not available on the load side of the switch, the switch contacts are open. If voltage is available on the load side it would be necessary to continue checking the circuit until the open is identified.

In a parallel circuit, identifying an open depends on where the open occurs. If the open occurs in the main line, none of the loads or components will work. All parallel branches will not operate. Additionally, an open in the return ground path would have the same effect as an open in the main line. An open in the return ground path is referred to as an open ground.

If the open occurs in any of the branches below the main line, only the load on that specific branch is affected. All other branch loads will operate normally. Illustration 2 shows an example of an open in the main line and in a parallel branch.

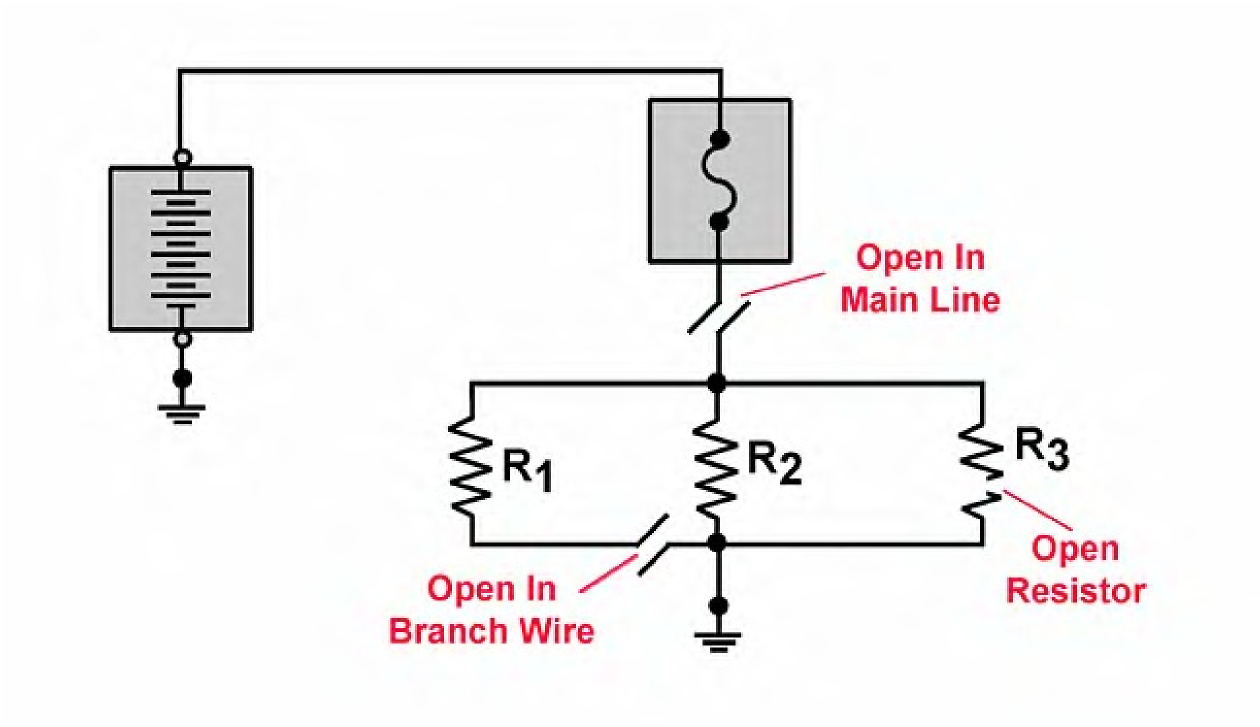

Illustration 2 g01070636

When you are troubleshooting or diagnosing an open in a circuit, the result is normally a component that fails to operate or to function. Since most circuits are protected with some type of a fuse or circuit protection device, it is recommended that the fuse or device be checked visually. If a visual check does not reveal an open condition, remove the device and perform a continuity check in order to ensure that the device is functional. The next most probable place to check for an open is at the component. Using a multimeter and a electrical schematic, determine if the system voltage or source voltage is available. If voltage is not present at the component, the next step is to determine what other electrical devices, such as switches or connectors, are in the circuit path. Eliminate those devices, starting at the easiest location and working back toward the voltage source.

Shorts

A short in a circuit is a direct electrical connection between two points. There is usually a very low resistance or opposition to current flow. A short in a circuit often describes an unwanted or an incorrect electrical connection. This may draw higher than expected current. In describing malfunctions that are caused by electrical shorts, the types of shorts are usually identified as a short to ground or a short to power.

A short to ground occurs when current flow is grounded before it was intended to be. This usually happens when wire insulation breaks and the conductor actually comes in contact with the machine ground. The effect of a short to ground depends on the design of the circuit and on the location in relationship to other circuit components (protection devices, switches, loads).

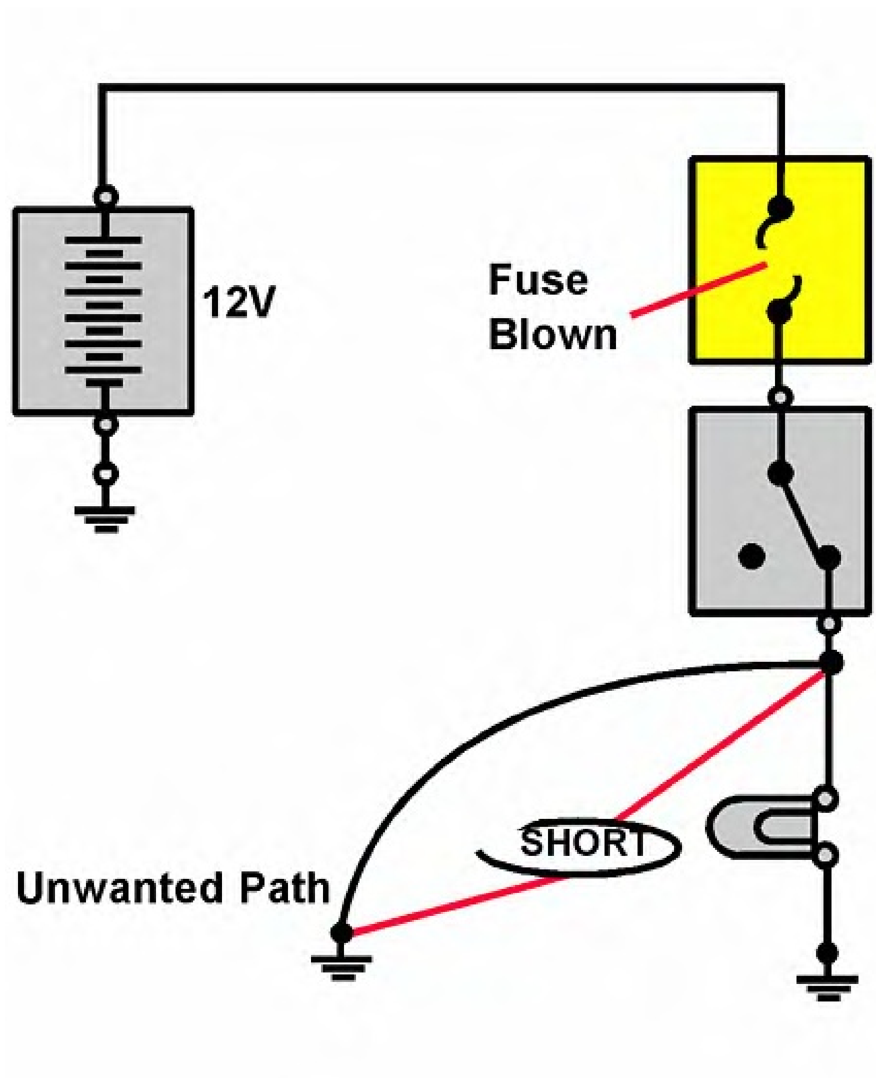

Illustration 3 g01070638

Illustration 3 shows the short occurring after the protection device and the switch, but before the circuit load (lamp). In this example, a low resistance path to ground occurs whenever the switch is turned on and the source voltage is available. The result of this unwanted path will result in a blown fuse when the switch is turned on.

Illustration 4 shows the short to ground occurring before the switch. This condition is often referred to as a dead short. In this situation, the fuse will blow anytime that the circuit voltage is applied.

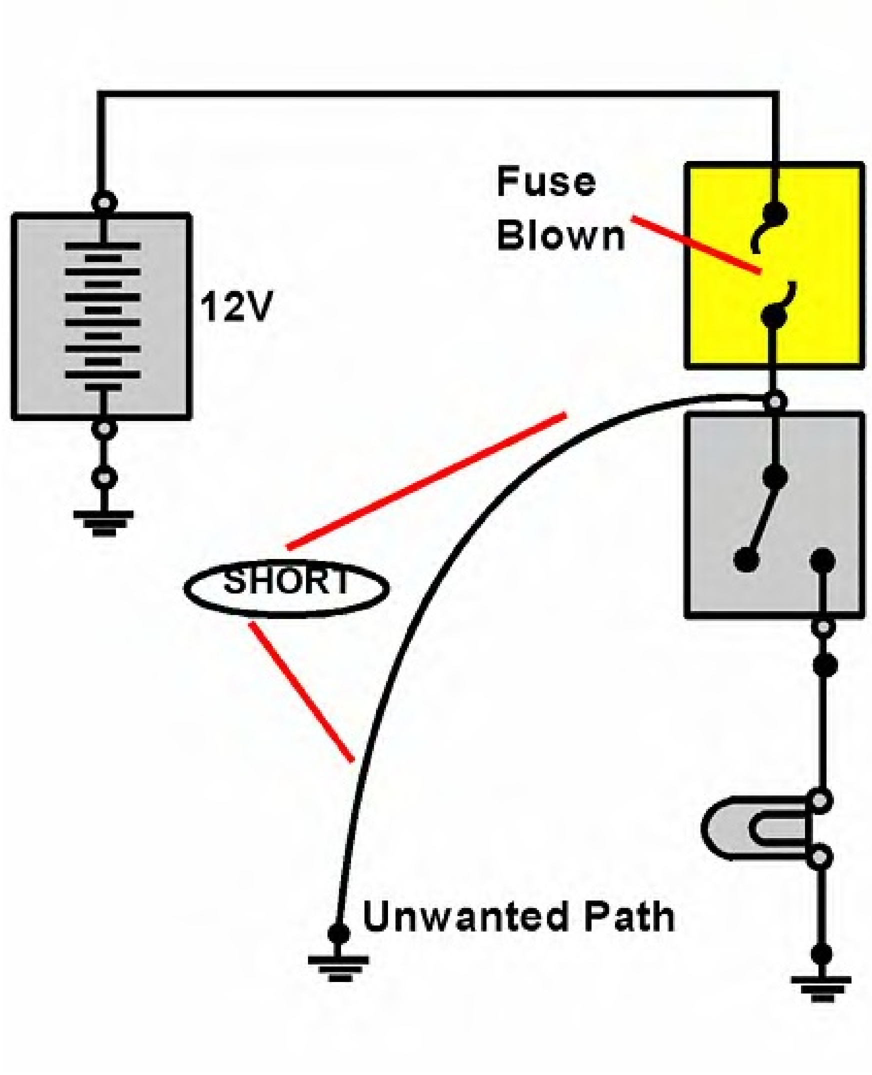

Illustration 4 g01070640

A short to power occurs when one circuit is shorted to another circuit. The symptoms of a short to power depends on the location of the short. The result of this of condition generally causes one or both circuits to operate improperly. A component that is being energized when it is not supposed to be is an example. The root cause of this condition is caused by worn electrical wiring or frayed electrical wiring. Also, this condition seldom causes protection devices to open or cause damage to other components.

Illustration 5 shows the short to power occurring before the controlling devices (switches). This condition allows both switches to control the two loads.

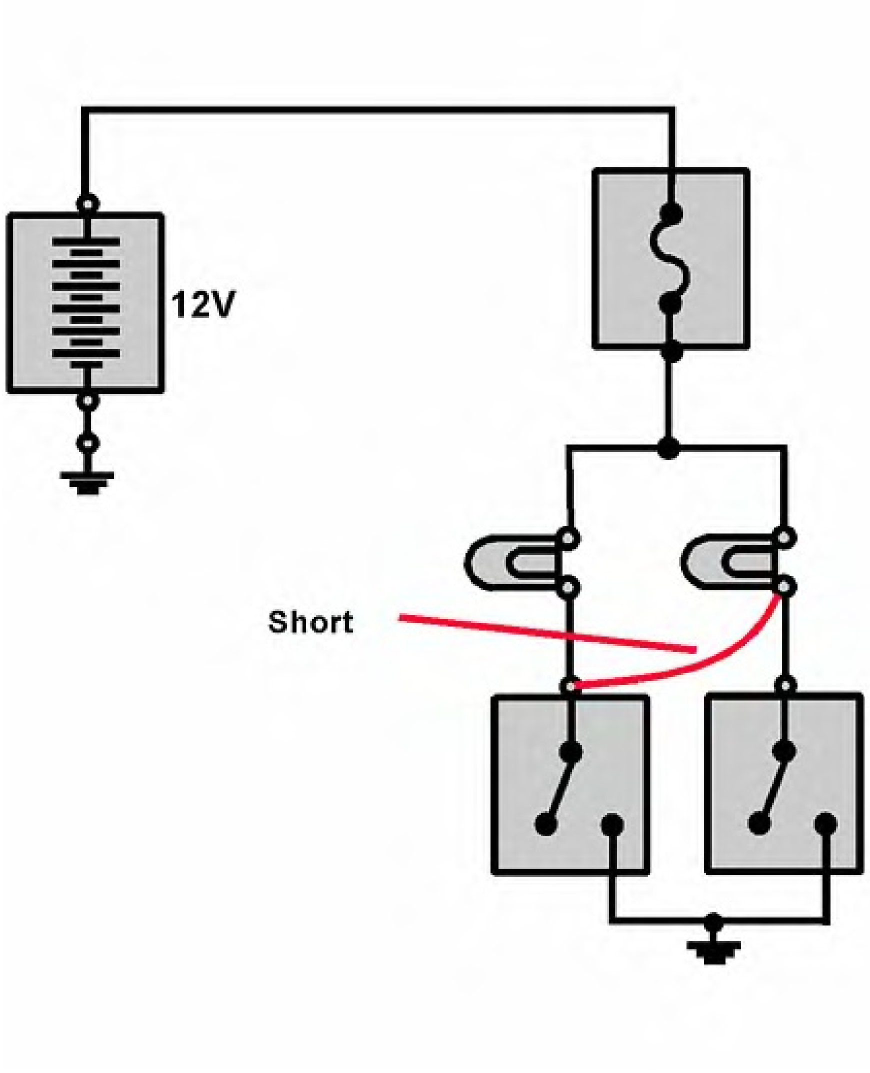

Illustration 5 g01070643

Illustration 6 shows the short to power that occurrs after the load in one branch, and before the load in the other. In this case, if the switch that controlls circuit no. 2 is turned on, the load does illuminate, but if the switch that controls circuit no. 1 is turned on, a direct short to ground occurs resulting in the fuse blowing.

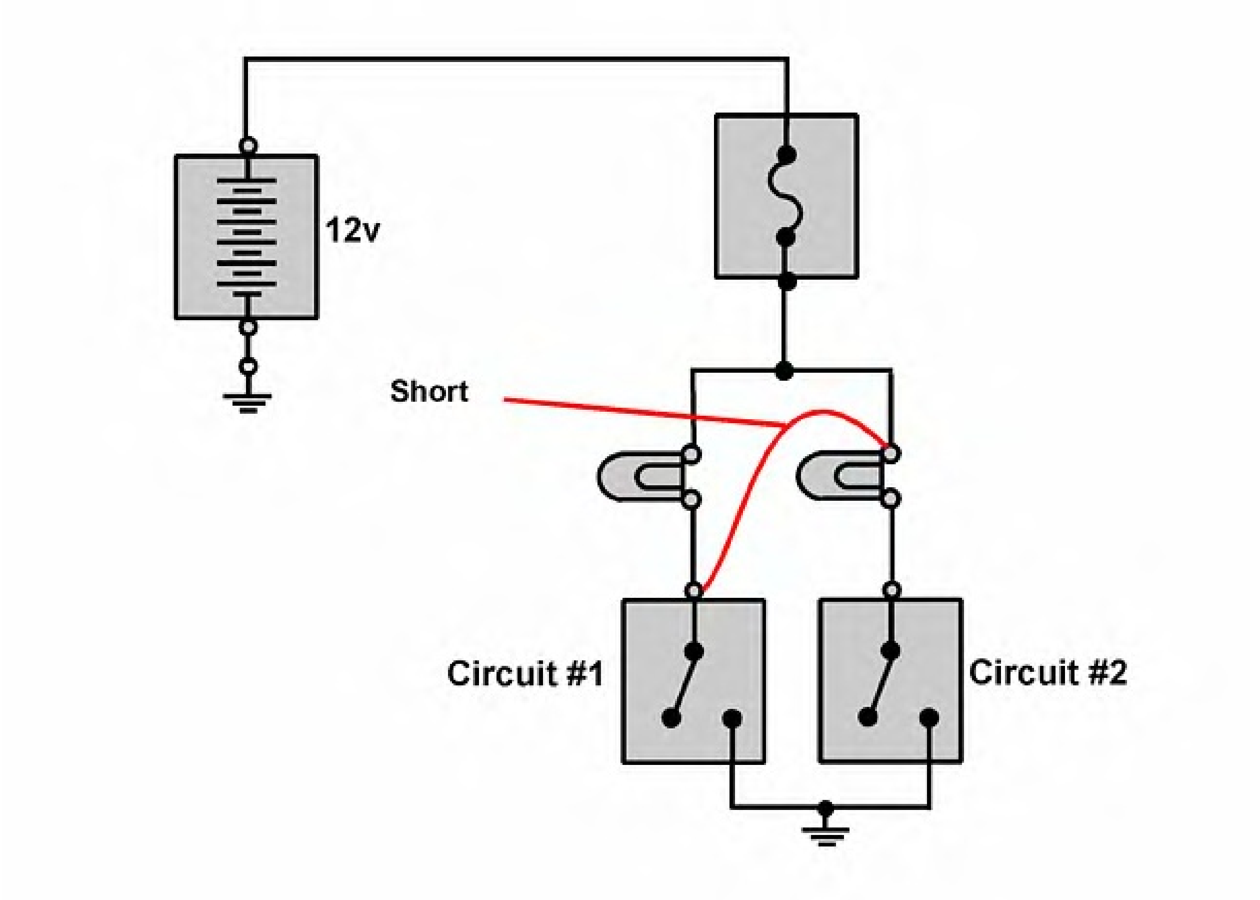

Illustration 6 g01070646

Grounds

A grounded circuit usually results in a component that fails to operate. A grounded condition indicates that the circuit has an unwanted path to the machine frame. The effect on the circuit is determined by where the ground occurs.

High Resistance

Circuit malfunctions also occur when resistance levels become too high. The circuit effect usually results in the component failing to operate or the component does not operate according to specification. The cause of high resistance is a build up of corrosion on connections, or dirt on connections and on contacts.

Intermittent

An intermittent condition occurs when contacts or connections become loose or when internal component parts break. These problems usually results in lights flickering, or in components working intermittently. This problem usually appears as the result of vibrations or machines moving. These problems are not easily diagnosed because the condition corrects itself when the machine is stopped.

CATERPILLAR®

Systems Operation - Fundamentals
Electrical System for All Caterpillar Products

Media Number -SEGV3008-01 **Publication Date -01/06/2004** **Date Updated -28/06/2004**

i02100235

Electrical Measurement

SMCS - 1400; 1450

Digital Multimeter

This information covers the basic functions and operation of the digital multimeter. Although an analog multimeter and test light may be used by a service technician, the digital multimeter performs the more complex measurements on the newer electronic systems. Digital multimeters use the metric system, in order to make it easier to work with large numbers.

Digital Multimeter

Illustration 1 g01070520

The digital multimeter is highly accurate. The digital multimeter is used to find the precise value of any type of voltage, current or resistance. The meter is powered by a 9 volt alkaline battery. The meter is sealed against dirt, dust, and moisture.

The meter has four main areas: the liquid-crystal-display, push buttons, rotary dial function switch, and inputs for the meter leads.

Liquid Crystal Display

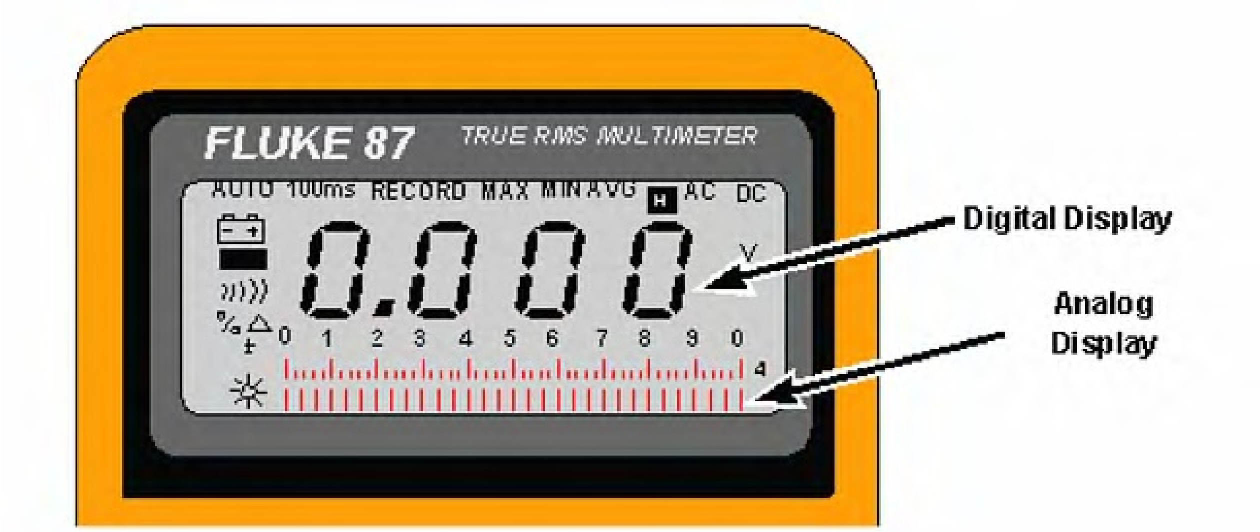

Illustration 2 g01070522

The meter's liquid crystal display, or LCD, uses display segments and indicators. Digital readings are displayed on a 4000 count display with polarity (±) indication and automatic decimal point placement. When the meter is turned ON, all display segments and annunciators appear briefly during a self test. The digital display (1) updates four times per second. When frequency readings are taken. The display updates three times per second.

The analog display (2) is a 32 segment pointer that updates at 40 times per second. The display segments have a pointer that rolls across the segments indicating a measurement change. The display also uses indicators to abbreviate various display modes and meter functions.

Push Buttons

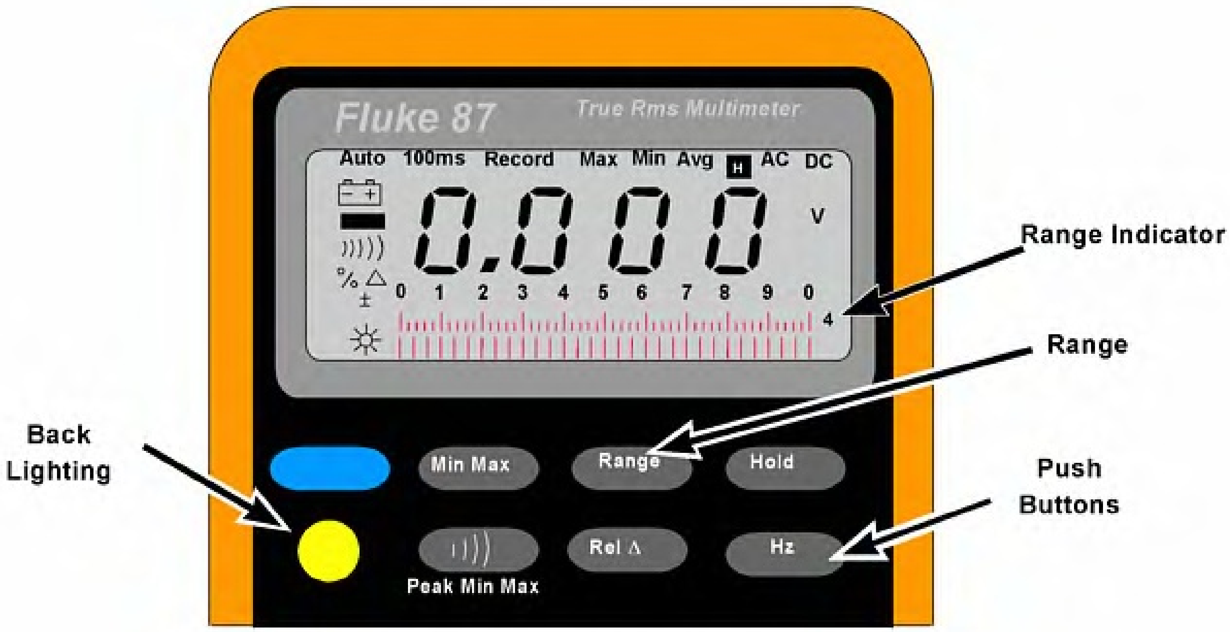

Illustration 3 g01070524

The buttons on the meter are used to perform additional functions. The additional buttons will be covered later in the course as they apply to the type of measurement taken.

When the meter is first switched on and a measurement is made, the meter automatically selects a range. The meter will display the word "AUTO" in the upper left corner. Pressing the range button will put the meter in manual range mode. The range scale will be displayed in the lower right corner of the meter. With each additional press of the range button, the next increment will be displayed. Press and hold the range button in order to return to the auto range mode. The yellow button can be used to backlight the meter display.

Rotary Switch

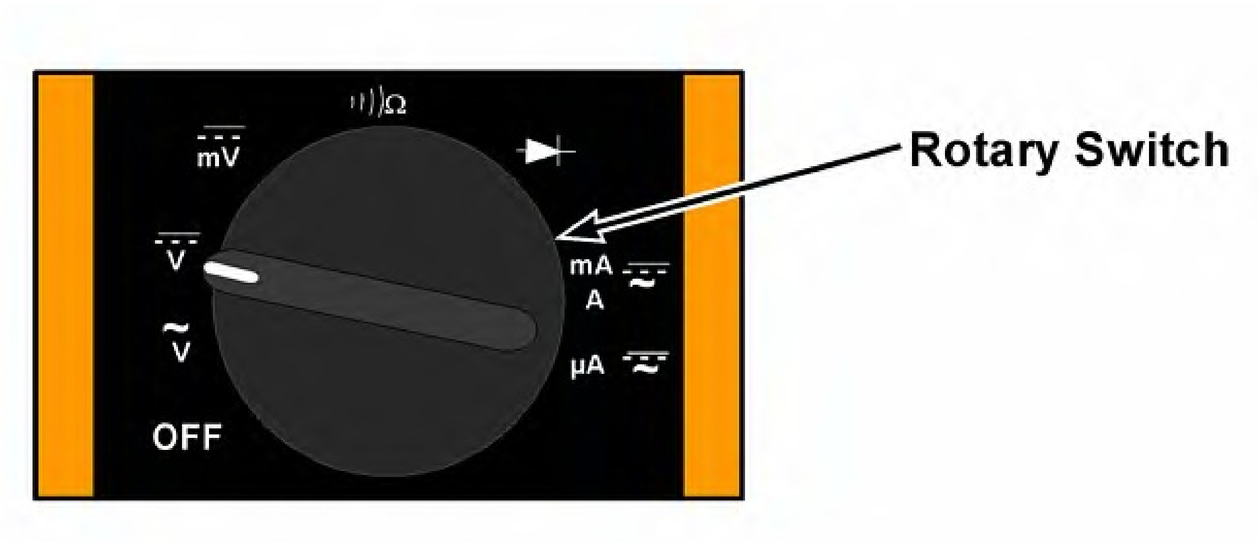

Illustration 4 g01078604

Various meter functions are selected by turning the meter's rotary switch. Each time the rotary switch is moved from OFF to a function setting, all display segments and indicators turn on as part of a self test routine. Moving clockwise from the OFF switch, the first three positions on the rotary switch are used for measuring AC voltage, DC voltage, and DC millivolts. The top position is used for measuring resistance. The next position will allow the meter to check diodes. The last two positions are used for measuring AC and DC current in amperes, milliamperes, and microamperes.

Meter Lead Inputs

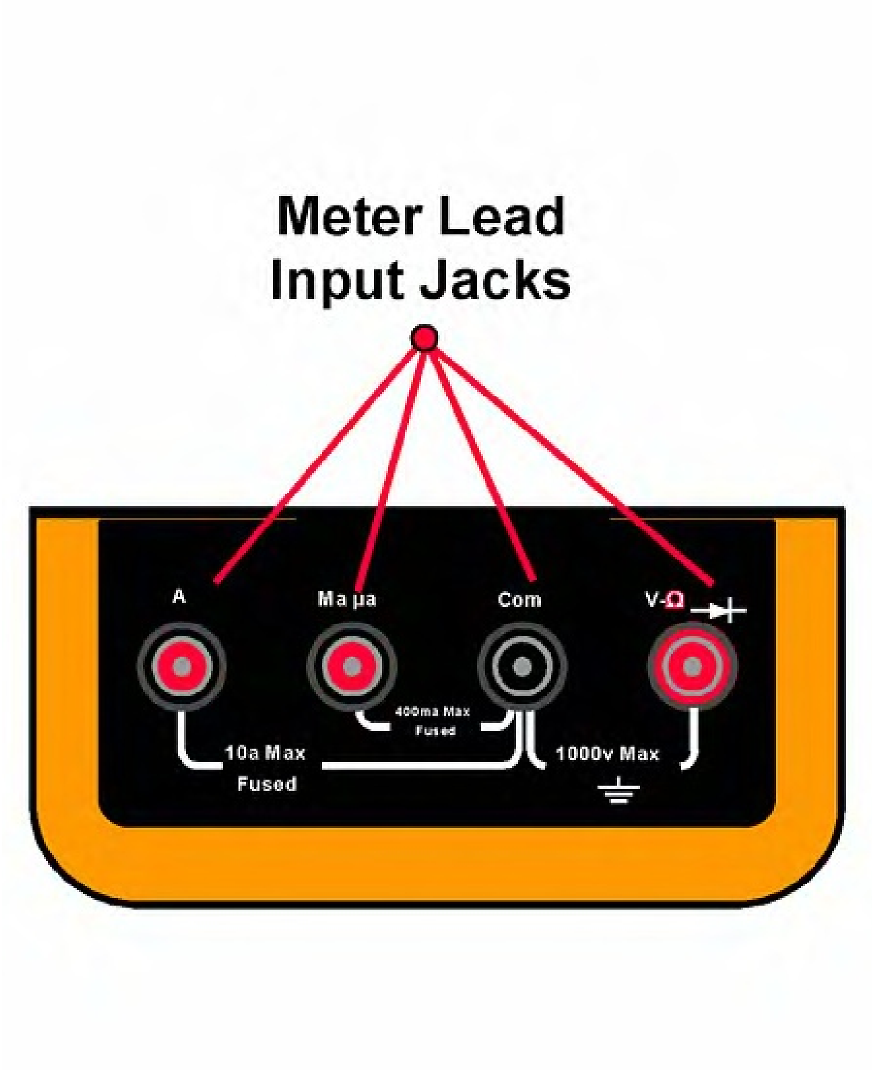

Illustration 5 g01070529

Depending on the measurement that you wish to make, the meter leads must be placed in the correct terminals. Notice the insides of the input terminals are color coded, red or black. The positive lead can go in any of the red inputs.

The "Com" or common terminal is used for most measurements. The black lead will always remain in the "Com" terminal.

The first input terminal that is on the left side of the meter is for measuring amps. This input is fused at 10 amps continuous (20A for 30 seconds).

The next position to the right is for measuring milliamperes or microamps. No more than 400 milliampere can be measured when the rotary switch is in this position. If you are unsure of a circuit's amperage, you may want to start out with the red meter lead in the 10 amp input jack (highest range).

The input terminal on the right side of the meter is for measuring voltage, resistance, and diode test.

Overload Display Indicator

While you make some measurements, you may see "OL" displayed. "OL" indicates that the value being measured is outside of the limits for the range selected. The following conditions can lead to an overload display:

- In autorange, a high resistance reading indicates an open circuit.
- In manual range, a high resistance reading indicates an open circuit or an incorrect scale that has been selected.
- In manual range, a voltage reading that exceeds the range selected.
- When you perform a diode check, voltage readings are greater that 3 volts or open test leads.

Input Terminal and Limits

The following chart shows the meter functions, the minimum display reading, the maximum display reading, and the maximum input for the 9U7330 Digital Multimeter.

Table 1

Function	Min Reading	Max Reading	Max Input
AC Volts	0.01 mV	1000V	1000V
DC Volts	0.0001V	1000V	1000V
mVolts	0.01mV	400.0 mV	1000V
Ohms	0.01Ohms	40.00 MOhms	1000V
AC/DC Amps	1.0 mA	10.0 A (cont)	600V
mA/µA	0.01 mA	400.0 mA	600V
	0.1µA	4000 µA	600V

Measuring AC/DC Voltage

When you use the multimeter to make voltage measurements, remember that the voltmeter must always be connected in parallel with the load or with the circuit under test. The accuracy of the 9U7330 multimeter is approximately ± 0.01% in the five AC/DC voltage ranges with an input impedance of approximately 10 mOhms when connected in parallel.

To measure voltage, perform the following tasks:

1. Make sure that the circuit is turned ON.
2. Place the black meter lead in the "Com" input port on the meter and the red lead in the VOLT/OHM input port.
3. Place the rotary switch in the desired position AC or DC.
4. Place the black meter lead on the low side or the ground side of the component or circuit that is being measured.

5. Place the red meter lead on the high side or the positive side of the component or circuit that is being measured.

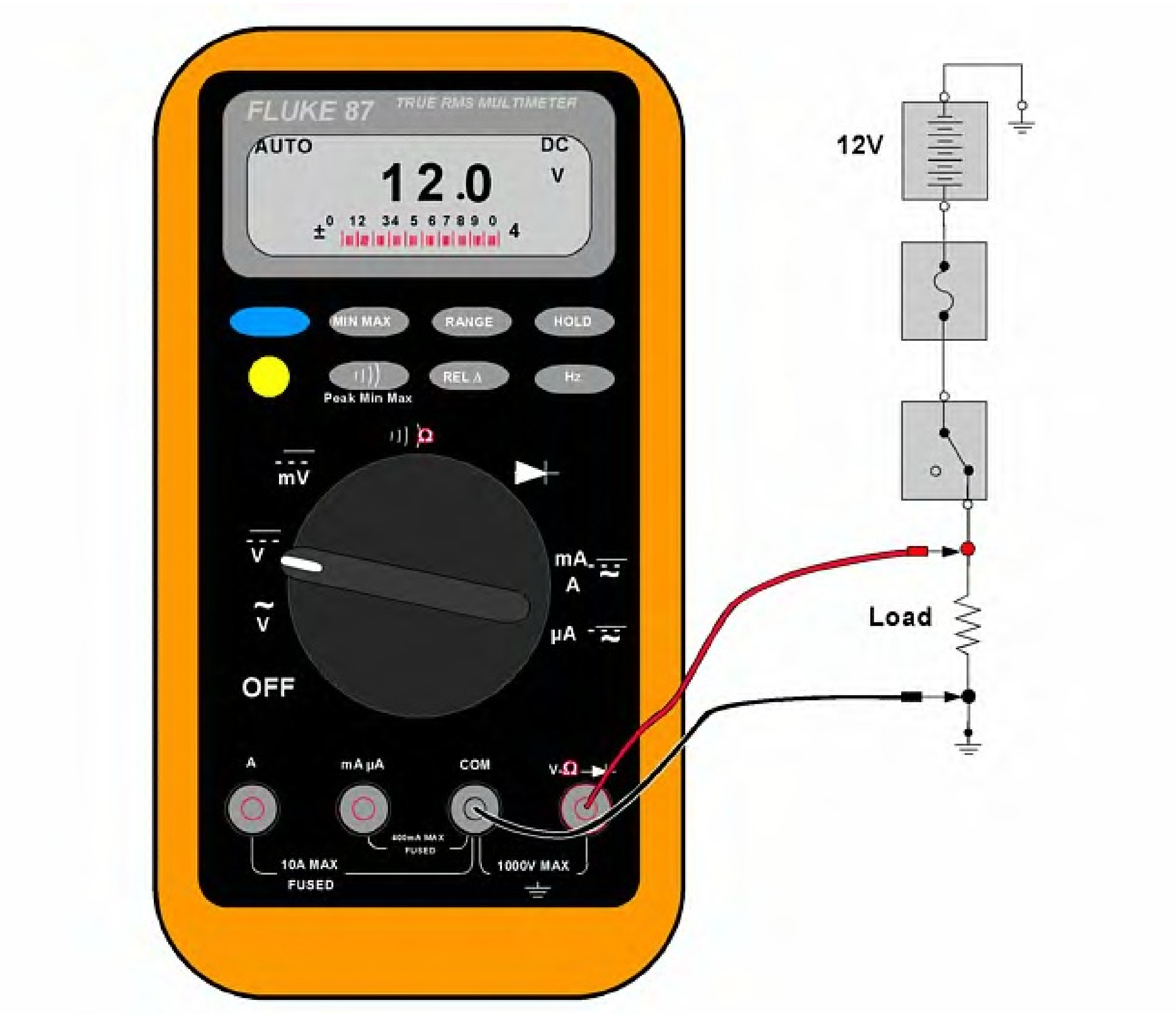

Illustration 6 g01070559

Observe the circuit in Illustration 6. The tests leads are connected in parallel across the circuit load. With a 12 volt power source connected to the load, the meter should read a voltage drop equal to the source voltage or to 12 volts.

If the meter reads a voltage drop less than 12 volts, it would indicate that an unwanted resistance was present in the circuit. A logical process would be to measure the voltage drop across the closed switch contacts. If a voltage reading was present, it would indicate that the switch contacts were corroded. This will require the switch to be replaced.

Note: In actual measurements, the meter reading will not exactly equal the power source voltage, because the individual wires will offer some small resistance. In most practical applications, a voltage drop of 0.1 volts is acceptable for normal circuit wiring conditions.

The 9U7330 digital multimeter is a high impedance meter. This means the meter will not significantly increase the current flow in the circuit that is being measured. Voltage measurements should always be made with the circuit under power. The 9U7330 Digital Multimeter is ideal for use in circuits controlled by solid state devices such as, electronic components, computers, and microprocessors.

Measuring AC/DC Current

Illustration 7 g01070561

When you use the multimeter to make current measurements, it is necessary that the meter probes must be connected in series with the load or circuit under test. To toggle between alternating and direct current measurements, use the "Blue" push button.

When you measure current, the meter's internal shunt resistors develop a voltage across the meter's terminals. This is called burden voltage. The burden voltage is very low, but the voltage could possibly affect precision measurements.

When you measure current flow, the Fluke 87 multimeter is designed with low resistance to not affect the current flow in the circuit. When you measure current in a circuit, always start with the red lead of the multimeter in the Amp input (10 A fused) of the meter. Only move the red lead into the mA/µA input after you have determined the current is below the mA/µA input maximum current rating (400 mA).

The meter has a buffer which allows it to momentarily measure current flows higher than 10A. This buffer is designed to handle the surge current when a circuit is first turned on. The meter is capable of reading 20 amps for a period not to exceed 30 seconds.

To measure current, perform the following tasks:

1. Place the black multimeter input lead in the "Com" port and the red input lead in the "A" (amp) port.

2. Create an open in the circuit, by pulling the fuse, or by opening the switch.

3. Place the leads in series with the circuit, so that the circuit amperage is flowing through the meter.

4. Apply power to the circuit.

NOTICE

If the current flow exceeds the rating of the fuse in the meter, the fuse will open.

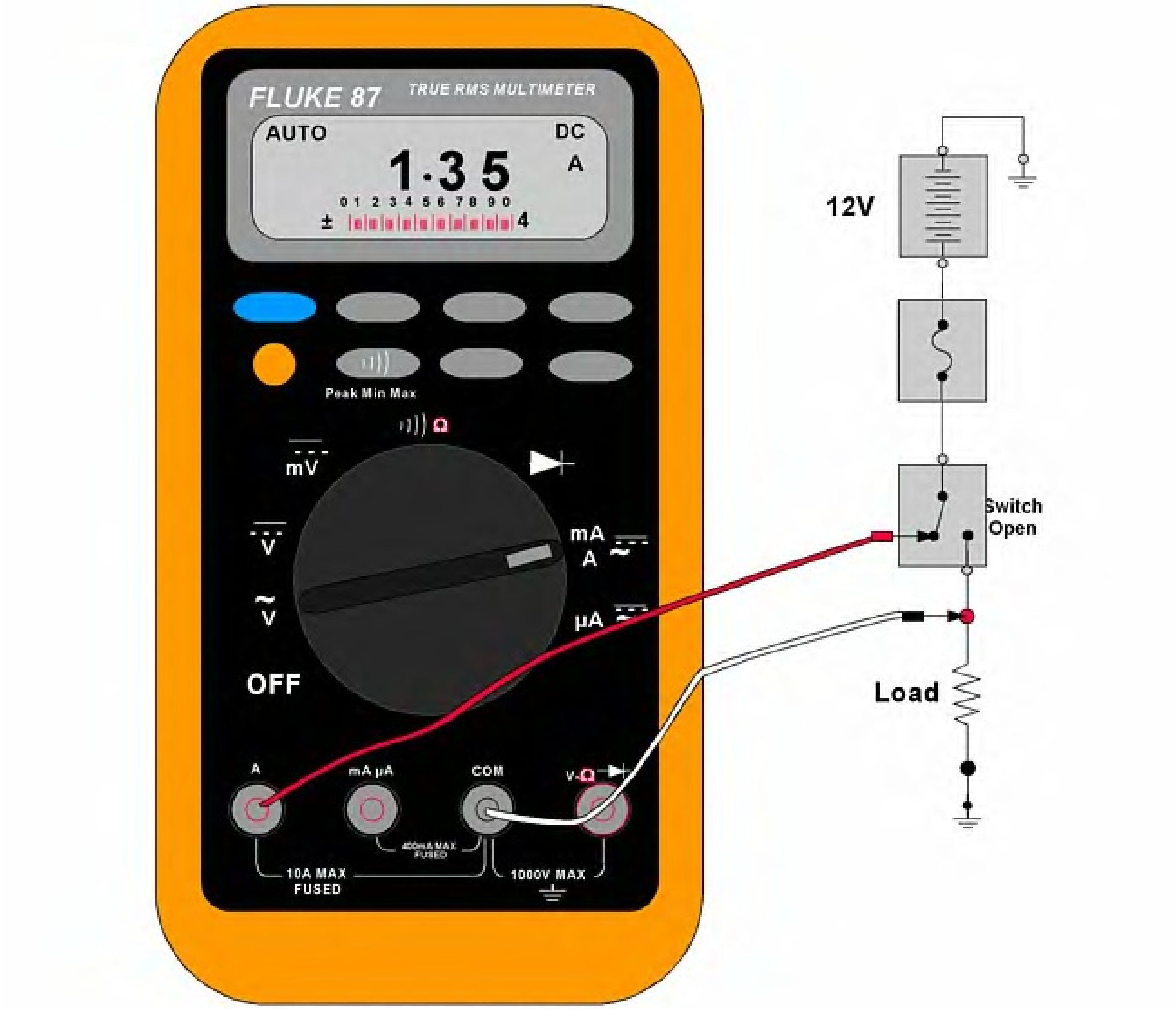

Illustration 8 g01070563

Measuring Resistance

When you use the multimeter to make resistance measurements, it is necessary to turn off the circuit power and discharge all capacitors before attempting circuit measurements. If an external voltage is present across the component being tested, it will be impossible to record an accurate measurement.

The digital multimeter measures resistance by passing a known current through the external circuit or the component. The digital multimeter measures the respective voltage drop. The meter then internally calculates the resistance using the Ohm's Law equation R = E/I. It is important to remember that the resistance displayed by the meter is the total resistance through all possible paths between the two meter probes. To accurately measure most circuits or most components, it is necessary to isolate the circuit or the component from other paths.

The resistance of the test leads can affect the accuracy when the meter is in the lowest (400 ohm) range. The expected error is approximately 0.1 to 0.2 ohms for a standard pair of test leads. To determine the actual error, short the test leads together and reads the value displayed on the meter. Use the "REL" mode on the 9U7330 to automatically subtract the lead resistance from the actual measurements.

To accurately measure resistance, perform the following tasks:

1. Make sure that the circuit or the component power is turned OFF.
2. Place the red lead in the jack marked Volt/Ohms and the black lead in the jack marked "Com".
3. Place the rotary selector in the Ohms position.
4. Place the meter leads across the component or the circuit that is being measured.

Note: It is important that your fingers are not touching the tips of the meter leads when you are performing resistance measurements. Internal body resistance can affect the measurement.

Illustration 9 g01070568

Note: In the circuit under test in Illustration 9, the power source is isolated from the circuit by opening the switch. The switch isolates the resistor from any other path that may affect the accuracy of the measurement.

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Systems Operation - Fundamentals
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i02104629

Electrical Schematic

SMCS - 1400; 1450; 7566

Schematics

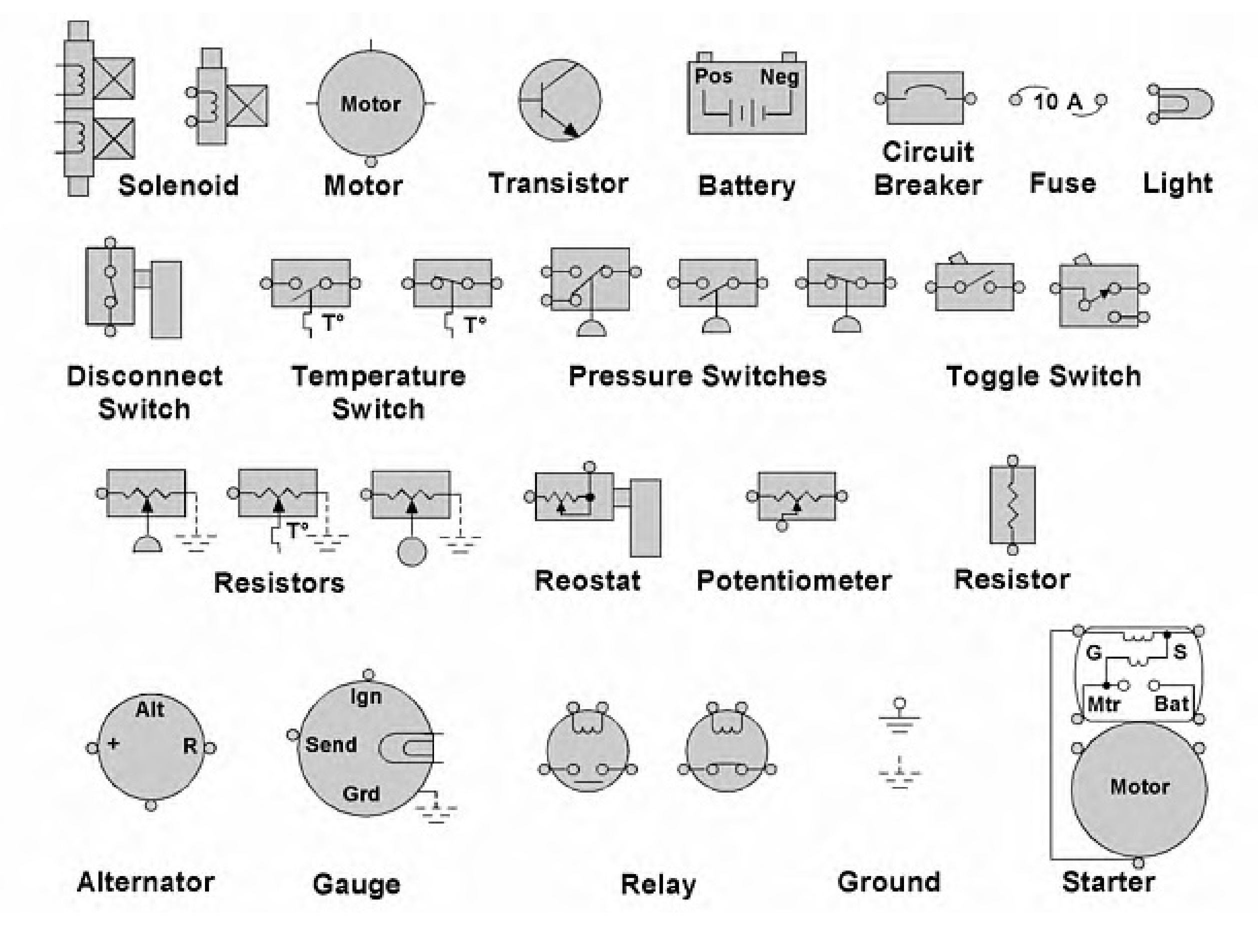

Illustration 1 g01072788

Schematics are basically line drawings that explain how a system works by using symbols and connecting lines. Symbols are used to represent devices or components of both simple and complex electrical and electronic systems. Schematic symbols are used extensively in Caterpillar publications for diagnosing electrical concerns.

Schematics are used by technicians in order to determine how a system works, and to assist in the repair of a system that has failed.

Schematic symbols present a great deal of information in a small amount of space. The reading of schematic symbols requires highly developed skills and practice. A logical, step by step approach to using schematic diagrams for troubleshooting begins with the technician's understanding of the complete system. Although, there are many electrical symbols that are used in circuit diagrams, Illustration 1 shows the more common Caterpillar electrical symbols.

Schematic Features

Caterpillar electrical schematics contain very valuable information. The information is printed on the front and reverse side of the schematic. The technician needs to become very skilled in reading and interpreting all the information that is contained on both sides of the schematic.

The following features are found on the front of a schematic:

- Color codes for circuit identification
- Color abbreviation codes
- Symbol descriptions
- Wiring harness information
- Schematic notes and conditions
- Grid design for component location
- Component part numbers

The following information is recommended for clearing up the confusion that is associated with dashed lines:

- Dashed colored lines represent attachment circuits. Use the color identification code that is located on the schematic in order to determine the circuit.
- The heavy double dashed lines identify the circuitry and components that are located in the operator station.
- A dashed (thin black) line is used to identify an attachment, wire, cable, or component. (See the symbol description on the schematic).

Machine Electrical Schematics with New Format

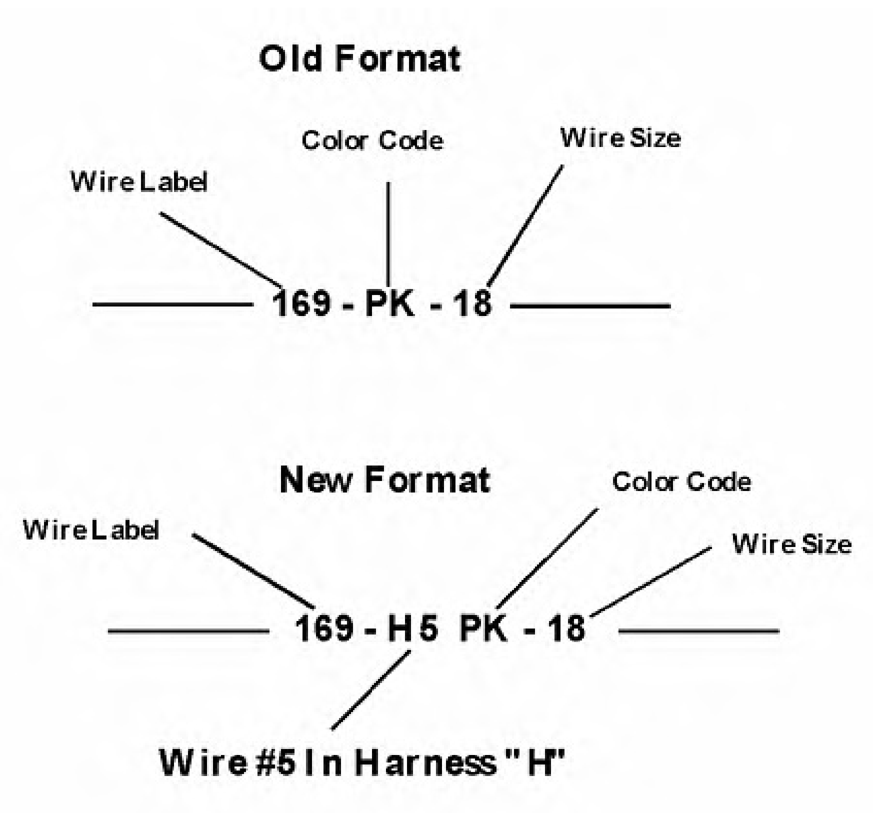

Illustration 2 g01072790

Some Caterpillar machines use a new format for electrical system schematics. The new format is called PRO/E and provides additional information for wire, connector, component and splice symbols. The following information describes the new format.

Wire Identification Labels

Illustration 2 shows the new wire identification format. The label includes the circuit identification wire label number "169", harness identification code "H", the wire number in the harness "5", color code "PK" and the wire size "18".

Note: The codes that are shown are examples of the new identification system. Consult the appropriate electrical schematic for more detailed, accurate information.

Connectors

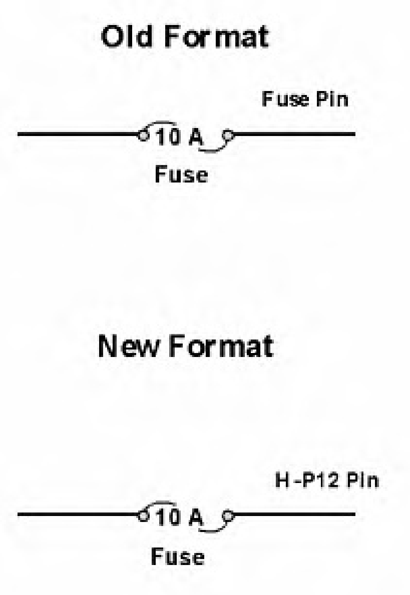

Illustration 3 g01072793

The new connector identification format includes the harness identification code "H", identifies the assembly as a connector "C", identifies the number of the connector within the harness "7", and lists the connector part number 3E3382.

Note: The codes that are shown are examples of the new identification system. Consult the appropriate electrical schematic for more detailed, accurate information.

Components

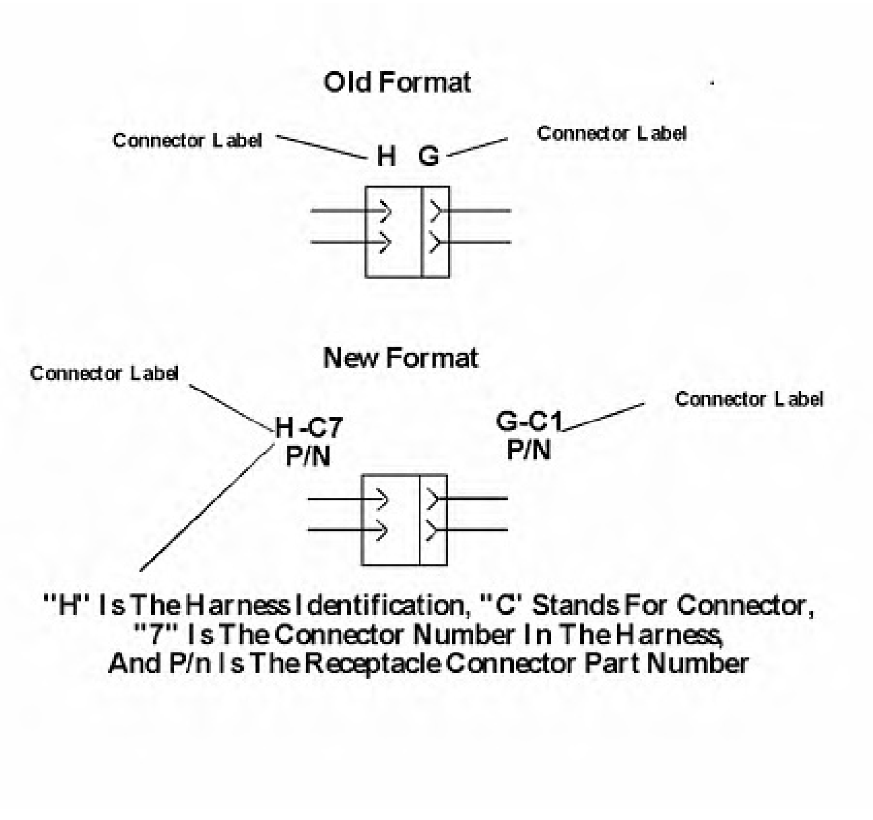

Illustration 4 g01072792

The previous method of component labeling on a schematic shows the descriptive name and the component part number. The schematics that are drawn in PRO/E format contain a harness identification letter "H", and a serializing code "P-12". "P" stands for part and "12" stands for harness position (number "12" part in harness "H"), and the component part number 113-8490 .

Note: The codes that are shown are examples of the new identification system. Consult the appropriate electrical schematic for more detailed, accurate information.

Splices

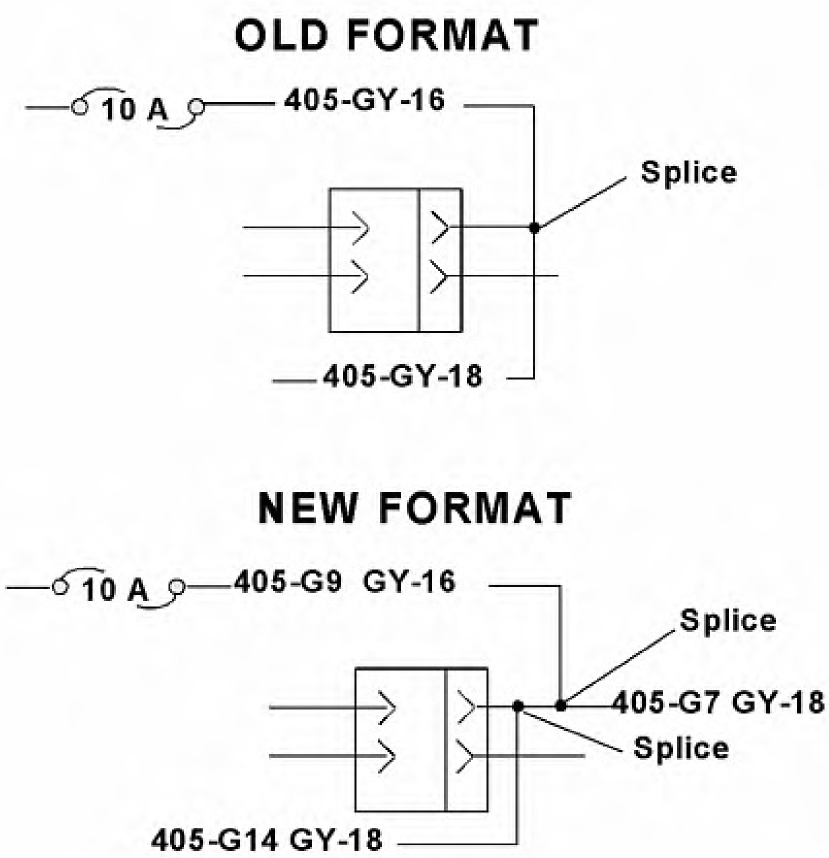

Illustration 5 g01072794

The PRO/E format for splices uses two connection points to indicate which side a given wire exits. The previous splice symbol used a simple filled in dot to indicate a splice.

The new format shows that in harness "G", wire "405-G9 GY-16" is spliced into two wires, "405-G7 GY-18" and "405-G14 GY-18".

Note: The codes that are shown are examples of the new identification system. Consult the appropriate electrical schematic for more detailed and accurate information.

The following features are listed on the back of the schematic:

- Harness and wire electrical schematic symbols and identification
- Electrical schematic symbols and definitions
- Wire description chart
- Related electrical service manuals
- Harness connector location chart
- Off machine switch specifications

- Machine harness connector and component locations, identified as a machine silhouette
- Component Identifier (CID) list and flash code conversion
- Component location chart
- Resistor and solenoid specifications
- Failure Mode Identifier (FMI) list

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i02096635

Electricity - How It Works

SMCS - 1400; 1450

Introduction to Electricity

Flashlights, electric drills, and motors are electric. Computers and televisions are refered as electronic.

Any component that works with electricity is electric, including both flashlights and electric drills, but not all electric components are electronic. The term electronic refers to semiconductor devices known as electron devices. These devices depend on the flow of electrons for operation.

Illustration 1 g01068921

To better understand electricity, it is necessary to have a basic knowledge of the fundamental atomic structure of matter. Matter has mass and occupies space. Matter can take several forms or states. The three common forms are a solid, a liquid and a gas. This course will provide a basic understanding of the theoretical principles needed to develop a foundation for studying and working with electrical circuits and components as a Caterpillar technician.

Matter and Elements

Matter takes up space and has weight when matter is subjected to gravity. Matter consists of extremely tiny particles grouped together to form atoms. There are approximately 100 different naturally, occurring atoms called elements. An element is a substance that cannot be decomposed any further by chemical action. Most elements have been found in nature. The following are examples of some of the natural elements: copper, lead, iron, gold and silver. Other elements (approximately 14) have been produced in the laboratory. Elements can only be changed by an atomic reaction or nuclear reaction. Elements can be combined to make compounds. The atom is the smallest particle of an element that still has the same characteristics as the element. Atom is the greek word meaning a particle too small to be subdivided.

Atoms

Although an atom has never been seen, the structure fits evidence that has been measured accurately. The size and electric charge of the invisible particles in an atom are indicated, by how much the atoms are deflected by known forces. The present atomic model, with a nucleus at the center was proposed by Niels Bohr in 1913. The atomic model is patterned after the solar system with the sun at the center and the planets revolving around it.

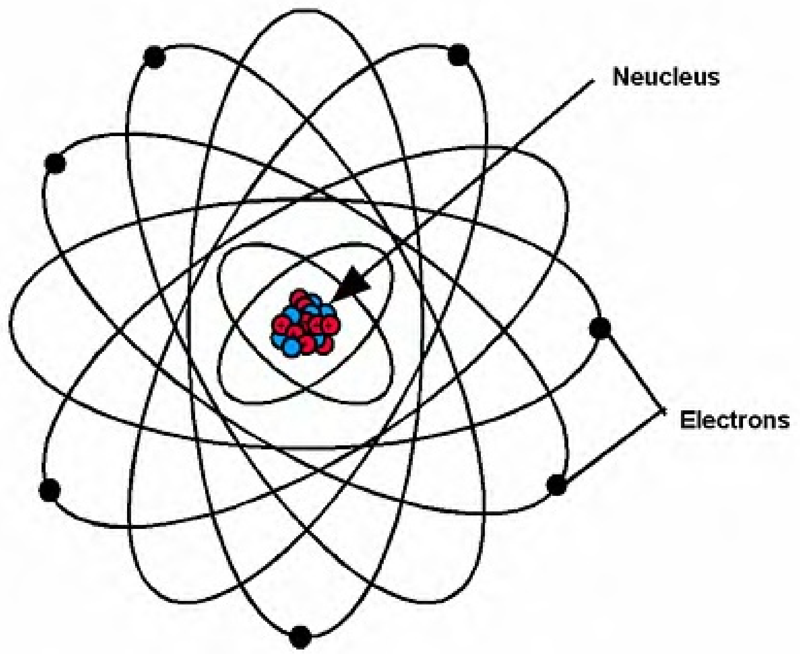

Illustration 2 g01068922

The center of an atom is called the nucleus. The nucleus is composed primarily of particles called protons and neutrons. Orbiting around every nucleus are small particles called electrons. These electrons are much smaller in mass than either the proton or neutron. Normally, an atom has an equal number of protons in the nucleus and electrons around the nucleus. The number of protons or electrons is called the atomic number. The atomic weight of an element is the total number of particles, protons, and neutrons that are in the nucleus.

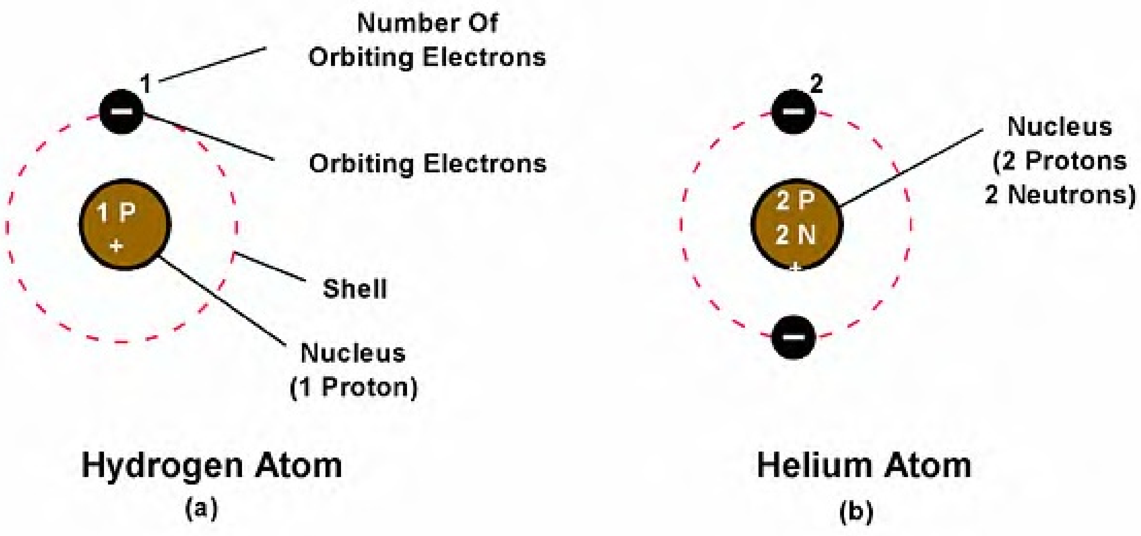

Illustration 3 g01068923

Illustration 3 shows the structure of two of the simpler atoms. Illustration 3(a) is an atom of hydrogen, which contains 1 proton in its nucleus balanced by 1 electron in the orbit or shell. The atomic number for a hydrogen atom is 1. Illustration 3(b) shows a simple atom of helium, which has 2 protons in its nucleus balanced by 2 electrons in orbit. The atomic number for helium is 2 and the atomic weight would be 4 (2 protons + 2 neutrons).

Scientists have discovered many particles in the atom. In order to explain basic electricity, only three particles will be discussed: electrons, protons and neutrons. To better understand the basics of electricity, we will use an atom of copper as an example.

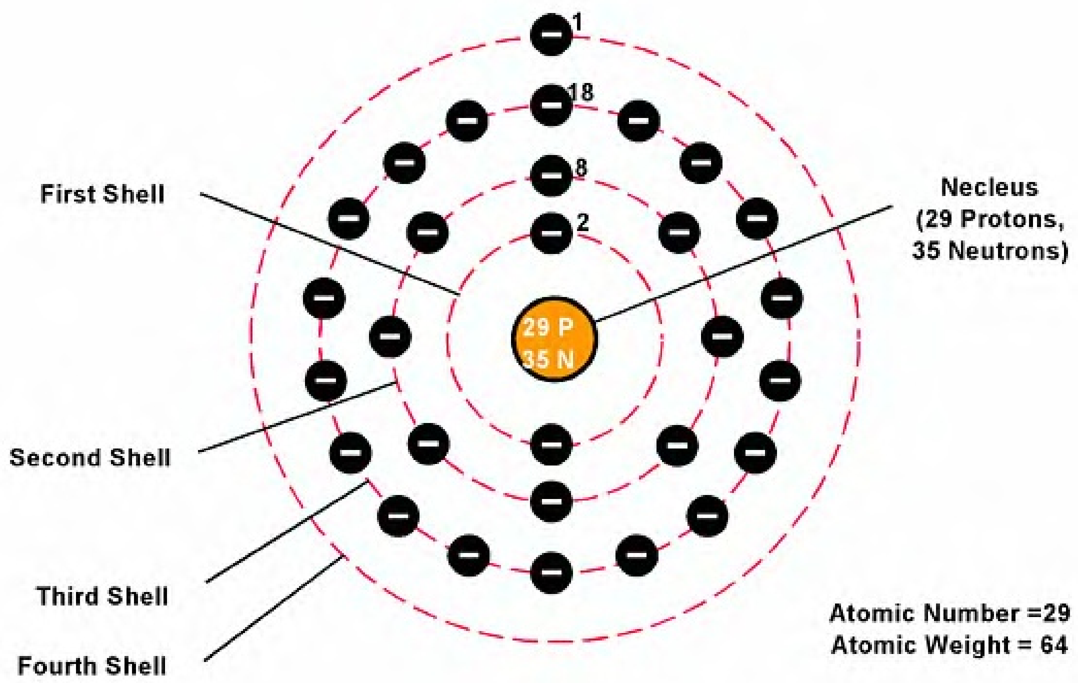

Illustration 4 g01068924

Illustration 4 shows a typical copper atom. The nucleus of the atom is not much bigger than an electron. In the copper atom the nucleus contains 29 protons (+), 35 neutrons. The copper atom has 29 electrons (-) orbiting the nucleus. The atomic number of the copper atom is 29 and the atomic weight is 64. When a length of copper wire is connected to positive and negative source, such as a dry cell battery, the following process occurs.

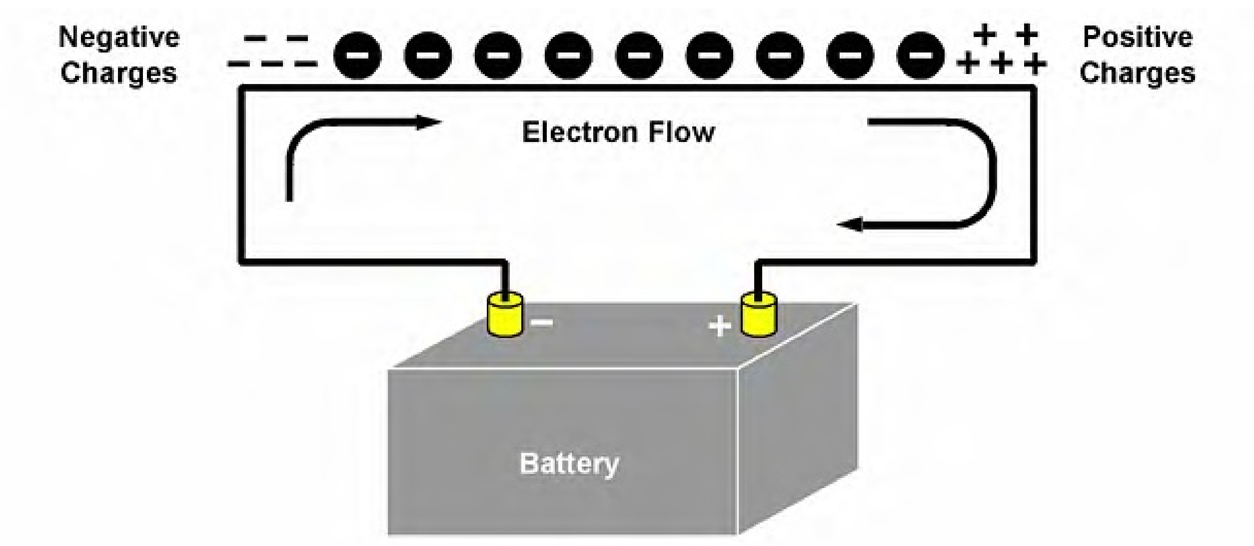

Illustration 5 g01068926

An electron (-) is forced out of orbit and attracted to the positive (+) end of the battery. The atom is now positive (+) charged because it now has a deficiency of electrons (-). The atom in turn attracts an electron from a neighbor. The neighbor in turn receives an electron from the next atom, and so on until the last copper atom receives an electron from the negative end of the battery.

The result of this chain reaction is that the electrons move through the conductor from the negative end to the positive end of the battery. The flow of electrons will continue as long as the positive charges and negative charges from the battery are maintained at each end of the conductor.

Electrical Energy

There are two types of forces at work in every atom. Under normal circumstances, these two forces are in balance. The protons and electrons exert forces on one another. These are over and above gravitational or centrifugal forces. Besides mass, electrons and protons carry an electric charge. These additional forces are attributed to the electric charge that they carry. However, there is a difference in the forces. Between masses, the gravitational force is always one of attraction while the electrical forces both attract and repel. Protons and electrons attract one another, while protons exert forces of repulsion on other protons, and electrons exert repulsion on other electrons.

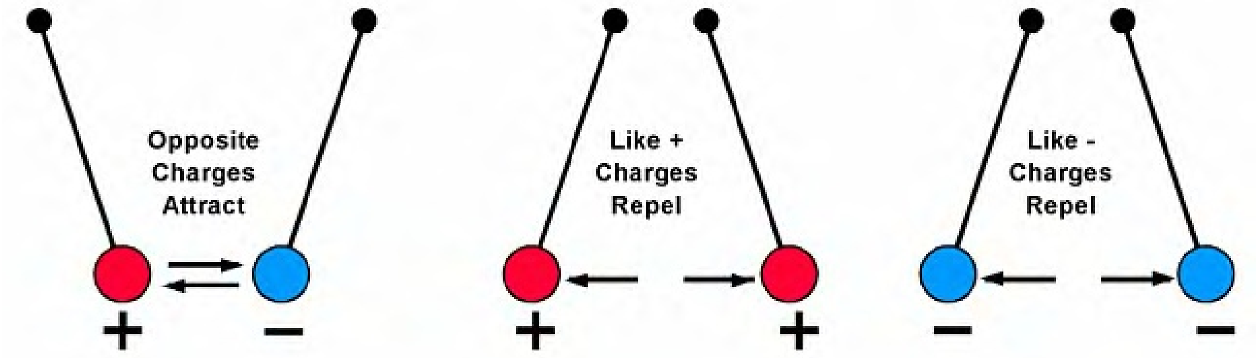

Illustration 6 g01068928

There appears to be two kinds of electrical charge. The protons are said to be positive (+). The electrons are said to be negative (-). The neutron carries a neutral charge. Polarity is based on directional flow of electricty. The type of change determines direction. This leads to the basic law of electrostatic which states, UNLIKE charges attract each other, while LIKE charges repel each other.

Charges and Electrostatics

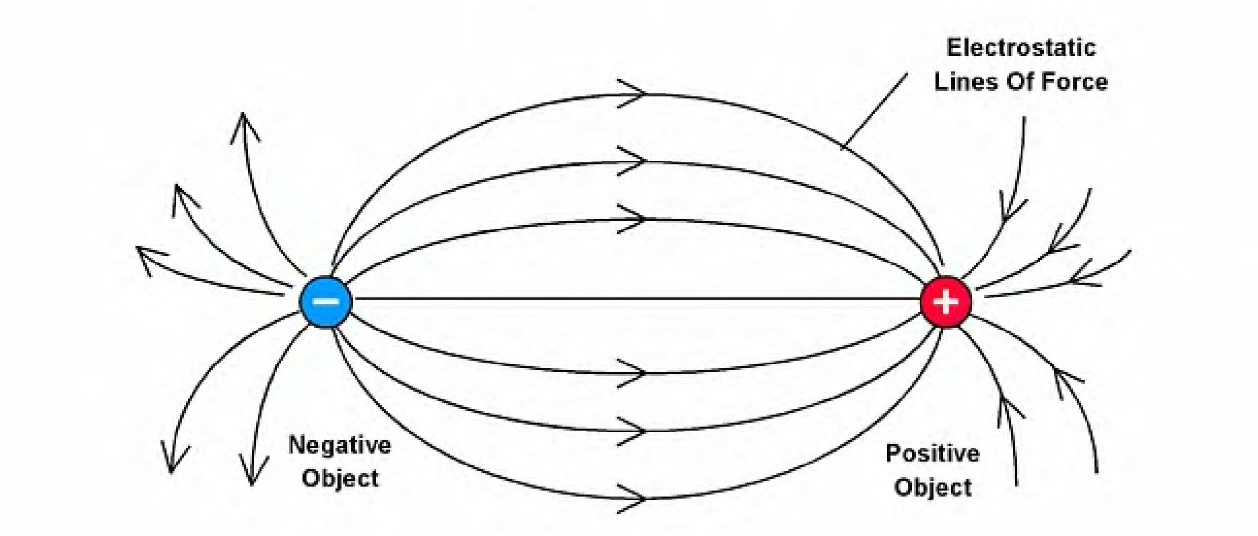

Illustration 7 g01068930

The attraction or repulsion of electrically-charged bodies is due to an invisible force called an electrostatic field, which surrounds the charged body. Illustration 7 shows the force between charged particles as imaginary electrostatic lines from the negative charge to the positive charge.

When two like charges are placed near each other, the lines of force repel each other as shown below.

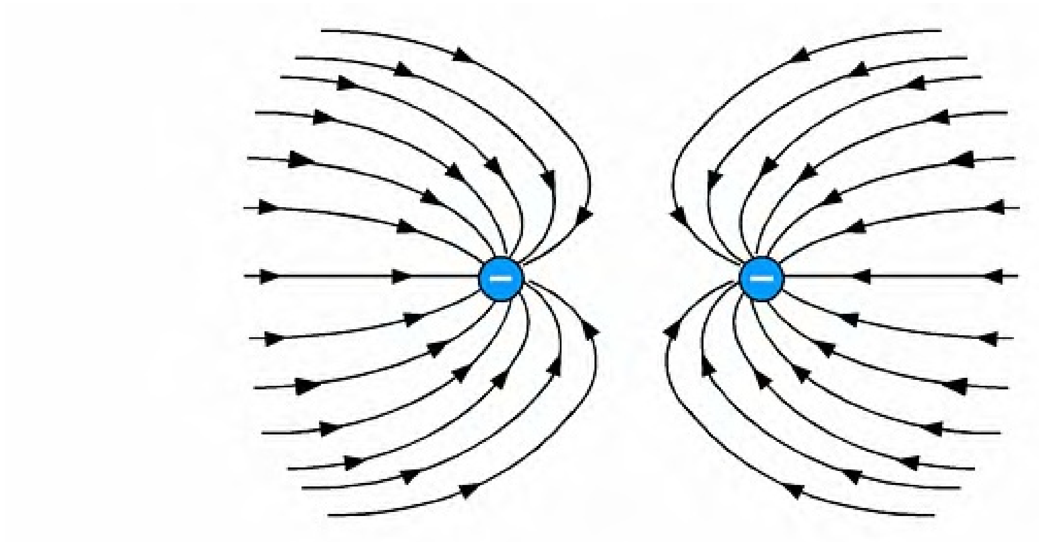

Illustration 8 g01068932

Potential Difference

Because of the force of the electrostatic field, an electric charge has the ability to move another charge by attraction or by repulsion.

The ability to attract or repell is called potential. When one charge is different from the other, there must be a difference in potential between them.

The sum difference of potential of all charges in the electrostatic field is referred to as electromotive force (EMF). The basic unit of potential difference is the volt (V). The volt is named in honor of Alessandro Volta an Italian scientist. Volta invented the voltaic pile, the first battery cell. The symbol for potential is V, that indicates the ability to force electrons to move. Because the volt unit is used, the potential difference is called voltage.

The following conditions will produce voltage: friction, solar, chemical and electromagnetic induction. A photocell, such as on a calculator, would be an example of producing voltage from solar energy.

Coulomb

A need existed to develop a unit of measurement for electrical charge. A scientist named Charles Coulomb investigated the law of forces between charged bodies and adopted a unit of measurement that is called the Coulomb. When the Coulomb is written in scientific notation this measurement is expressed as One.

Coulomb = 6.28×10^{18} electrons or protons. Stated in simpler terms, in a copper conductor, one ampere is an electric current of 6.28 billion electrons passing a certain point in the conductor in one second.

Current

Another theory that needs to be explained is the theory of motion in a conductor. The motion of charges in a conductor is an electric current. An electron will be affected by an electrostatic field in the same manner as any negatively charged body. An electron is repelled by a negative charge and attracted by a positive charge. The drift of electrons or movement constitutes an electric current.

The magnitude or intensity of current is measured in amperes. The unit symbol is A. An ampere is a measure of the rate when a charge is moved through a conductor. One ampere is a coulomb of charge that moves past a point in one second.

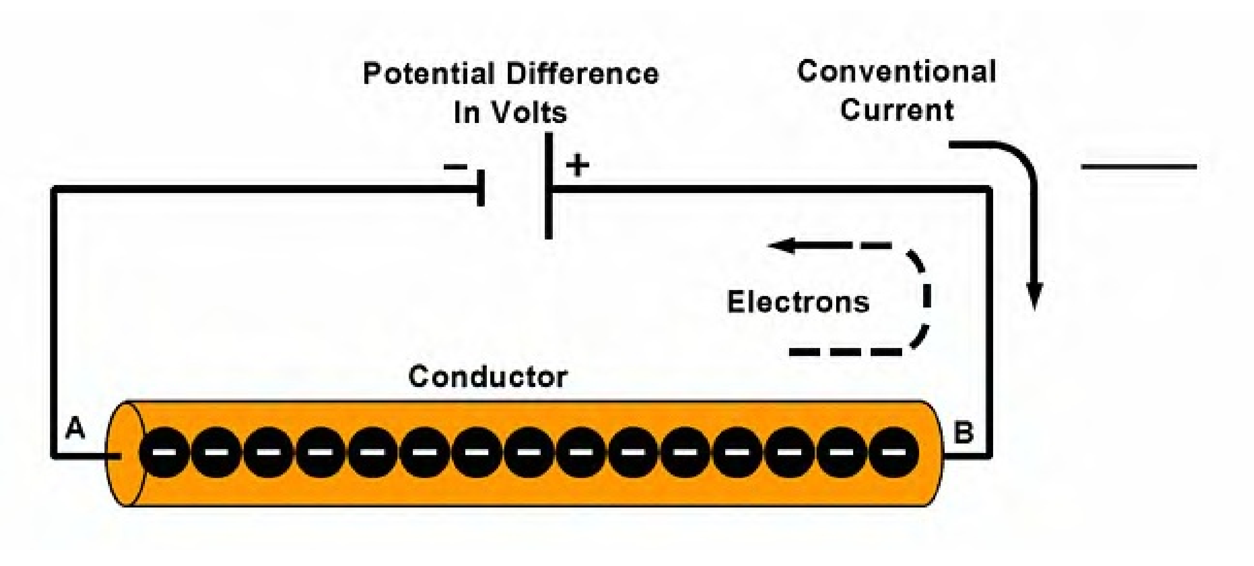

Illustration 9 g01068934

Conventional versus Electron Flow

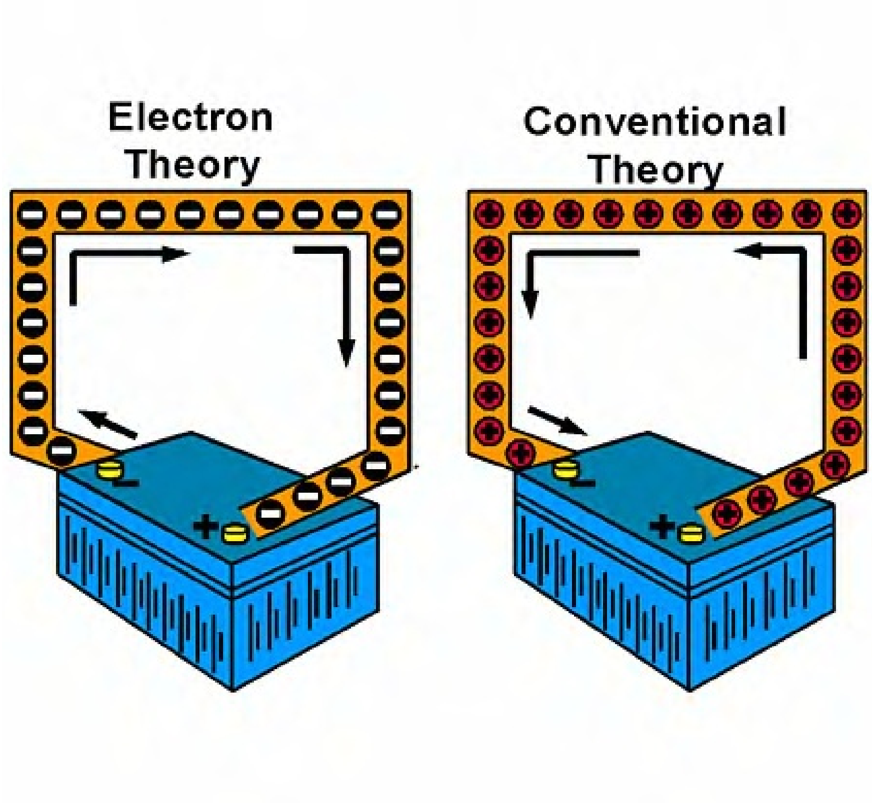

Illustration 10 g01068935

There are two ways to describe an electric current flowing through a conductor. Prior to the use of atomic theory to explain the composition of matter, scientists defined current as the motion of positive charges in a conductor from a point of positive polarity to a point of negative polarity. This conclusion is still widely held in some engineering standards and textbooks. Some examples of positive charges in motion are applications of current in liquids, gases, and semiconductors. This theory of current flow has been termed conventional current.

With the discovery of using atomic theory to explain the composition of matter, it was determined that current flow through a conductor was based on the flow of electrons (-), or negative charge. Therefore, electron current is in the opposite direction of conventional current and is termed electron current.

Either theory can be used, but the more popular conventional theory describing current as flowing from a positive (+) charge to a negative (-) charge will be used in this course.

Resistance

George Simon Ohm discovered that for a fixed voltage, the amount of current flowing through a material depends on the type of material and the physical dimensions of the material. In other words, all materials present some opposition to the flow of electrons. That opposition is termed resistance. If the opposition is small, the material is labeled a conductor. If the opposition is large, it is labeled an insulator.

The Ohm is the unit of electrical resistance. The symbol to represent an Ohm is the Greek letter omega, Ohms. A material is said to have a resistance of one ohm, if a potential of one volt results in a current of one ampere.

It is important to remember that electrical resistance is present in every electrical circuit, including components, interconnecting wires, and connections. Electrical circuits and the laws that relate to the electrical circuits will be discussed later in this unit.

As resistance works to oppose current flow, it changes electrical energy into other forms of energy, such as, heat, light, or motion. The resistance of a conductor is determined by four factors:

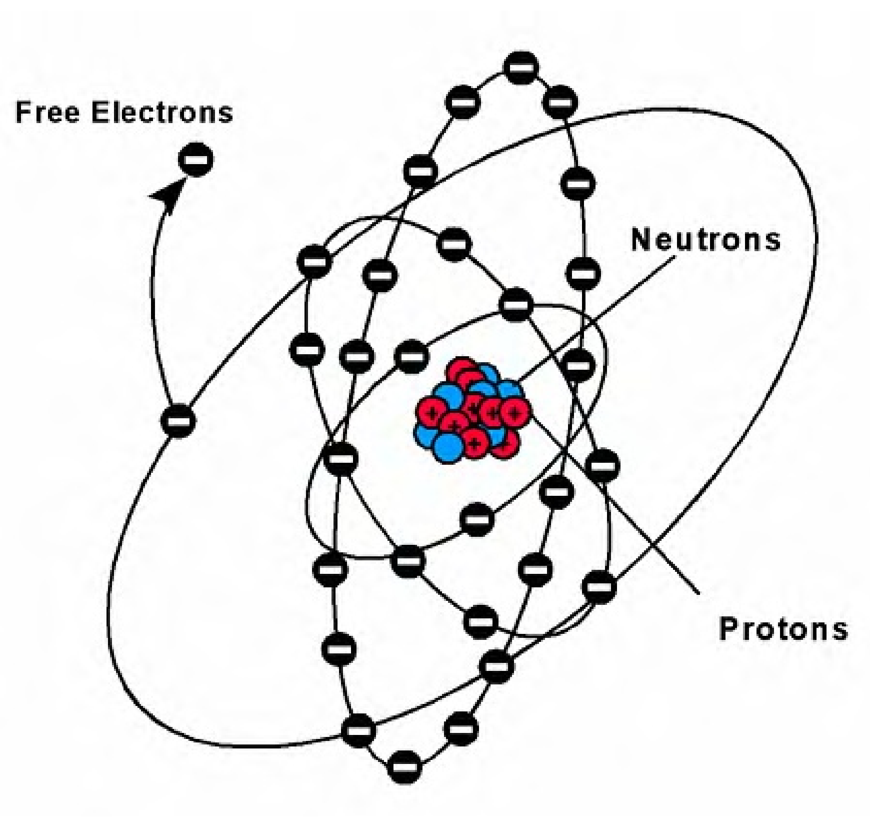

Illustration 11 g01068936

1. Atomic structure is the amount of free electrons. The more free electrons a material has, the less resistance that is offered to current flow.

2. Length. The longer the conductor, the higher the resistance. If the length of the wire is doubled, as shown in Illustration 12(a), the greater the resistance between the two ends.

3. Width (cross sectional area). The larger the cross sectional area of a conductor, the lower the resistance (a bigger diameter pipe allows for more water to flow). If the cross section area is reduced by half, as shown in Illustration 12(b), the resistance for any given length is increased by a factor of 4.

4. Temperature. For most materials, the higher the temperature, the higher the resistance. Illustration 12(c) shows the resistance increasing as the temperature rises. Please note, there are a few materials whose resistance decreases as temperature increases.

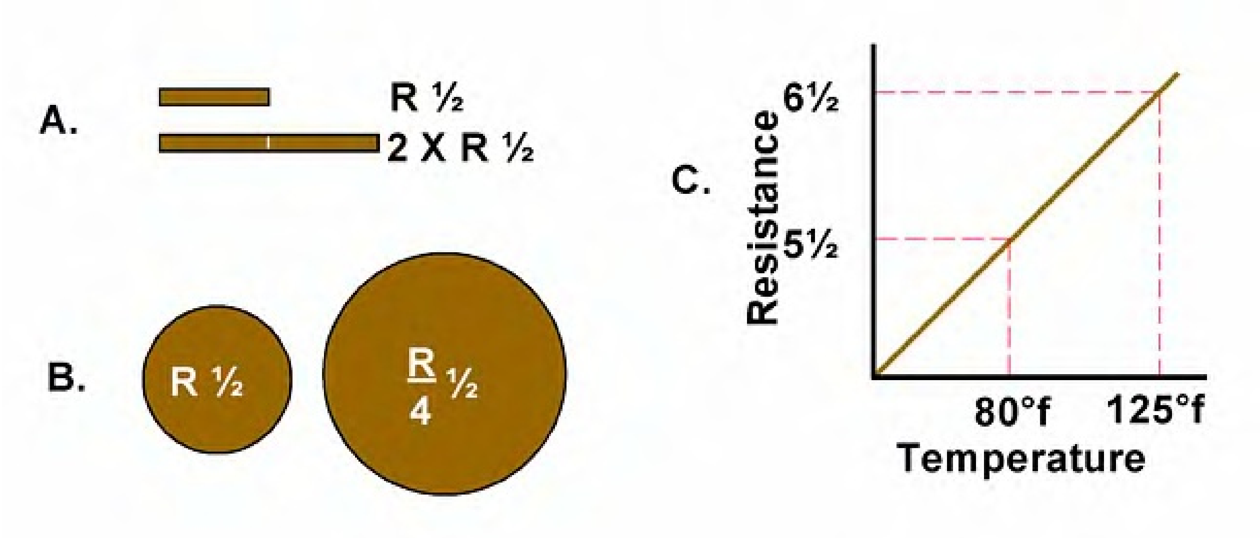

Illustration 12 g01068937

Electrical Circuits and Laws

An electrical circuit is a path or a group of interconnecting paths, that are capable of carrying electrical currents. The electrical circuit is a closed path that contains a voltage source or sources. There are two basic types of electrical circuits: series and parallel. The basic series and parallel circuits may be combined to form more complex circuits, but these combinational circuits may be simplified and analyzed as the two basic types. It is important to understand the laws that are needed to analyze electrical circuits and to diagnose electrical circuits. They are Kirchoff's Laws and Ohm's Law.

Gustav Kirchoff developed two laws for analyzing circuits. The two laws are stated below:

- Kirchoff's Current Law (KCL) states that the algebraic sum of the currents at any junction in an electrical circuit is equal to zero. Simply stated, all the current that enters a junction is equal to all the current that leaves the junction.
- Kirchoff's Voltage Law (KVL) states that the algebraic sum of the electromotive forces and voltage drops around any closed electrical loop is zero. Simply said, the addition of all differences of potential in a closed circuit will equal zero.

George Simon Ohm discovered one of the most important laws of electricity. The law describes the relationship between three electrical parameters: voltage, current and resistance. Ohms' law is stated as follows: The current in an electrical circuit is directly proportional to the voltage and inversely proportional to the resistance. The relationship can be summarized by a single mathematical equation:

Current = Electromotive Force/Resistance

or, stated in electrical units: I= Volts/Ohms

Single letters are used to represent mathematical equations that express electrical relationships. Resistance is represented by the letter R or the Omega symbol (Ohms). The voltage or the difference in potential is represented by the letter E or the letter V (electromotive force). Current is represented by the letter I (intensity of charge). Using these laws to calculate circuits will be discussed later in this course.

Electrical Conductors

In electrical applications, electrons travel along a path that is called a conductor or a wire. The electrons move by traveling from atom to atom. Some materials make it easier for electrons to travel.These are called good conductors.

The following materials are examples of good conductors :

- silver
- copper
- gold
- chromium
- aluminum
- tungsten

A material is said to be a good conductor if the material has many free electrons. The amount of electrical pressure or voltage it takes to move electrons through a material depends on how free the electrons are.

Although silver is the best conductor, silver is also expensive. Gold is a good conductor, but gold is not as good as copper. The advantage gold has is gold will not corrode like copper. Aluminum is not as good as copper, but is less expensive and lighter.

The conductivity of a material determines the quality of the material. Illustration 13 shows some of the common conductors and the relative conductivity to copper.

CONDUCTIVITY CHART

Conductor	Conductivity (to copper)
Silver	1.064
Copper	1.000
Gold	0.707
Aluminum	0.659
Zinc	0.288
Brass	0.243
Iron	0.178
Tin	0.018

Illustration 13 g01068940

Other materials make it difficult for electrons to travel. These materials are called insulators. A good insulator keeps the electrons tightly bound in orbit. The following examples of insulators are: rubber, wood, plastics and ceramics. It is possible to make an electric current flow through every material. If the applied voltage is high enough, even the best insulators will break down and will allow current flow. The following chart, shown in Illustration 14, lists some of the more common insulators.

COMMON INSULATORS

Rubber	Plastics
Mica	Glass
Wax or Paraffin	Fiberglass
Porcelain	Dry Wood
Bakelite	Air

Illustration 14 g01068943

Dirt and moisture may serve to conduct electricity around an insulator. A dirty insulator or moisture could cause a problem. The insulator is not breaking down, but the dirt or moisture can provide a path for electrons to flow. It is important to keep the insulators and contacts clean.

Wires

A wire in an electrical circuit is made up of a conductor and an insulator. The conductor is typically made up of copper and the insulator (outside covering) is made of plastic or rubber. Conductors can be a solid wire or a stranded wire. In most earthmoving applications, the wire is stranded copper with a plastic insulation. This insulation covers the conductor.

There are many sizes of wire. The smaller the wire is, the larger the identification number. The numbering system is known as the American Wire Gage (AWG). Illustration 15 describes the AWG wire size standard.

AWG	Diameter (mils)	Ohms per 1000 ft
10	102.9	.9989
12	80.8	1.588
14	64.1	2.525
16	50.8	4.016
18	40.3	6.385
20	32.0	10.15
22	25.4	16.14
24	10.0	103.2
26	3.10	1049.0

Illustration 15 g01068945

Resistance can also be affected by other conditions, such as, corrosion. These conditions need to be considered when resistance measurements are made.

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Magnetism

SMCS - 1400; 1450

Introduction to Magnetism

Magnetism is another form of force that causes electron flow or current. A basic understanding of magnetism is necessary to study electricity. Magnetism provides a link between mechanical energy and electricity. The use of magnetism causes an alternator to convert some of the mechanical power developed by an engine to electromotive force (EMF). Magnetism will allow a starter motor to convert electrical energy from a battery into mechanical energy for cranking the engine.

The Nature of Magnetism

Most electrical equipment depends directly or indirectly upon magnetism. There are a few electrical devices that do not use magnetism.

There are three basic types of magnets:

- Natural
- Man-made
- Electromagnets

Natural Magnets

The Chinese discovered magnets about 2637 B.C. The magnets that were used in the primitive compasses were called lodestones. Lodestones were crude pieces of iron ore. The lodestones are known as magnetite. Since magnetite has magnetic properties in the natural state, lodestones are classified as natural magnets.

Man-made Magnets

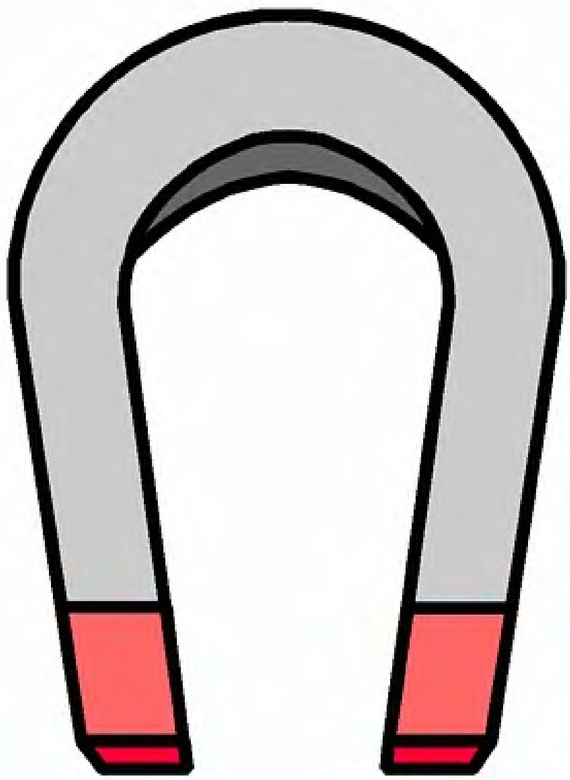

Illustration 1 g01069088

Man-made magnets are typically produced in the form of metal bars. These bars have been subjected to very strong magnetic fields. All man-made magnets are produced. These man-made magnets are sometimes referred to as artificial magnets.

Electromagnets

A Danish scientist named Oersted discovered a relation between magnetism and electric current. Oersted discovered that an electric current flowing through a conductor produced a magnetic field around the conductor.

Magnetic Fields

Every magnet has two points opposite each other which attract pieces of iron. These points are called the poles of the magnet: the north pole and the south pole. Just like electric charges repel each other and opposite charges attract each other, like magnetic poles repel each other and unlike poles attract each other.

A magnet clearly attracts a bit of iron because of some force that exists around the magnet. This force is called a magnetic field. Although it is invisible to the naked eye, the force can be shown by sprinkling small iron filings on a sheet of glass or paper over a bar magnet. In Illustration 1, a piece of glass is placed over a magnet and iron filings are sprinkled on the glass. When the glass cover is gently tapped the filings will move into a definite pattern, which shows the field force around the magnet.

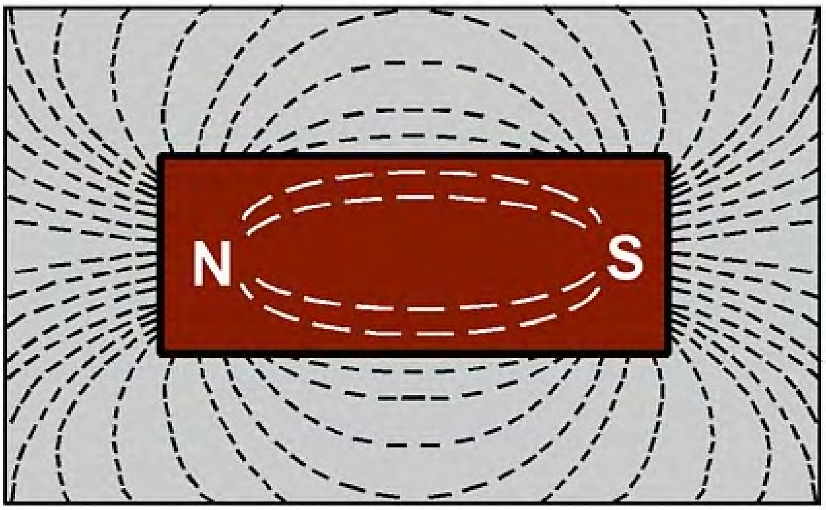

Illustration 2 g01069089

The field seems to be made up of lines of force that appear to leave the magnet at the north pole. The lines of force travel through the air around the magnet. The lines of force continue through the magnet to the south pole to form a closed loop of force. The stronger the magnet is, the greater the lines of force are, and the larger the area covered by the magnetic field.

Lines of Force

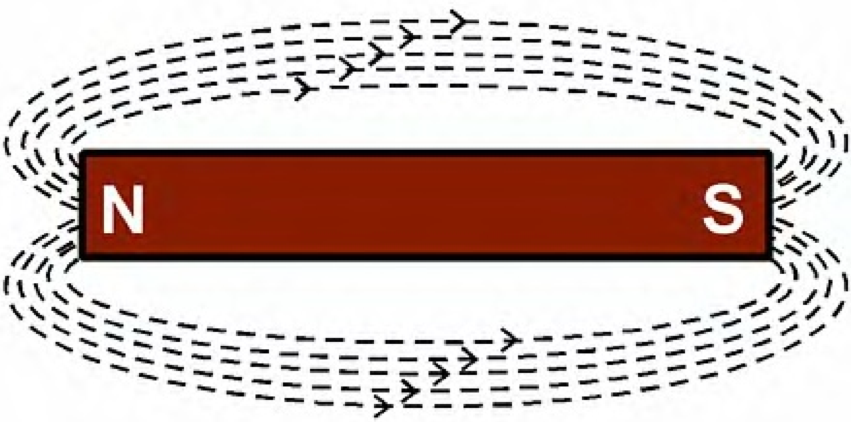

Illustration 3 g01069091

To better visualize the magnetic field without iron filings, the field is shown as lines of force in Illustration 3. The direction of the lines outside the magnet shows the path a north pole would follow in the field, repelled away from the north pole of the magnet and attracted to the south pole. Inside the magnet, which is the generator for the magnetic field, the lines are from south pole to north pole.

Lines of Magnetic Flux

The entire group of magnetic field lines is called magnetic flux. The flux density is the number of magnetic field lines per unit of a section perpendicular to the direction of flux. The unit is lines per square inch in the English system. The unit is lines per square centimeter in the metric system. One line per square centimeter is called a gauss.

Magnetic Force

Magnetic lines of force pass through all materials. There is no known insulator against magnetism. Flux lines pass more easily through materials that can be magnetized than through those that cannot be magnetized. Materials that do not readily pass flux lines are said to have high magnetic reluctance. Air has high reluctance. Iron has low reluctance.

An electric current flowing through a wire creates magnetic lines of force around the wire. Illustration 4 shows lines of small magnetic circles that form around the wire.

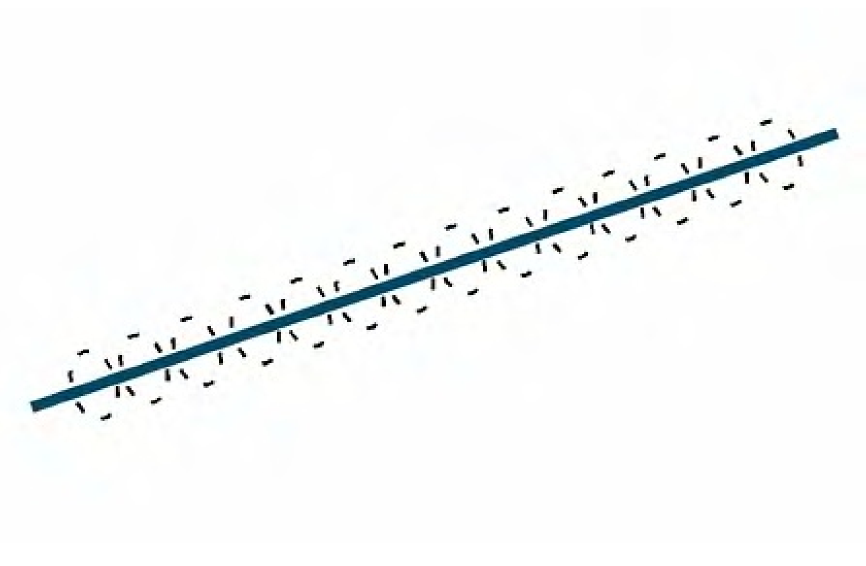

Illustration 4 g01069093

Because such flux line are circular, the magnetic field has no north pole or no south pole. Individual circular fields merge when the wire is wound into a coil. The result is a unified magnetic field with north and south poles, as shown in Illustration 5.

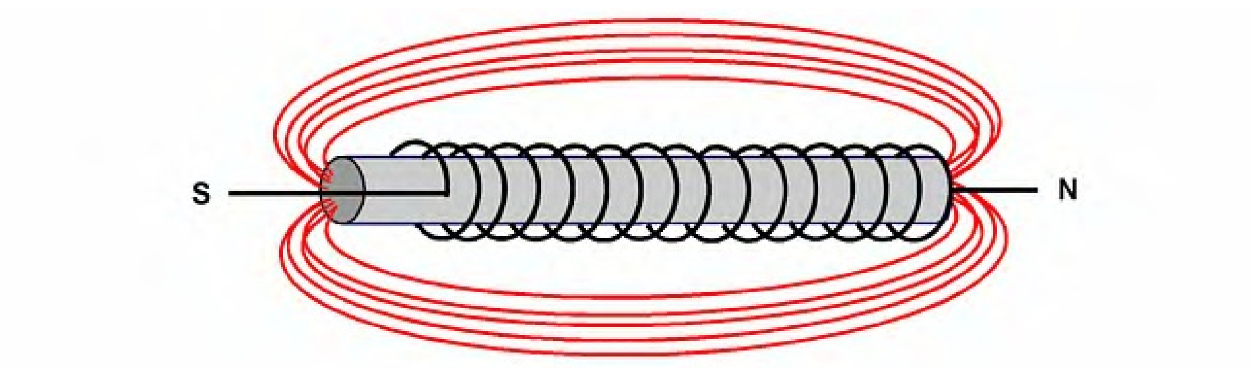

Illustration 5 g01069096

As long as current flows through the wire, it behaves just like a bar magnet. The electromagnetic field remains as long as current flows through the wire. The field that is produced on a straight wire does not have enough magnetism in order to do work. To strengthen the electromagnetic field, the wire can be formed into a coil. The magnetic strength of an electromagnet is proportional to the number of turns of wire in the coil, and the current flowing through the wire. Whenever electrical current flows through the coil of wire, a magnetic field, or lines of force, build up around the coil. If the coils are wound around a metal core, like iron, the magnetic force strengthens considerably.

Relays and Solenoids

Types of electromagnets that are typically used in Caterpillar machines are relays and solenoids. Relays and solenoids operate on the electromagnetic principle, but function differently. Relays are used as an electrically controlled switch. A relay is made up of an electromagnetic coil, a set of contacts, and an armature. The armature is a movable device that allows the contacts to open and to close. Illustration 6 shows the typical components of a relay.

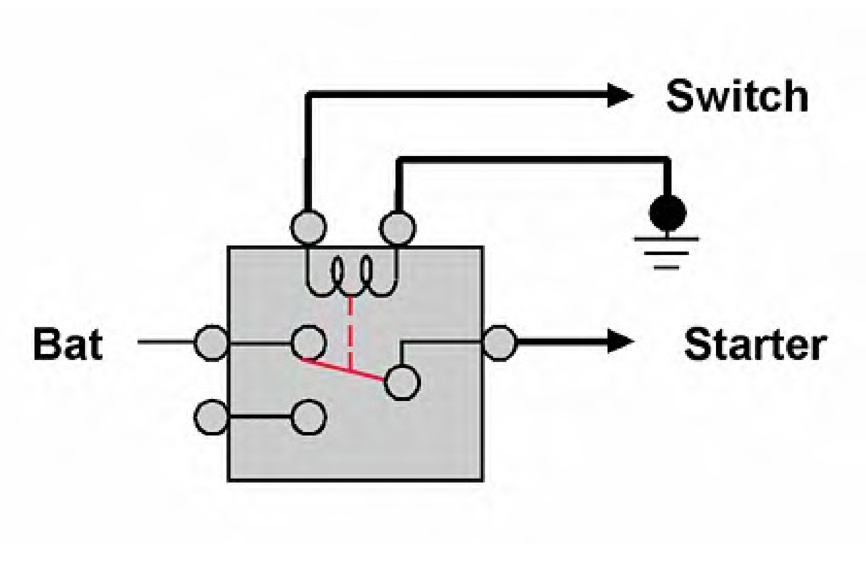

Illustration 6 g01069098

When a small amount of electrical current flows in the coil circuit, the electromagnetic force causes the relay contacts to close. This process provides a much larger current path to operate another component, such as, a starter.

A solenoid is another device that uses electromagnetism. Like a relay, the solenoid also has a coil. Illustration 7 shows a typical solenoid. When current flows through the coil, electromagnetism pushes or pulls the core into the coil creating linear, or back and forth movements. Solenoids are used to engage starter motors, or control shifts in an automatic transmission.

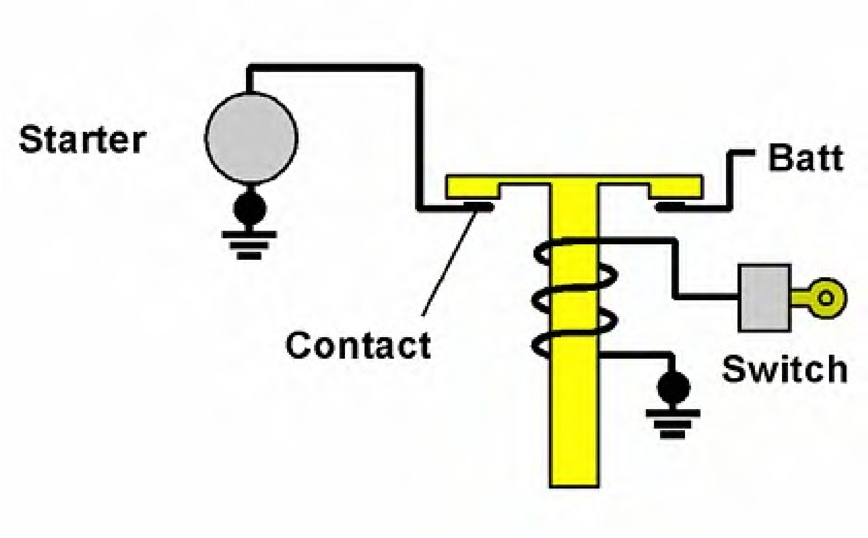

Illustration 7 g01069099

Electromagnetic Induction

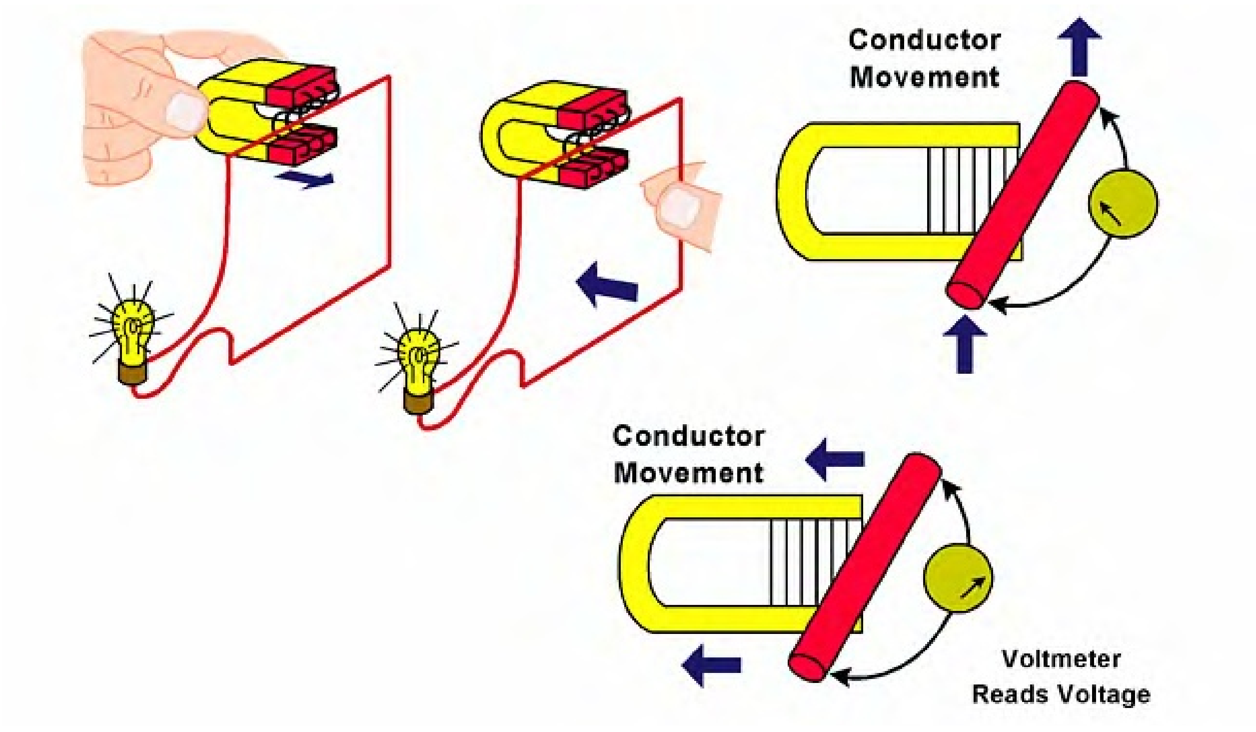

Illustration 8 g01069100

The effect of creating a magnetic field with current has an opposite condition. It is also possible to create current with a magnetic field by inducing a voltage in the conductor. This process is known as electromagnetic induction. Electromagnetic induction happens when the flux lines of a magnetic field cut across a wire or any conductor. It does not matter whether the magnetic field moves or the wire moves. When there is relative motion between the wire and the magnetic field, a voltage is induced in the conductor. The induced voltage causes a current to flow. When the motion stops, the current stops.

If a wire is passed through a magnetic field, voltage is induced. The voltage induced strengthens when the wire is wound into a coil. This method is the operating principle that is used in speed sensors, generators, and alternators. In some cases, the wire is stationary and the magnet moves. In other cases, the magnet is stationary and the field windings move.

Movement in the opposite direction causes current to flow in the opposite direction. This causes back and forth motion to produce AC voltage (current).

In practical applications, multiple conductors are wound into a coil. This concentrates the effects of electromagnetic induction and makes it possible to generate useful electrical power with a relatively compact device. In a generator, the coil moves and the magnetic field is stationary. In an alternator, the magnet is rotated inside a stationary coil.

The strength of an induced voltage depends on several factors:

- The strength of the magnetic field
- The speed of the relative motion between the field and the coil
- The numbers of conductors in the coil

Means of Induction

There are three ways voltage can be induced by electromagnetic induction:

- Generated Voltage
- Self-Induction
- Mutual Induction

Generated Voltage

Illustration 9 shows a simple DC generator that is used to show a moving conductor that passes a stationary magnetic field to produce voltage and current. A single loop of wire is rotating between the north and south poles of a magnetic field.

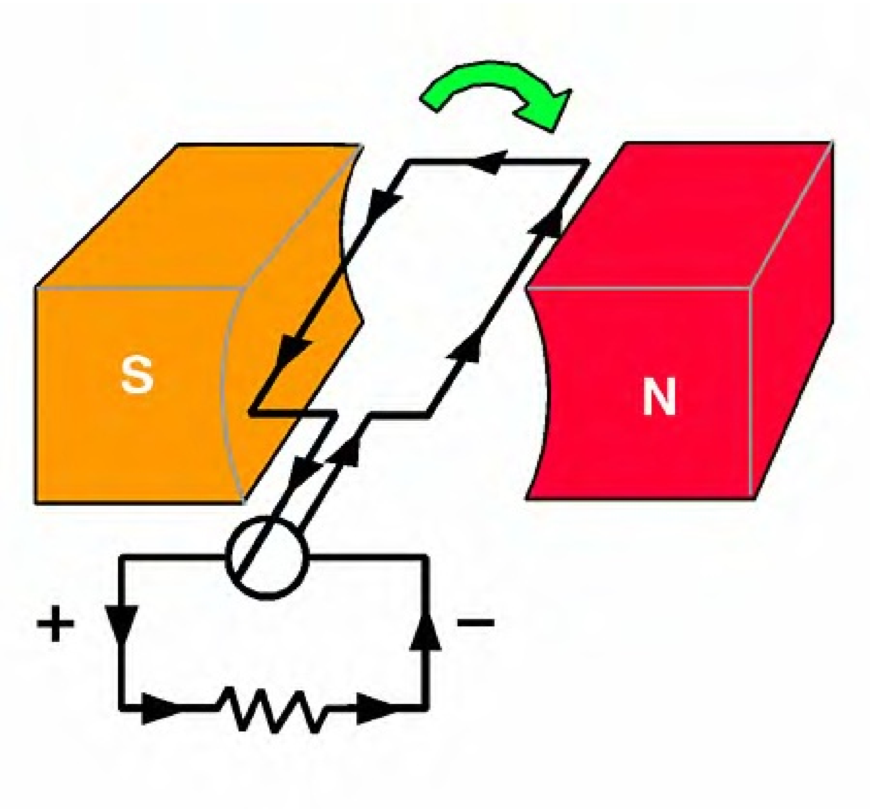

Illustration 9 g01069103

Self-Induction

Self-induction occurs in a current carrying wire when the current flowing through the wire changes. Since the current flowing through the conductor creates a magnetic field around the wire that builds up and collapses as the current changes, a voltage is induced in the conductor. Illustration 10 shows self-induction in a coil.

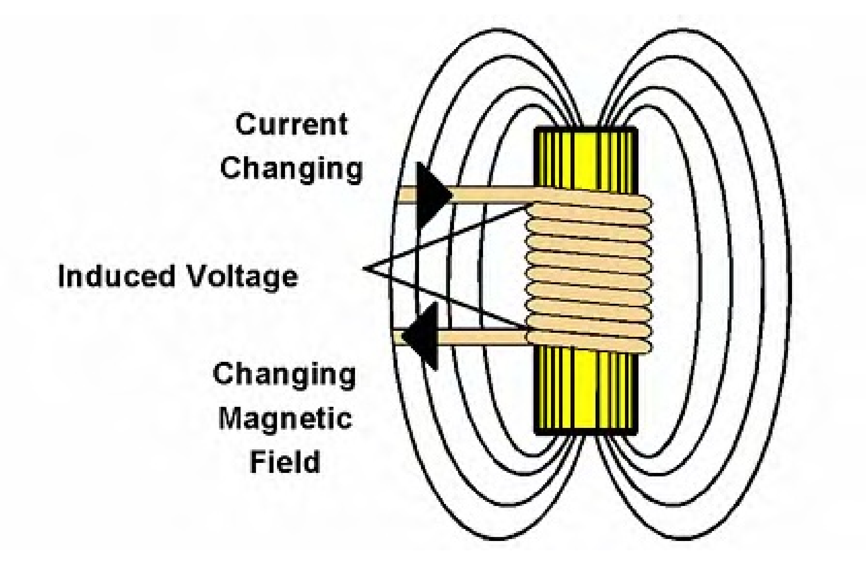

Illustration 10 g01069105

Mutual Induction

Mutual induction occurs when the changing current in one coil induces a voltage in an adjacent coil. A transformer is an example of mutual induction. Illustration 11 shows two inductors that are relatively close to each other. When an AC current flows through coil L1 a magnetic field cuts through coil L2 inducing a voltage and producing current flow in coil L2.

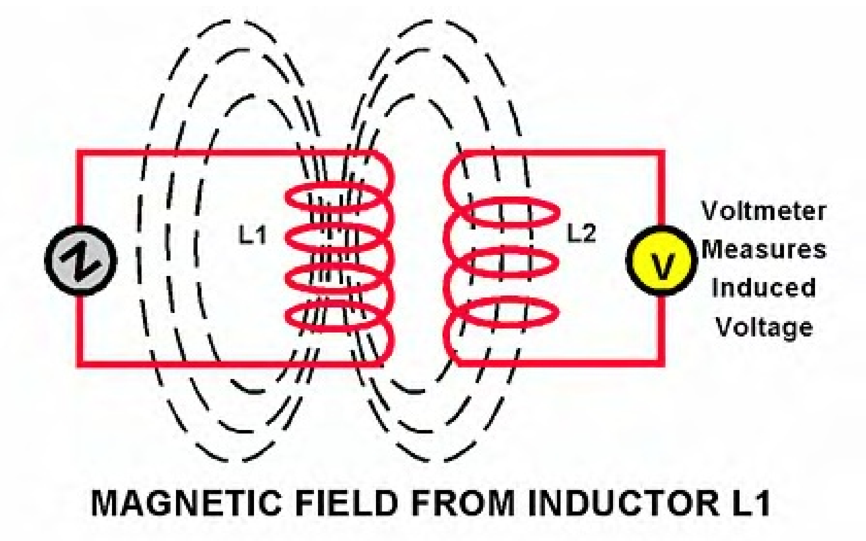

Illustration 11 g01069106

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Ohms Law

SMCS - 1400; 1450

Introduction to Ohm's Law

In 1827 a mathematic reasoning to electronics called Ohm's Law was established by George Simon Ohm. Ohm's Law is a fundamental law of electricity, that relates the quantities of voltage, current, and resistance in a circuit.

Basic Direct Current Circuit Elements

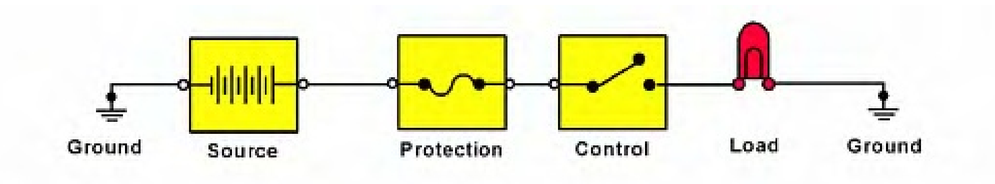

Illustration 1 g01070291

A circuit is a path for electric current. Current flows from one end of a circuit to the other end when the ends are connected to opposite charges. The ends are usually called power and ground. Current flows only in a closed circuit or a completed circuit. Current cannot flow if there is a break in the circuit. Every electrical circuit should contain the following components:

- Power Source
- Protection device (fuse or circuit breaker)
- Load (light)
- Control Device (switch)
- Ground

These devices are connected together with conductors in order to form a complete electrical circuit.

General Rules of Ohm's Law

Ohm's Law states that current flow in a circuit is directly proportional to circuit voltage and inversely proportional to circuit resistance.

This means that the amount of current flow in a circuit depends on how much voltage or how much resistance there is in the circuit.

Since most Caterpillar electrical circuits that are on mobile equipment use a 12 volt source or 24 Volt source, the amount of current will be determined by how much resistance is present in the circuit.

Remember, current flow does the work. Voltage is only the pressure that moves the current. Resistance is opposition to the current flow.

The rules that are needed to understand, predict, and calculate the behavior of electrical circuits are grouped under the title Ohm's Law. You can derive the following general rules from the Ohm's Law equation.

Assuming the resistance does not change:

- As voltage increases, current increases.
- As voltage decreases, current decreases.

Assuming the voltage does not change:

- As resistance increases, current decreases.
- As resistance decreases, current increases.

Ohm's Law Equation

Ohm's Law can be expressed as the following algebraic equation:

- E stands for electromotive force (voltage).
- I stands for intensity (amperage).
- R stands for resistance (ohm's).

If you know two parts of the Ohm's Law equation, you can calculate the third part. For example:

To determine voltage, multiply current times resistance.

To determine current, divide voltage by resistance.

To determine resistance, divide voltage by current.

Ohm's Law Solving Circle

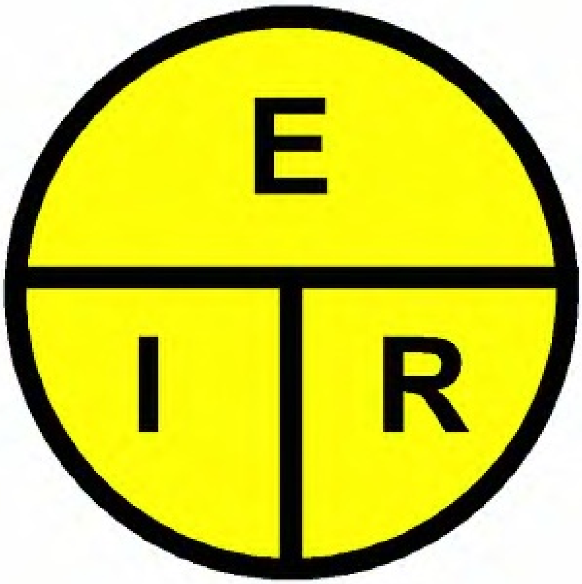

Illustration 2 g01070294

The Ohm's Law solving circle is an easy way to remember how to solve any part of the equation. To use the solving circle (Illustration 2), cover any letter that you do not know. The remaining letters give you the equation for determining the unknown quantity.

Voltage Unknown

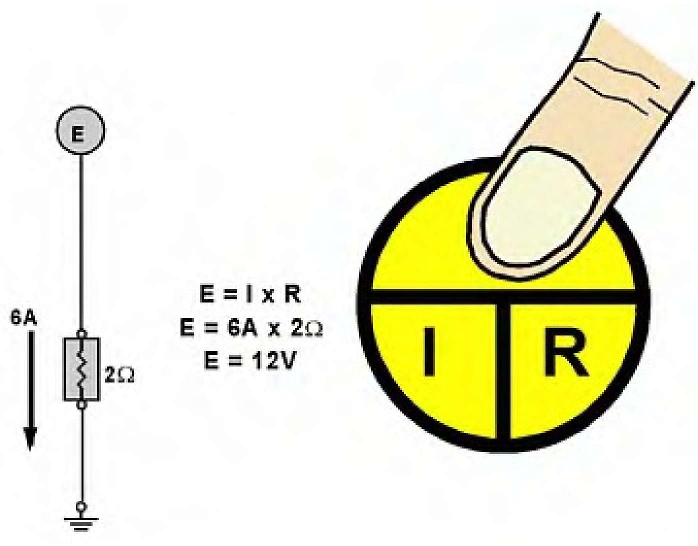

Illustration 3 g01070300

In this circuit, the value of the source voltage is unknown. The resistance of the load is 2 ohms. The current flow through the circuit is 6 amps. Since the voltage is unknown, the equation to solve for voltage is current times resistance. So, multiplying 6 amps times 2 ohms equals 12 volts. Therefore, the source voltage in this circuit is 12 volts.

Resistance Unknown

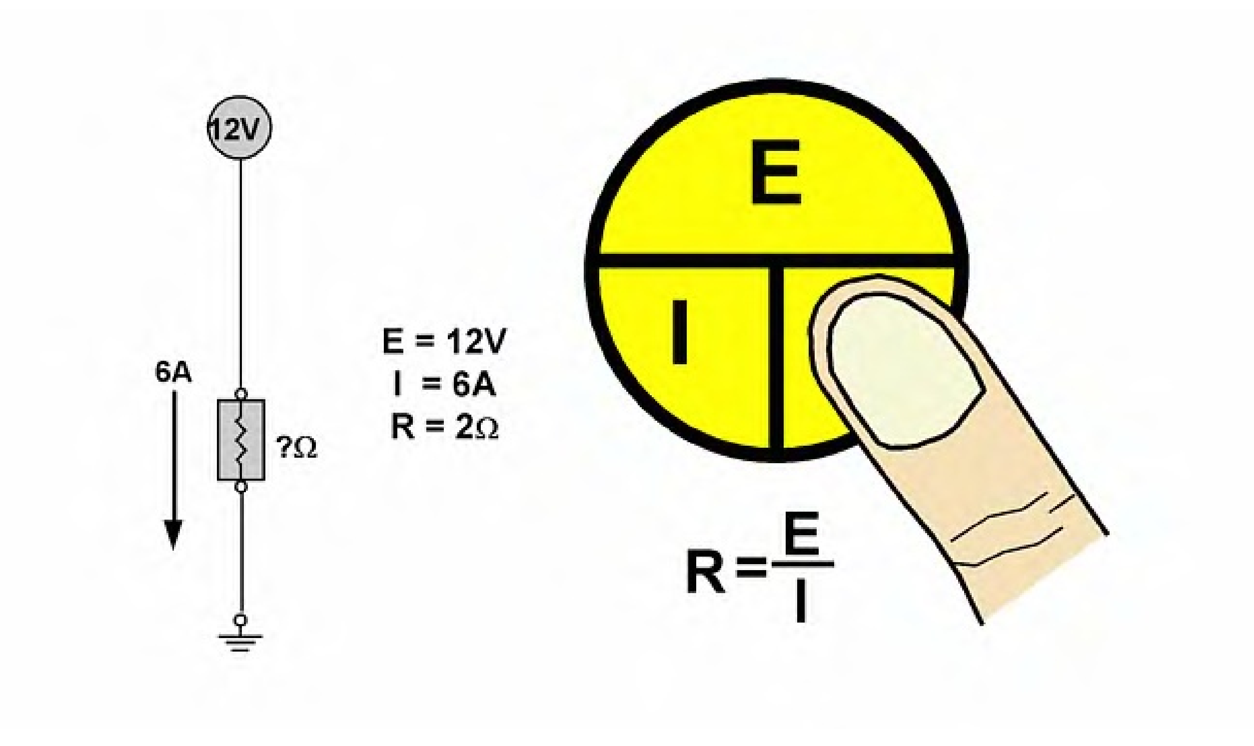

Illustration 4 g01070303

In this circuit, the value of the resistance is unknown. The current flow through the circuit is 6 amps and the source voltage is 12 volts. Since the resistance is unknown, the equation to solve for resistance is, voltage divided by current. So, 12 volts divided by 6 amps equals 2 ohms. Therefore, the resistance in the circuit is 2 ohms.

Current Unknown

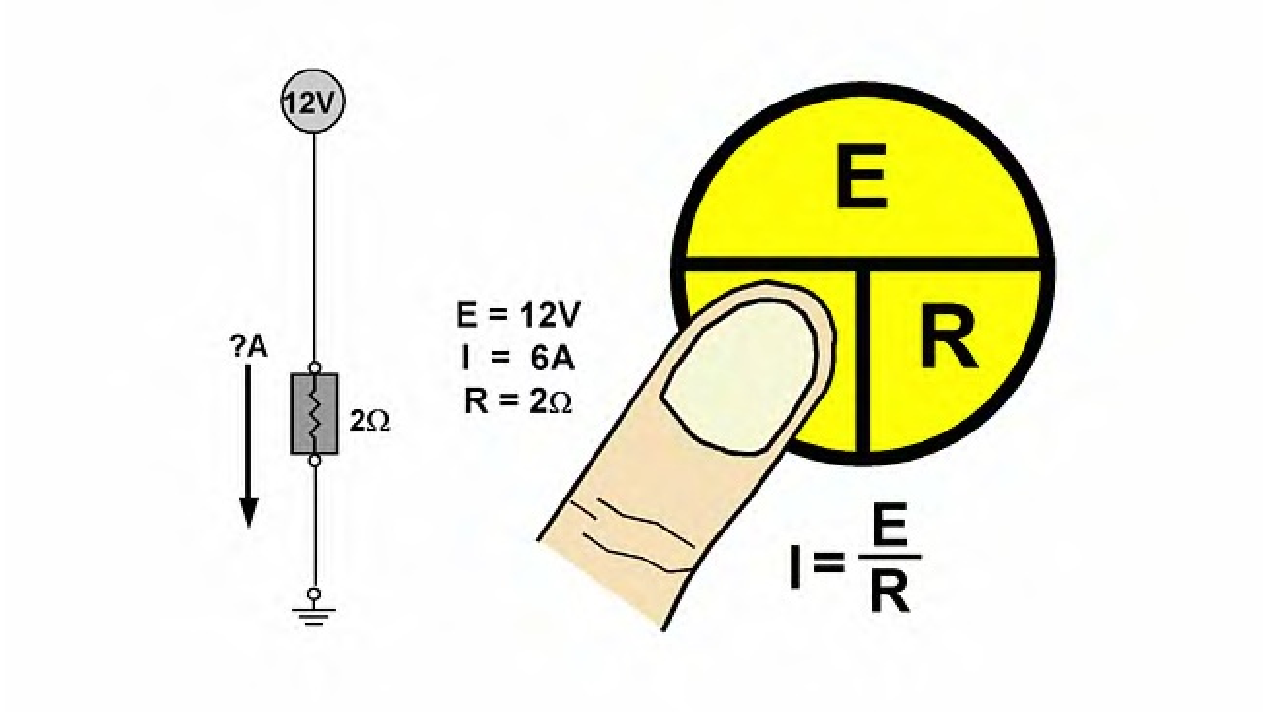

Illustration 5 g01070307

In this circuit, the current is unknown. The resistance of the load is 2 ohms and the source voltage is 12 volts. Since the current is unknown, the equation to solve for current is voltage divided by resistance. So, 12 volts divided by 2 ohms equals 6 amps. Therefore, the current flow in this circuit is 6 amps.

Metric System of Measure

When you measure something, you find a number to express the size or the quantity of the item that is being measured. Numbers are used to express the results of simple calculations. In addition to using numbers, there is always a unit, or an expression to describe what the number means. In the study of electrical systems, the metric system is used for units of measurement.

When you work in the metric system, there are only a few basic units that you need to be familiar with. Basically, you simply multiple or divide the basic unit by factors of 10 if you need a larger or smaller measuring unit. These factors of 10, or multiples of 10, have special names in the metric system. The names are used as prefixes. The names are attached to the beginning of the names of basic units.

The following is an example of a metric prefix:

- 1500 Volts of electricity would be expressed metrically as 1.5kV.
- The equation would be stated in power of 10 as $1.5 \times 10_3$ or $1.5 \times 1000 = 1500$.
- The prefix k is equal to 1000, so the equation for 1500 volts is therefore stated as 1.5kV.

Electrical applications and electronic applications work with either very large quantities or very small quantities. These quantities are expressed in metric prefixes.

The metric system units make up an internationally recognized measuring system that is used throughout the world. The measuring system is called the International System of Units (SI). The following units are the most common units in the study of basic electrical theory: Mega (millions), Kilo (thousands), Milli (thousandths) and Micro (millionths).

The following table lists some of the more common prefixes. The table lists the standard abbreviations and the powers of 10.

Prefix	Symbol	Power of 10
mega	M	10^6
kilo	k	10^3
milli	m	10^{-3}
micro	µ	10^{-6}

Illustration 6 g01070311

The entire metric system will not be covered in this course. Only the metric prefixes that are most commonly used in measuring electrical properties and electronic properties are covered in this course.

Base Units

Base units are standard units. These units are without a prefix. Volts, ohms, and amperes are the primary base units that are used in electronics. Prefixes are added to base units in order to change the unit of measurement.

Mega

Mega stands for one million and is abbreviated with a capital M. One megohm equals a million ohms. To convert any value from megohms to ohms, move the decimal point six places to the right. For example, 3.5 megohms would convert to 3,500,000 ohms.

Kilo

Kilo means one thousand and is abbreviated with a k. A kilohm is equal to 1,000 ohms. To convert any value from kilohm to ohms, move the decimal point three places to the right. For example, 0.657 kilohms would convert to 657 ohms.

Milli

Milli stands for one thousandth and is abbreviated by the lower case letter m. A milliampere is one-thousandth of one ampere. To convert any value from milliamperes to amperes, move the decimal point three places to the left. For example, 0.355 milliamp would convert to .000355 amp.

Micro

Micro means one millionth and is abbreviated by the symbol µA. Microampere is equal to one millionth of an amp. To convert any value from microamperes to amperes, move the decimal point six places to the left. For example, 355 microamperes would convert to .000355 amp.

Power

Power is a measure of the rate at which energy is produced or is consumed. In an engine, the output horsepower rating is a measure of the ability to do mechanical work. In electronics, power is a measure of the rate at which electrical energy is converted into heat by the resistive elements within a conductor. In an electrical circuit, resistance uses electrical power. Remember that many kinds of devices can have resistance. Devices that offer electrical resistance include conductors, insulators, resistors, coils, and motors. Many electrical devices are rated by how much electrical power they consume, rather than by how much power they produce. Power consumption is expressed in watts.

746 watts = 1 horsepower

The unit of measurement for power is the watt. Power is the product of current multiplied by voltage. One watt equals one amp times one volt. In a circuit, if voltage or current increases, power increases. If current decreases, power decreases. The relationship among power, voltage, and current is determined by the Power Formula. This is the basic equation for the power formula:

$P = I \times E$, or Watts = amp × Volts

You can multiply the voltage times the current in any circuit and find out how much power is consumed. For example, a typical hair dryer can draw almost 10 amps of current. The voltage in your home is about 120 volts. Multiplying 10 volts by 120 volts shows that the power produced by the hair dryer would be approximately 1200 watts.

The most common application of a watts rating is the light bulb. Light bulbs are classified by the number of watts they consume. Common examples of items with wattage ratings are audio speakers, some motors, and most home appliances.

Resistor Ratings

Resistors are rated by how many ohm's of resistance they create and by how many watts they can handle. Common ratings for carbon-composition resistors are 1/4 watt, 1/2 watt, 1 watt, and 2 watts.

A resistor converts electrical energy to heat. As the resistor works, the resistor always generates some heat. If a resistor is forced to handle more watts than the resistor was designed for, the resistor will generate excessive heat. When substantially overloaded the resistor may fail prematurely.

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Systems Operation - Fundamentals
Electrical System for All Caterpillar Products
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i02104628

Solid State Electrical Components

SMCS - 1400; 1450

Introduction to Solid State Electrical Components

Modern electronic circuits use solid state components. Solid state electrical components are found in most Caterpillar machines.

Semiconductors

Some elements, such as copper, are good conductors. Other elements are poor conductors, but good insulators. There are other elements that are neither good conductors nor good insulators. If an element falls into this group, but the element can be changed into a useful conductor, the element is called a semiconductor. Silicon and germanium are the most commonly used elements for semiconductors.

Examples of semiconductors include diodes, transistors, and integrated circuits (ICs). Semiconductors are used throughout most Caterpillar machines. Semiconductors often replace mechanical switches.

All semiconductors are solid state devices. A solid state device is one that can control current without moving parts, heated filaments, or vacuum bulbs. There are other solid state devices that are not semiconductors. A transformer is not a semiconductor.

How Semiconductors Work

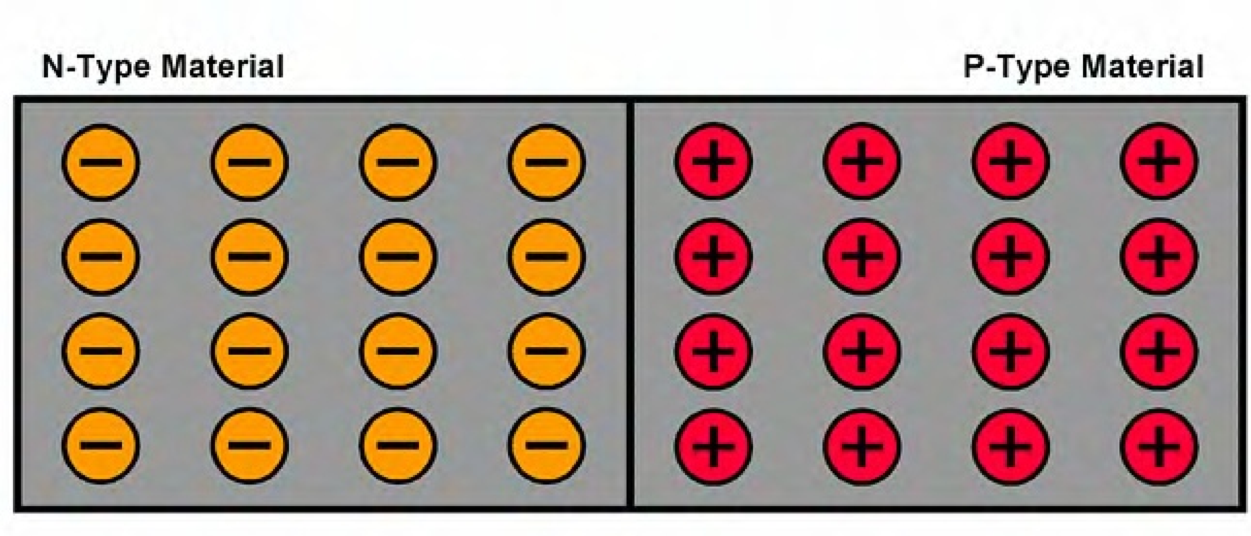

Illustration 1 g01072606

Pure semiconductors have tight electron bonding. There is no place for electrons to move. In this natural state, these elements are not useful for conducting electricity.

However, semiconductors can be made into good conductors through doping. Doping is the addition of impurities. The impurities affect the free electrons in the semiconductor. Depending on which impurity is added, the resulting material will have either an excess of free electrons or a shortage of free electrons.

If the added material creates an excess of free electrons, the semiconductor is negative or N type. If added material creates a shortage of free electrons, the semiconductor is positive or P type.

Semiconductors are made from a sandwich of at least one slice of N type material and at least one slice of P type material. These slices are mounted inside a plastic or a metal housing. The area where the N type material and P type material meet is called the PN junction.

Current Flow through Semiconductors

The flow of electricity through a semiconductor is different from other electrical devices. Usually, you define the movement of electricity as the movement of free electrons that bump each other from the negative terminal of the voltage source through the conductor and toward the positive terminal. When you discuss semiconductors, you describe not only the flow of electrons, but also the flow of holes. Holes are spaces in an electron shell to which an electron will be attracted.

The flow of electrons is relatively easy to visualize. You can think of a flow of marbles through a channel, for example. The flow of holes is slightly harder to visualize.

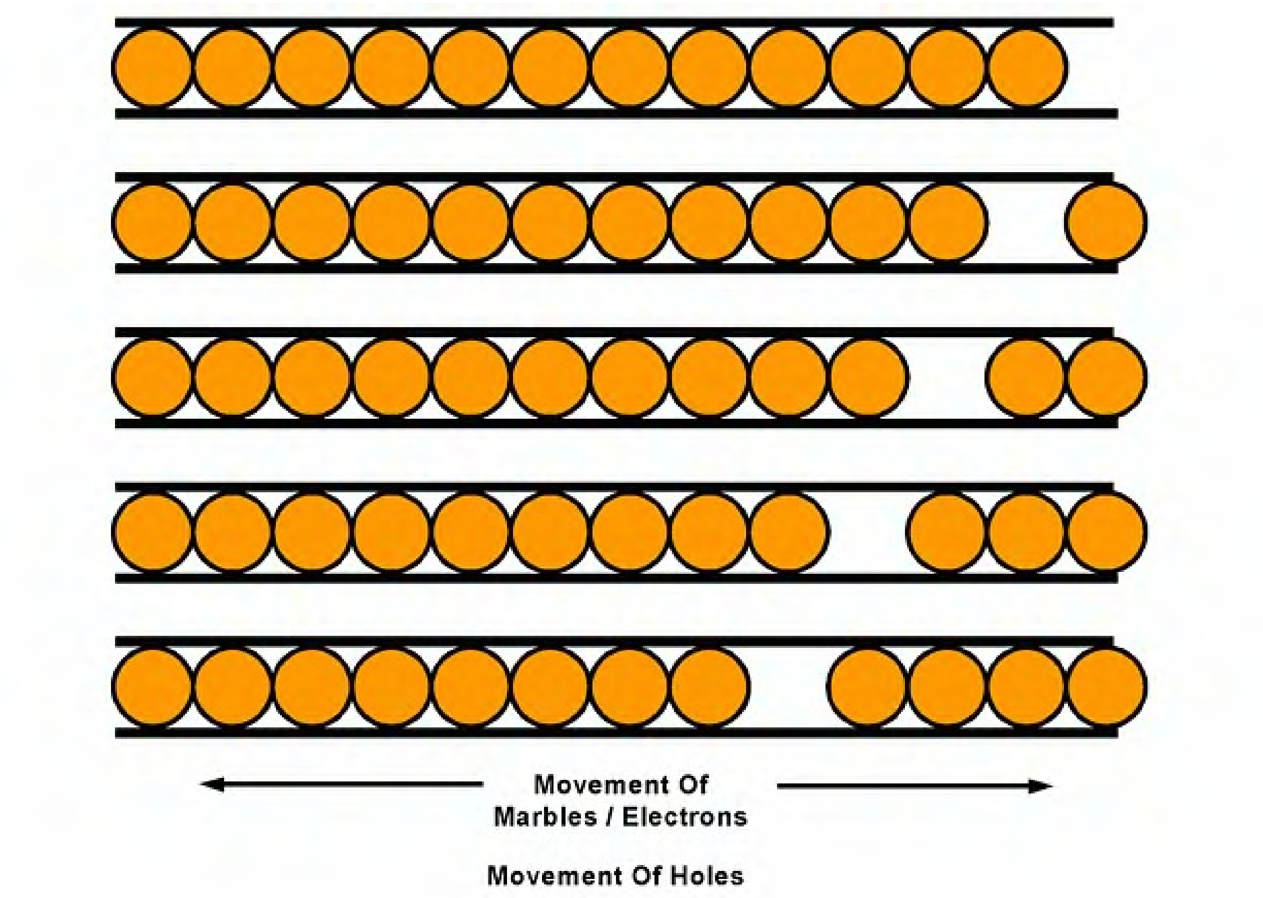

Illustration 2 g01072607

Think of the same channel, that is filled with marbles, as shown in Illustration 2. One marble moves ahead, leaving a hole in the marbles place. The next marble moves into the position vacated by the first marble. At the same time, the hole can be said to be moving from the position that the first marble had held to the position that the second marble had held. As marbles move in one direction in the channel, holes can be said to be moving in the opposite direction.

With no voltage applied to a semiconductor, the free electrons at the PN junction are attracted to the holes in the P type material. Some electrons drift across the junction in order to combine with holes. Similarly, holes from the P type material can be said to be attracted to the free electrons in the N type material. Although, holes are not particles themselves the holes can be visualized as crossing the PN junction in order to combine with electrons.

Depletion Region

As long as no external voltage is applied to the semiconductors, there is a limit to how many electrons and holes will cross the PN junction. Each electron that crosses the junction leaves behind an atom that is missing a negative charge. Such an atom is called a positive ion. In the same way, each hole that crosses the junction leaves behind a negative ion. As positive ions accumulate in the N type material, the ions exert a force (a potential) that prevents any more electrons from leaving. As negative ions accumulate in the P type material, the ions exert a potential that keeps any more holes from leaving. Eventually, this results in a stable condition that leaves a deficiency of both holes and electrons at the PN junction. This zone is called the depletion region.

Barrier Voltage

When voltage is applied to a PN semiconductor electrons flow from the N side, across the junction, and through the P side. Electrons will flow in this manner if the semiconductor is configured in the circuit to allow electricity to flow. Holes flow in the opposite direction. The effect of the PN junction on current flow in a circuit depends on where it is placed and on the order of the P and N type materials.

The voltage potential across the PN junction is called the barrier voltage. Doped germanium has a barrier voltage of about 0.3 volts. Doped silicon has a barrier voltage of about 0.6 volts.

Diodes

The simplest kind of semiconductor is a diode. A diode is made of one layer of P type material and one of N type material. Diodes allow current flow in only one direction. On a schematic, the triangle in the diode symbol points in the direction that current is permitted to flow by using conventional current flow theory.

Diodes are used for many purposes in electrical circuits. These purposes include illumination, rectification, and voltage spike protection.

Anode and Cathode

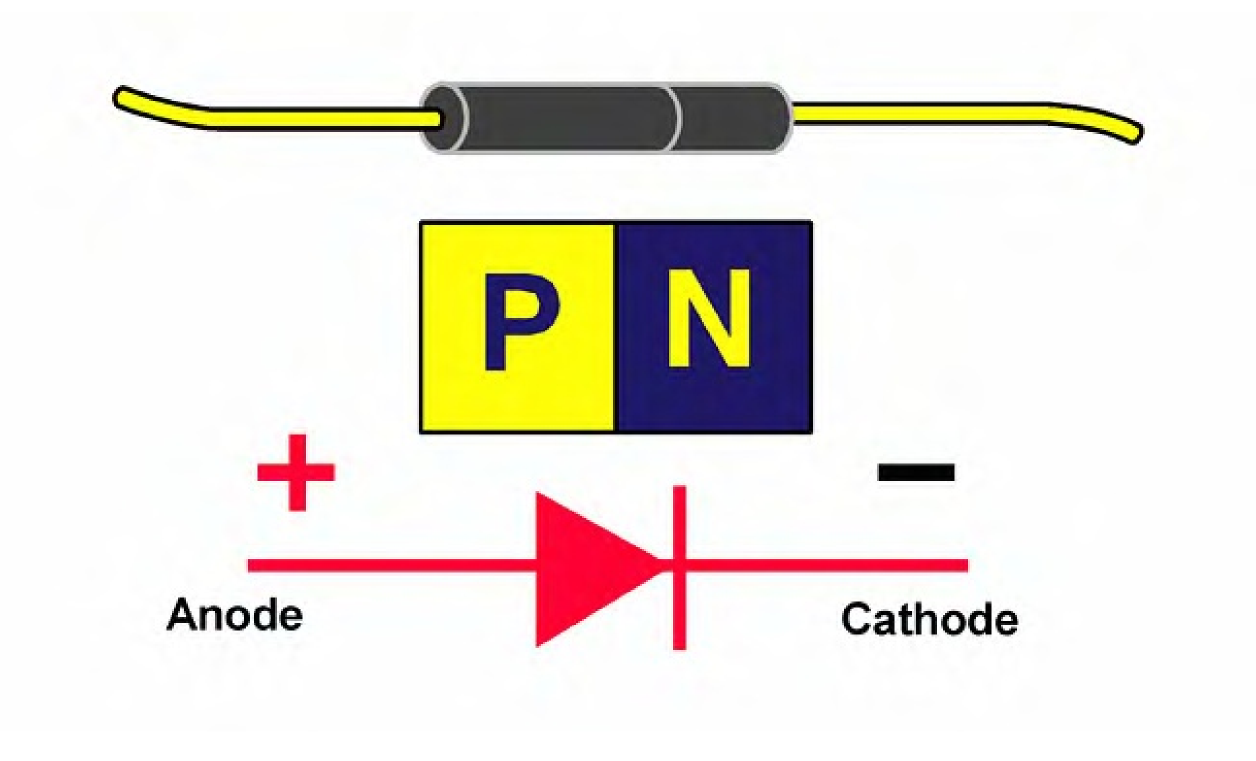

Illustration 3 g01072609

Current flows from left to right in Illustration 3. You can indicate this by a positive (plus) sign to the left and a negative (minus) sign to the right of the diode. The positive side of the diode is the anode and the negative side is the cathode.

There is an easy way to remember the names anode and cathode. Associate anode with A+ (the positive side) and cathode with C- (the negative side). The cathode is the end with the stripe. Current flows through a diode when the anode terminal is more positive than the cathode terminal.

Diode Bias

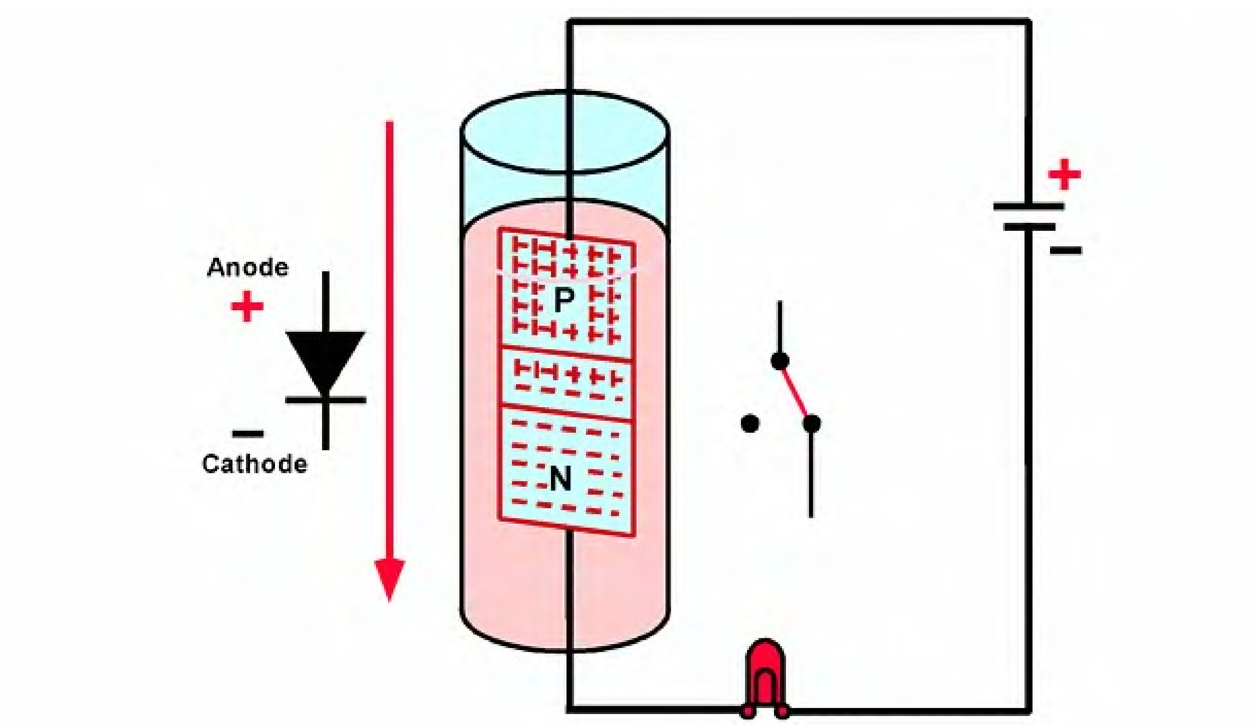

Illustration 4 g01072611

The term bias is used to refer to a diode's ability to allow or to prevent the flow of current in a circuit.

A forward biased diode is connected to a circuit to allow the flow of electricity. This is done by connecting the "N" side of the diode (the cathode) to the negative voltage, and the "P" side (the anode) to the positive voltage. When the diode is connected in this way, both electrons and holes are being forced into the depletion zone. This connects the circuit. Current flows in the direction of the arrowhead indicating that the diode is forward biased.

When a forward biased diode is connected to a voltage source the diode acts as a switch that closes a circuit. You can think of the voltage as forcing both electrons and holes into the depletion region, which allows current to flow.

A diode will not conduct (current flowing) until the forward voltage (bias) reaches a certain threshold. The threshold voltage is determined by the type of material that is used to construct the diode. A germanium diode usually starts conducting when the forward voltage reaches approximately 300 millivolts, while a silicon diode requires approximately 600 millivolts.

A diode is limited to the amount of current that can flow through the junction. The internal resistance of the diode will produce heat when current is flowing. Too much current produces too much heat, which can destroy the diode.

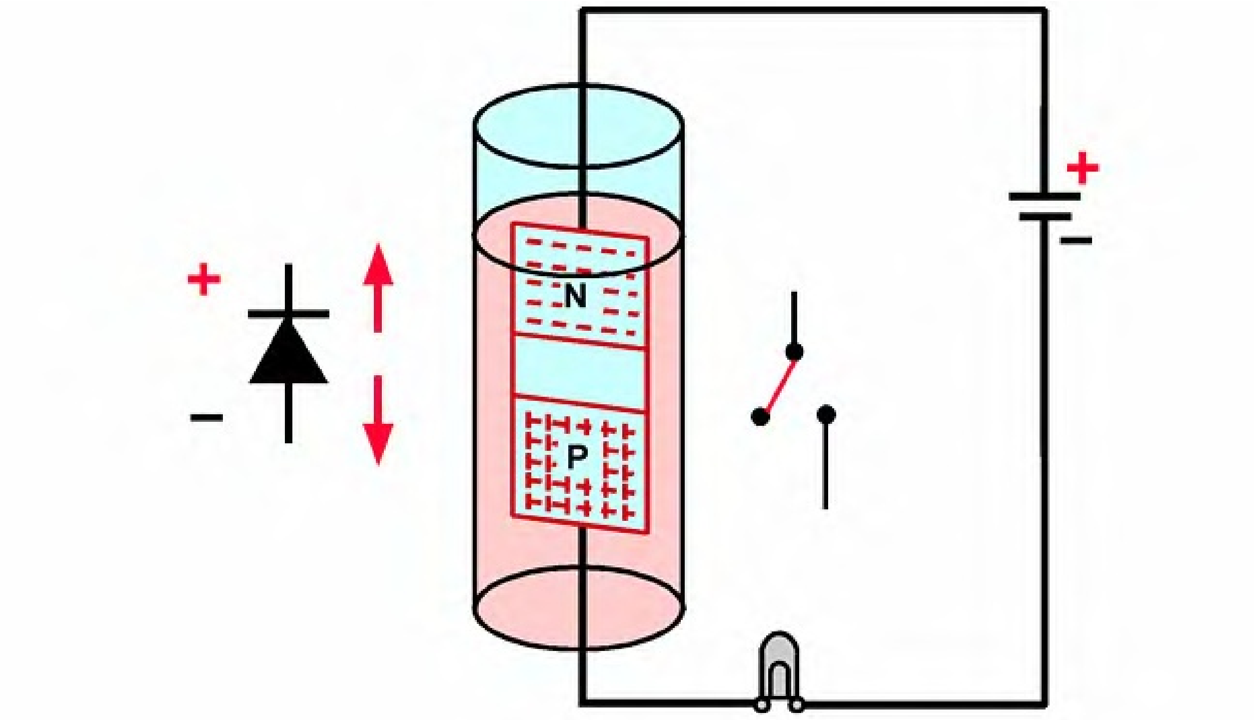

Illustration 5 g01072613

A diode that is connected to voltage so that current cannot flow is reverse biased. This means that the negative terminal is connected to the "P" side of the diode, and the positive terminal is connected to the "N" side. The positive potential is on the cathode terminal and, as such, current is being blocked against the arrowhead.

When voltage is applied to this circuit, the electrons from the negative voltage terminal combine with the electron holes in the P type material. The electrons in the N type material are attracted toward the positive voltage terminal. This enlarges the depletion area. Since the holes and electrons in the depletion area do not combine, current cannot flow.

When a diode is reverse biased, the depletion region acts like an open switch, blocking current. When the negative terminal is connected to the P material, holes are attracted away from the depletion region. When the positive terminal is connected to the N material, electrons are attracted away from the depletion region. The result is an enlarged zone that contains neither holes nor electrons that cannot support current flow.

Diode Leakage Current

A very small amount of current can flow through a reverse biased diode. If the supply voltage becomes high enough, the atomic structure inside the diode will break down, and the amount of current that flows through the diode will rise sharply. If the reverse current is large enough and lasts long enough, the diode will be damaged by the heat.

In summary, if a diode is forward biased, the diode acts like a small resistance, or a short circuit. If the diode is reverse biased, the didode acts like a very large resistance or open circuit.

Zener Point

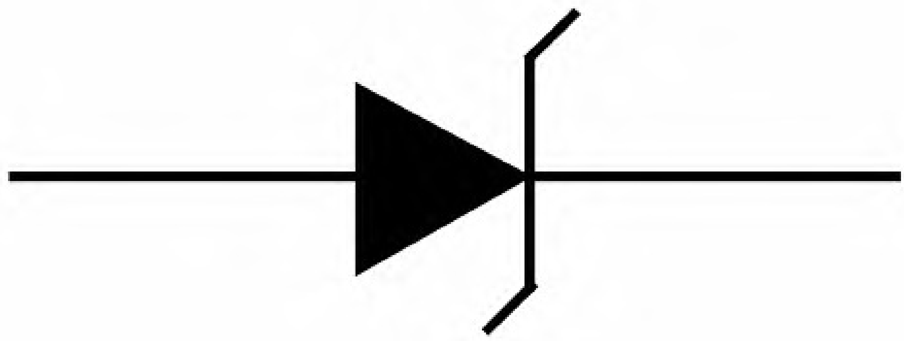

Illustration 6 g01072614

The applied voltage at which the diode fails is called the maximum reverse voltage or Zener Point. Diodes are rated according to this voltage. Circuits are designed to include diodes with a rating that is high enough to protect the diode and the circuit during normal operation.

Applications

The following diodes are used in electrical circuits:

- Voltage regulation (using Zener diodes)
- Indicators (using LEDs)
- Rectification (changing AC current to DC current)
- Clamping to control voltage spikes and surges that could damage solid state circuits (acting as a circuit protector)

Zener Diodes and Voltage Regulation

A Zener diode is a special kind of diode that is heavily doped during manufacture. This results in a high number of free electrons and electron holes. These additional current carriers permit reverse current flow when a certain reverse bias voltage is reached. This is called the avalanche point or Zener point. In forward bias, the Zener diode acts like a regular diode.

One common Zener diode will not conduct current in the reverse direction if the reverse bias voltage is below six volts. If the reverse bias voltage reaches or exceeds six volts, the diode will conduct reverse current. This Zener diode is often used in voltage control circuits.

For an example of Zener diodes, look at a charging system. Zener diodes are shown inside the alternator. These diodes act as a safety mechanism to limit the output of the stator. The Zener diodes in the alternators are rated in order to turn on at approximately 28 volts.

Light Emitting Diodes (LEDs) & Illumination

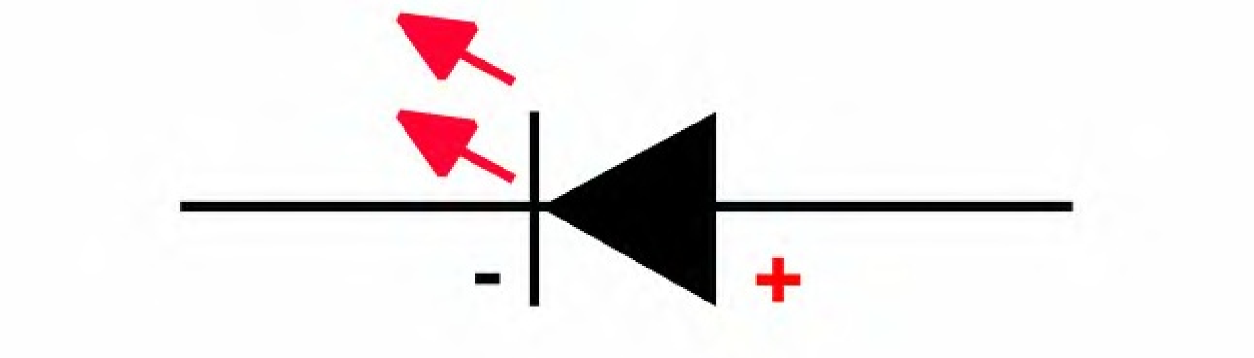

Illustration 7 g01072615

Another type of diode that is commonly used is a Light Emitting Diode (LED), which is used for indicator lamps. Like all diodes, LEDs allow current flow in only one direction. The difference is that when forward voltage is applied to an LED, the LED radiates light. Many LEDs that are connected in series can be arranged to light as numbers or as letters in a display.

While most silicon diodes need about 0.5 volts or 0.7 volts to be turned on, LEDs need approximately 1.5 volts to 2.2 volts. This voltage results in currents that are high enough to damage an LED. Most LEDs can handle only about 20 to 30 mA of current. To prevent damage to an LED, a current limiting resistor is placed in series with the LED.

LEDs Versus Incandescent Lamps

In complex electrical circuits, LEDs are an excellent alternative to incandescent lamps. The LEDs produce much less heat and need less current to operate. The LEDs also turn on and off more quickly.

Diodes as Rectifiers

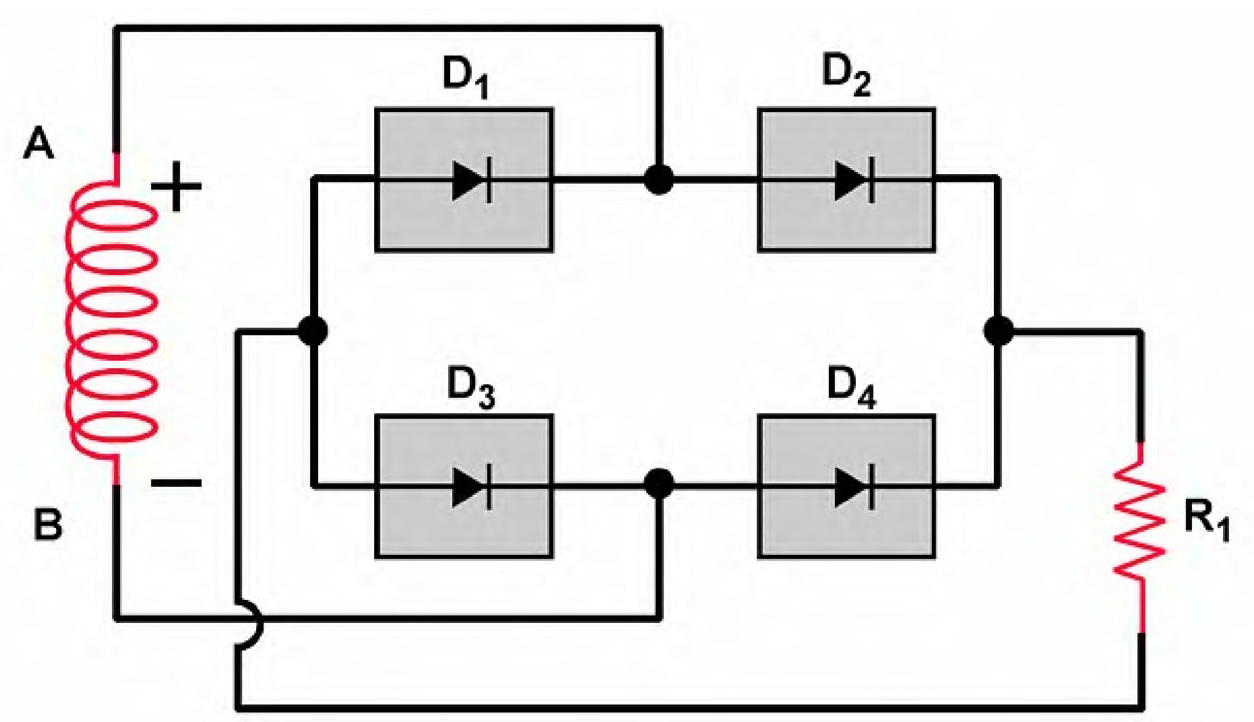

Illustration 8 g01072617

Rectifiers change alternating current (AC) to direct current (DC). Several diodes can be combined in order to build a diode rectifier, which is also called a rectifier bridge.

Rectifier and Generator

The most common use of a rectifier in Caterpillar electrical systems is in the alternator. The alternator produces alternating current (AC). Because electrical systems use direct current (DC), the alternator must convert the AC to DC. The DC is then provided at the alternator 's output terminal.

Alternators use a Diode Rectifier Bridge to change AC current to DC current.

Study Illustration 8 in terms of conventional theory. First, you must understand that the stator voltage is AC. That means the voltage at A alternates between positive and negative.

When the voltage at (A) is positive, current flows from (A) to the junction between diodes (D1) and (D2). Notice the direction of the arrows on each diode. Current cannot flow through (D1), but current can flow through (D2). The current reaches another junction, between (D2) and (D4). The current cannot flow through (D4), nor can current return through (D2). The current must pass through the circuit load because current cannot flow through (D4) or (D2). The current continues along the circuit until the current reaches the junction of (D1) and (D3) .

Note: The circuit load in this simplified example is a resistor. In a real charging system, the load would be the battery.

Even though the voltage that is applied to (D1) is forward biased, current cannot flow through D1 because there is positive voltage on the other side of the diode. There is no voltage potential. Current flows through (D3), and from (D3) to ground at (B). When the stator voltage reverses so that point (B) is positive, current flows through (D4) and (D1) to ground at (B) .

Whether the stator voltage at point (A) is positive or is negative, current always flows from top to bottom through the load (R1). This means the current is (DC).

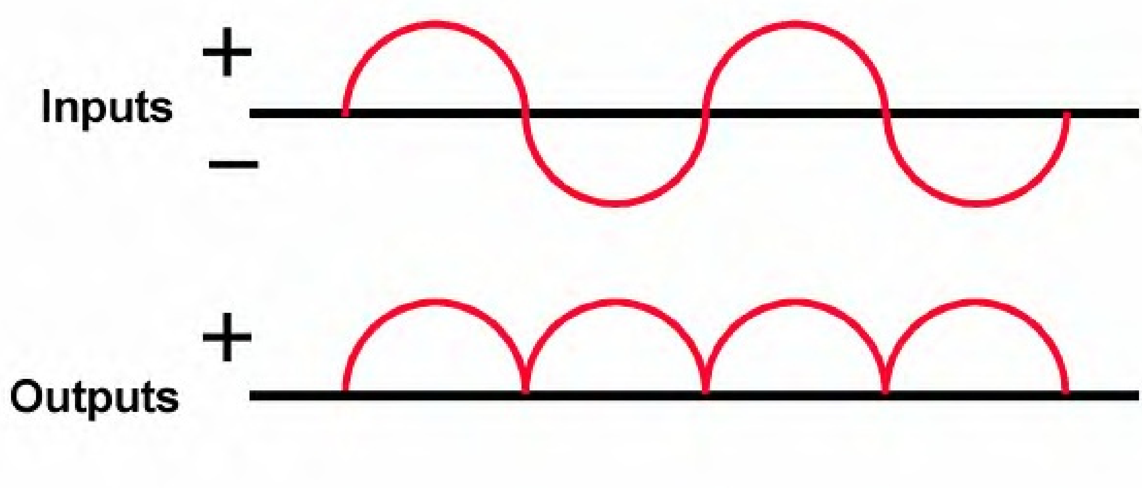

Illustration 9 g01072618

The rectifiers in generators are designed to have an output (positive) and an input (negative) diode for each alternation of current. This type of rectifier is called a full wave rectifier. In this type of rectifier, there is one pulse of (DC) for each pulse of (AC). The (DC) which is generated is called full-wave pulsating (DC), as shown in Illustration 9.

Diodes In Circuit Protection

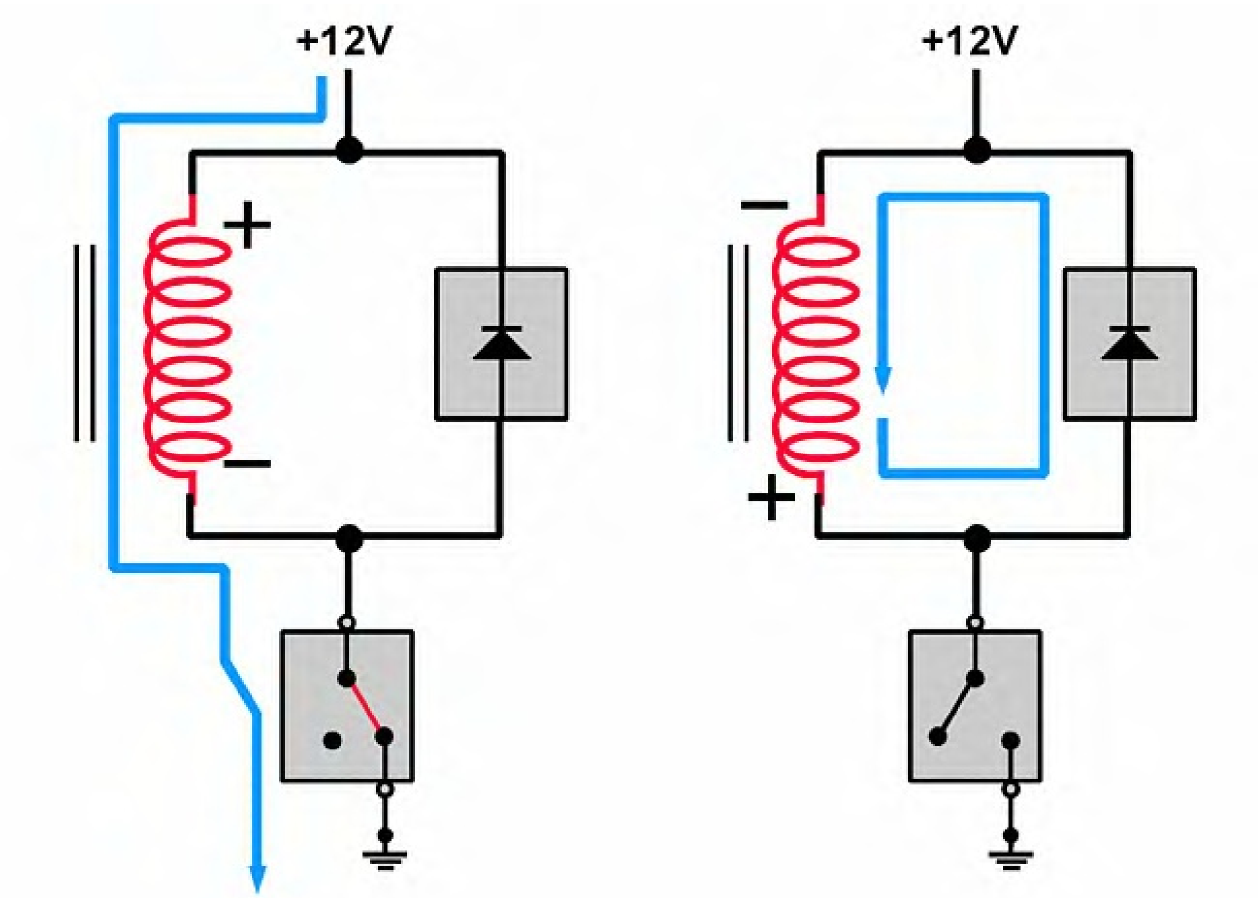

Illustration 10 g01072619

Electromagnetic devices like solenoids and relays have a unique characteristic that can cause voltage spikes if not controlled. The coil that is in the electromagnetic device sets up a magnetic field as the current flows through the device. When the circuit is abruptly opened and the supply voltage is removed, the collapsing magnetic field actually generates it's own voltage potential. The voltage potential may be high enough to damage some circuit components, especially sensitive solid state controllers.

To protect against sparks or surges, Clamping Diodes are added in parallel with the coil. While voltage is applied to the circuit, the diode is reverse biased and does not conduct electricity. When voltage is removed and the induced current is flowing, the diode is forward biased and does conduct electricity. The current flows in a circular path through the diode and coil until it dissipates.

Induced current can cause problems other than sparks. The computers in today's Caterpillar machines make decisions based on circuit voltages. The computers make the wrong decisions if electromagnetic devices cause abnormal voltages.

Testing Diodes

When a diode is functioning properly in a circuit, the diode acts as a large voltage drop in one direction, and as a very small voltage drop in the other. Unfortunately, testing diodes is not always this simple.

In fact, there are four possible ways in which you can test diodes:

- Take the diode out of the circuit. Sometimes this is not possible.
- If the diode is in a series circuit, the diode can be tested with the circuit power off.
- If the diode is in a series circuit, the diode can be tested with the power on. For a typical silicon diode, the forward biased voltage drop should be approximately 0.6 volts.
- If the diode is in a parallel circuit, the diode must be tested with an analog meter, not with a digital meter.

TRANSISTORS

A diode is only one type of semiconductor. By combining several kinds of semiconductor material, you can create transistors. Like diodes, transistors control current flow. Transistors can perform practically all the functions that were once performed by vacuum tubes, but in much less space and without creating as much heat. Transistors are used in many applications, including radios, electronic control modules and other solid state switches.

Transistor Types

There are many kinds of transistors. Transistors can be divided into two major groups: bipolar and unipolar (also called Field Effect Transistors, or FETs). While there are several differences between the two types, the most important difference is this:

- Bipolar transistors vary current to control voltage.
- FET transistors vary voltage to control current.

Bipolar transistors are more common in Caterpillar electrical circuits.

Transistor Construction

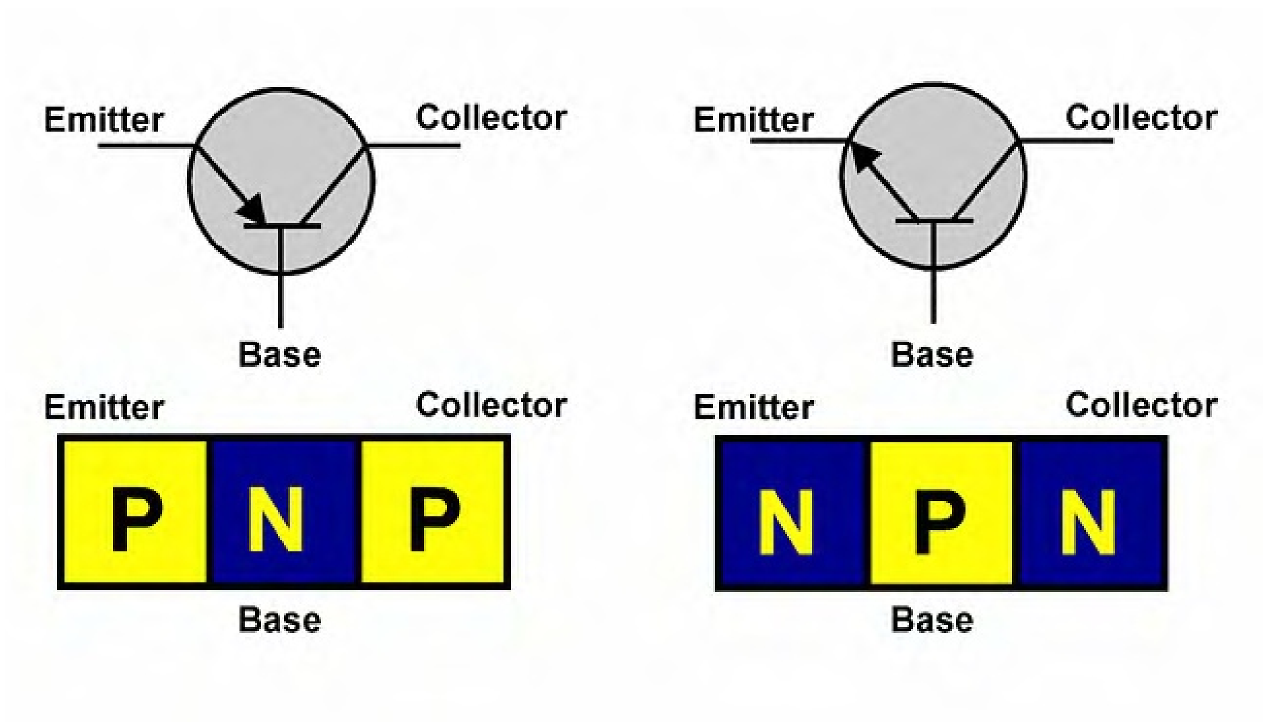

Illustration 11 g01072621

Like diodes, transistors contain a combination of N type and P type material. However, transistors contain three materials instead of two. The three materials are arranged so that N type and P type materials alternate (either as an NPN or a PNP group). This means that diodes have two leads while transistors have three. Illustration 11 is a symbolic representation of transistor construction.

Emitter, Base, and Collector

In Illustration 11, the material on the left is called the emitter. The material that is sandwiched in the middle is the base. The material on the right is the collector.

The symbols on the top of Illustration 11 are the schematic symbols for a transistor. The arrow indicates current flow direction this is conventional theory, and is always on the emitter. The arrow points in a different direction depending on whether the transistor is PNP or NPN.

FETs also have three sections. These sections are referred to as the gate, the source, and the drain .

- The gate approximates the function of the base.
- The source is similar to the emitter.
- The drain is similar to the collector.

Basic Function

A transistor works by using the base to control the current flow between the emitter and the collector. When the transistor is turned ON, current can flow in the direction of the arrow only. When the transistor is OFF, current cannot flow in either direction.

Base Paths

It is important to realize that the base leg of a bipolar transistor controls the flow of current. Current flow through the base accounts for only a small amount of the total current flow (typically around 2% of the total). Current flowing through the base also allows current to flow from emitter to collector.

PNP or NPN Transistors

There is an easy way to identify the kind of transistor without thinking about the movement of electrons or of electron holes. The arrow always points toward the N material and away from the P material. For a PNP transistor, the arrow points inward toward the base. For an NPN transistor, the arrow points away from the base.

In Caterpillar electrical circuits, NPN transistors are much more common than PNP.

Transistor Operation

When you are trying to understand how a transistor functions in a specific circuit, there are two facts you must remember. First, an NPN transistor is turned ON by applying voltage to the base leg. NPN is turned OFF by removing voltage from the base leg. This is very similar to the operation of a relay, which is turned on and off by applying and removing voltage to the coil.

Second, the current through the base circuit is always much smaller than the current across the collector circuit. Changing the base current a little results in a big change in the collector current. The current that flows through the emitter circuit is always the largest current of all. In fact, the emitter current must be equal to the base current that is added to the collector current. The current in the emitter circuit is split between the base circuit and the collector circuit.

Solid State Relays

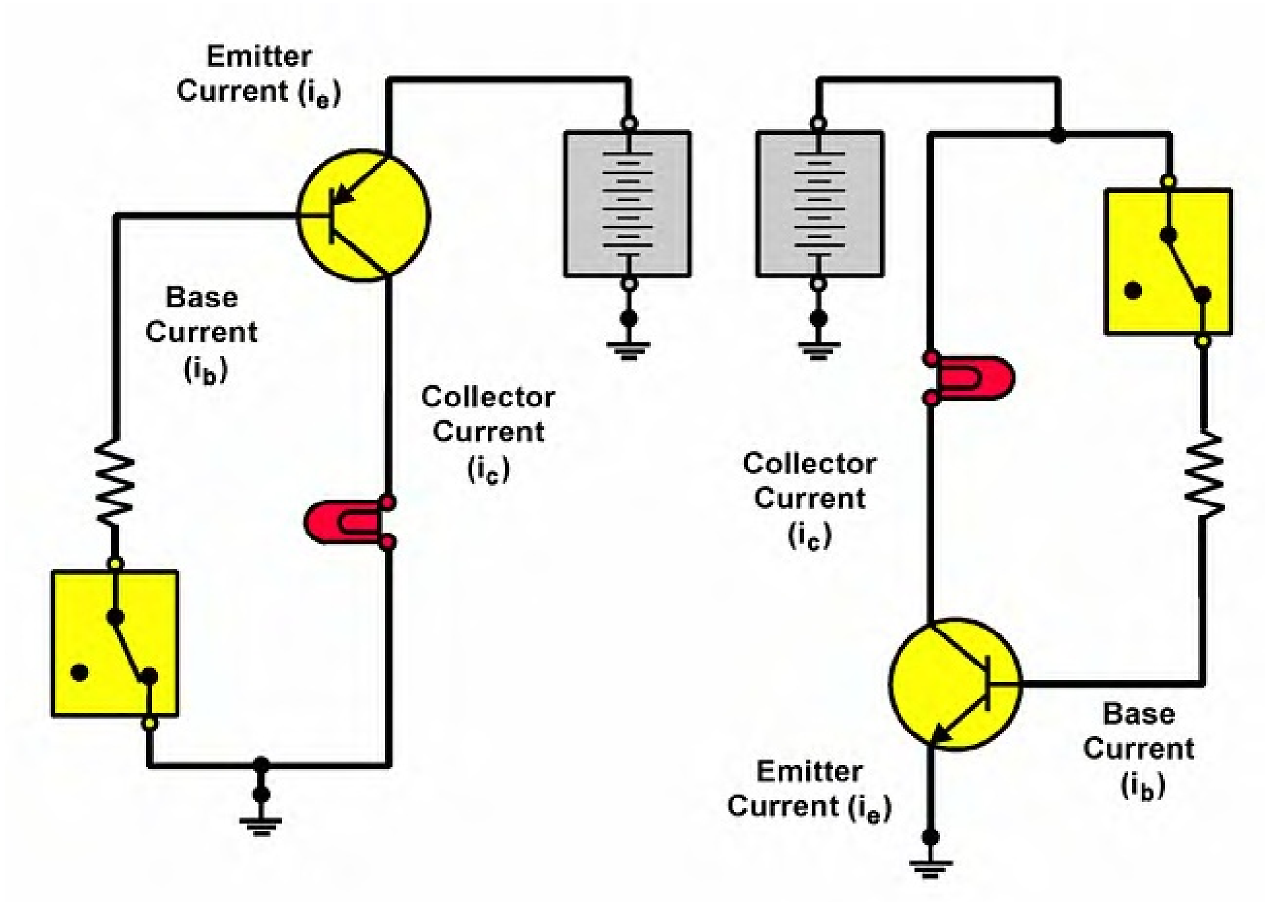

Illustration 12 g01072623

In some circuits, it is desirable to have transistors function like relays. For example, in Illustration 12, a switch with a very small current that controls a light consumes a large amount of current. This solid state relay has the following advantages over a mechanical relay:

- The solid state relay can switch faster.
- The solid state relay is smaller.
- The solid state relay will not wear out.

Transistor relays are different from mechanical relays. A mechanical relay acts as a switch that turns current completely on or completely off. A transistor varies the current flow according to the amount of current that is flowing through the base.

Resistors in Transistor Circuits

Resistors are used with transistors for several purposes. For example, using resistors, the voltage that is supplied to a transistor can be precisely controlled. This produces precise output currents. Resistors that are used in this way are placed on the base circuit.

The second function is transistor protection. If resistors or other resistances are not placed in the emitter and collector parts of the circuit, high currents can destroy the transistor.

Transistor Terminology

There are many terms that describe the characteristics of a specific transistor. For example, transistor current gain describes how much bigger the collector circuit current is than the base circuit current. If a transistor has a gain of 100 and a base current of 10 mA, then the current in the collector circuit is 100 multiplied by 10, which equals 1000 mA, or 1 A.

Transistors have many other ratings that are similar to those for diodes. Transistors can be rated according to the following conditions:

- How fast the transistor can turn on and off.
- How much heat the transistor can handle.
- How much current leaks through a transistor when the transistor is supposed to be turned off.

Other Applications

Transistors are useful as switching devices. If you see a transistor in an electrical circuit, the transistor is likely functioning as a switch. Transistors can also be used to amplify or to oscillate current, or as dimmers.

Systems Operation - Fundamentals
Electrical System for All Caterpillar Products
Media Number -SEGV3008-01 **Publication Date -01/06/2004** **Date Updated -28/06/2004**

i02104636

Starting System

SMCS - 1450

How the Starting System Works

The starting system converts electrical energy from the battery into mechanical energy in order to start the engine.

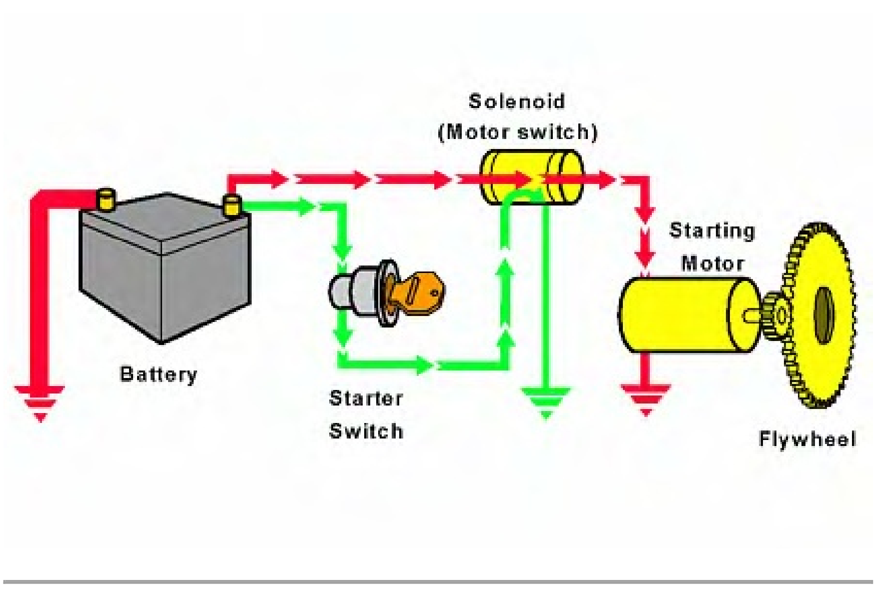

Illustration 1 g01073449

A basic starting system has four parts:

Battery - Supplies energy for the circuit

Starter switch - Activates the circuit

Solenoid (motor switch) - Engages the starting motor drive with the flywheel

Starting Motor - Drives the flywheel to crank the engine

When the starter switch is activated a small amount of current flows from the battery to the solenoid and back to the battery through the ground circuit.

The solenoid performs two functions. The solenoid engages the pinion with the flywheel and closes the switch inside the solenoid between the battery and starting motor, which completes the circuit and allows high current to flow into the starting motor.

The starting motor converts the electrical energy from the battery into rotary mechanical energy in order to crank the engine. The starting motor is similar to other electric motors. All electric motors produce a turning force through the interaction of magnetic fields inside the motor.

Starting Motor

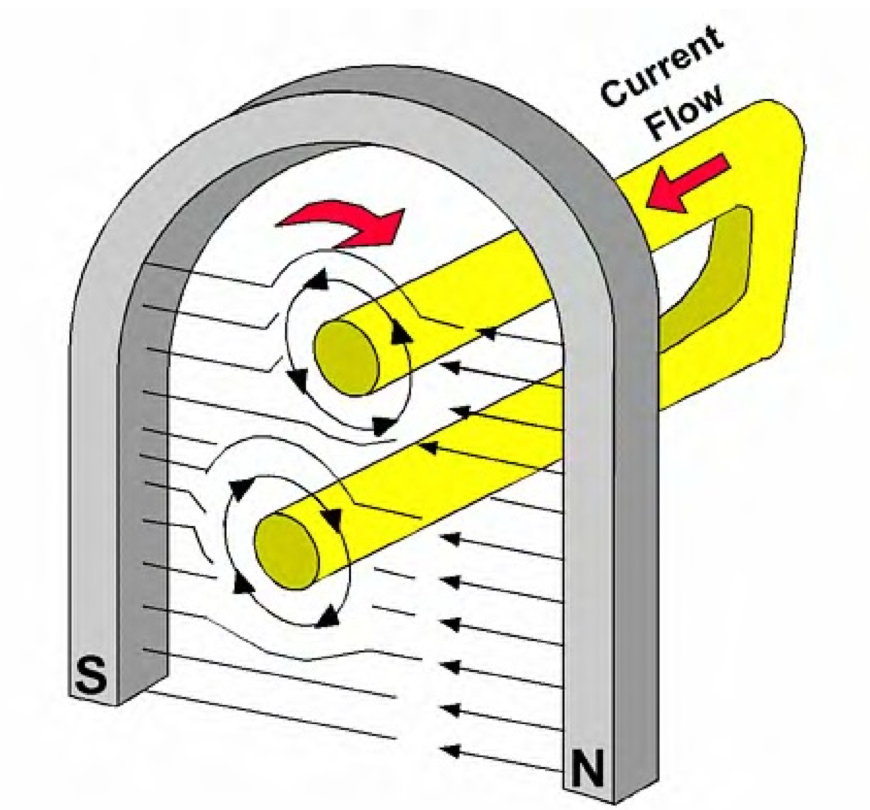

Illustration 2 g01079926

A review of some basic rules of magnetism is needed, to understand the basic operating principles of starting motors.

The following information is the basic rules of magnetism:

- Like poles repel. Unlike poles attract.
- Magnetic flux lines are continuous and exert force.
- DuriCurrent-carrying conductors have a magnetic field that surrounds the conductor in a direction that is determined by the direction of the current flow.

If a conductor has a current that has passed through the conductor, there will be a magnetic field that is formed. A permanent magnet has a field between the two poles. When the current carrying conductor is placed in the permanent magnetic field, there will be a force that is exerted on the conductor because of the magnetic field. If the conductor is formed in a loop and placed in the magnetic field, the result is the same. Since current flow is in opposite directions in the coil, one side will be forced upward while the other side is forced downward. This will provide a rotational effect or a torque effect on the coil.

Starting Motor Principles

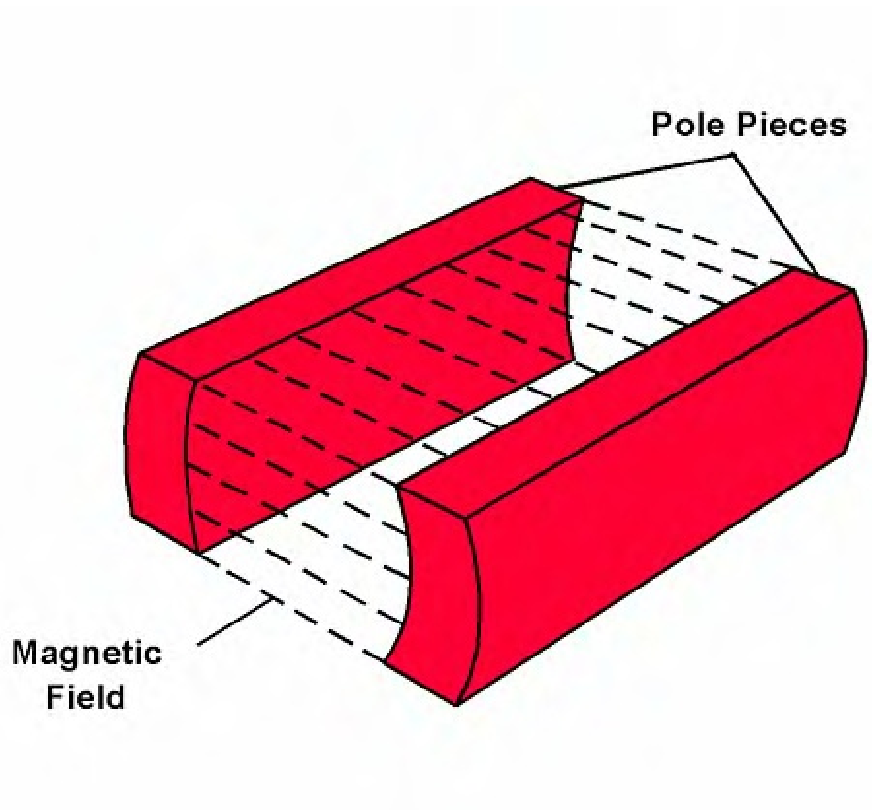

Illustration 3 g01073452

The pole pieces in the field frame assembly can be compared to the ends of a magnet. The space between the poles is the magnetic field.

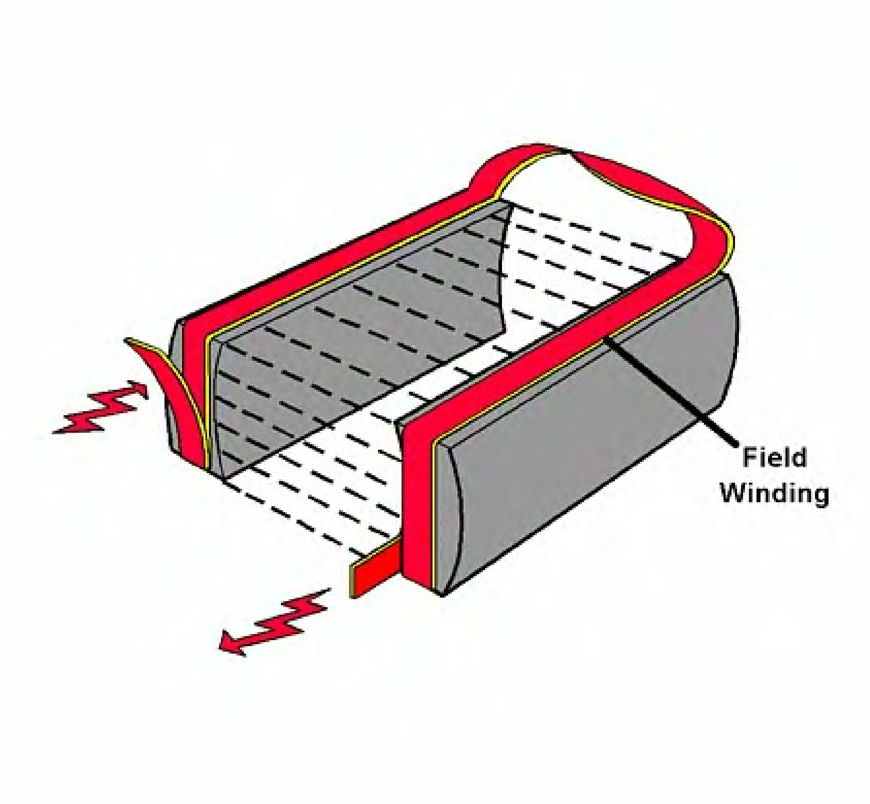

Illustration 4 g01073454

If a wire (field winding) is wrapped around the pole pieces and current is passed through the wire, the strength of the magnetic field between the pole pieces increases.

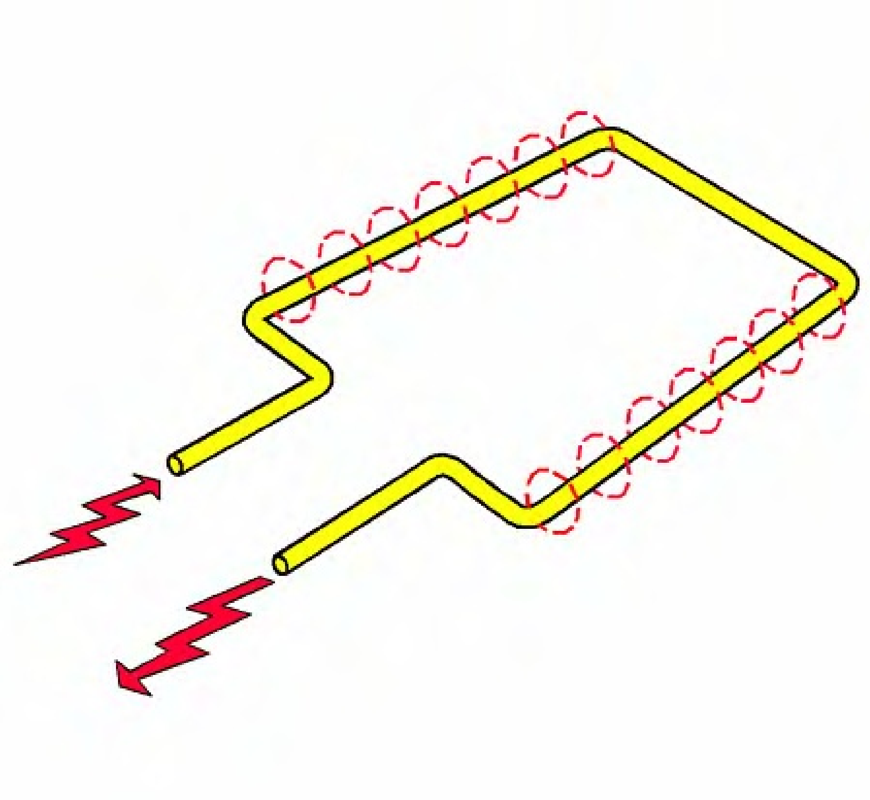

Illustration 5 g01073455

If you feed current from the battery into a loop of wire, a magnetic field is also formed around the wire.

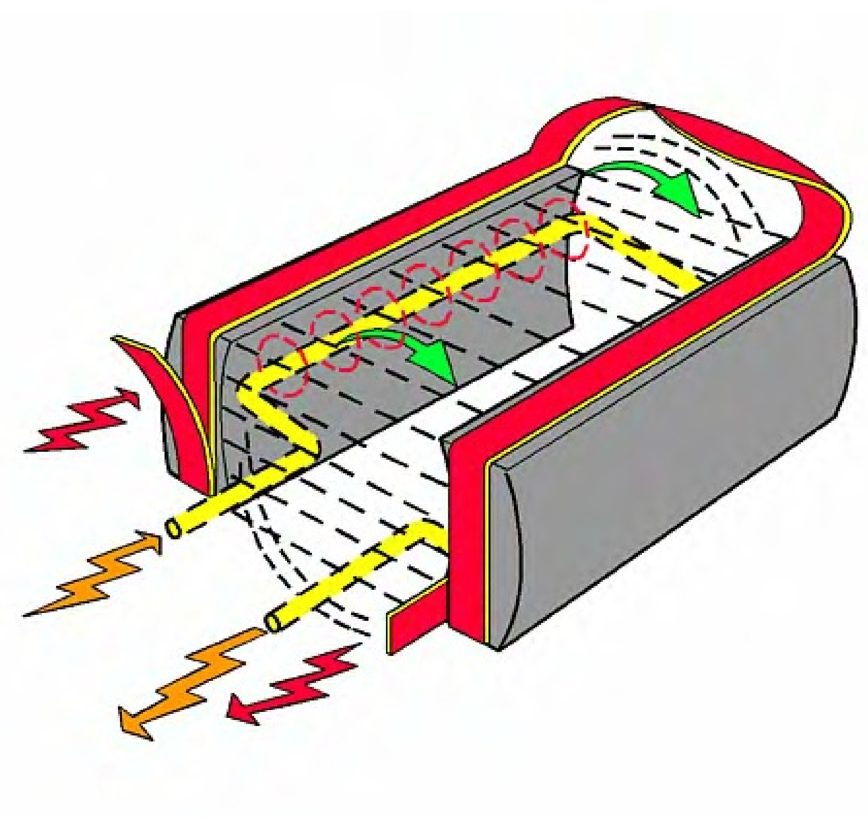

Illustration 6 g01073457

If the loop of wire is placed in the magnetic field between the two pole pieces and current is passed through the loop, a simple armature is created. The magnetic field around the loop and the field between the pole pieces repel each other, causing the loop to turn.

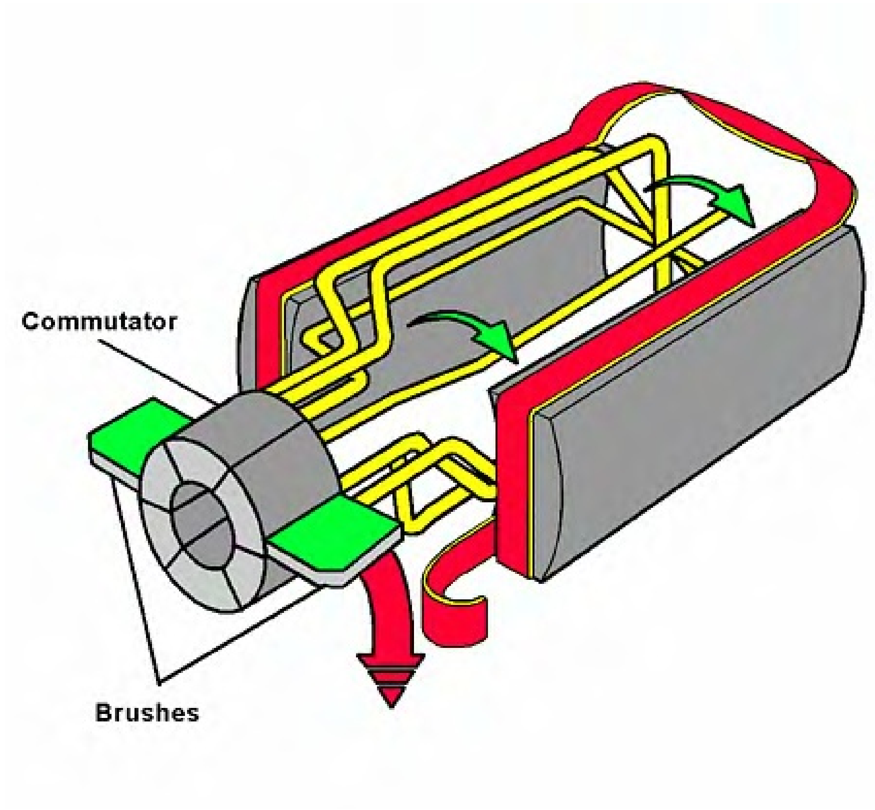

Illustration 7 g01073459

A commutator and several brushes are used to keep the electric motor spinning by controlling the current that is passing through the wire loop. The commutator serves as a sliding electrical connection between the wire loop and the brushes. The commutator has many segments, which are insulated from each other.

The brushes ride on top of the commutator and slide on the commutator in order to carry battery current to the spinning wire loops. As the wire loops rotate away from the pole shoes, the commutator segments change the electrical connection between the brushes and the wire loops. This reverses the magnetic field around the wire loops. The wire loop is again pulled around and passes the other pole piece. The constantly changing electrical connection keeps the motor spinning. A push-pull action is set up as each loop moves around inside the pole pieces.

Several loops of wire and a commutator with many segments are used to increase motor power and smoothness. Each wire loop is connected to the wire loops own segment on the commutator in order to provide current flow through each wire loop as the brushes contact each segment. As the motor spins, many wire loops contribute to the motion in order to produce a constant and smooth turning force.

Illustration 8 g01073460

A starting motor, unlike a simple electric motor, must produce very high torque and relatively high speed. Therefore, a system to support the wire loops and to increase the strength of each wire loop's magnetic field is needed.

A starter armature consists of the following components:

- Armature core
- Armature shaft
- Commutator
- Armature windings (wire loops)

The starting motor shaft supports the armature as the armature spins inside the starter housing. The commutator is mounted on one end of the armature shaft. The armatures core holds the windings in place. The core is made of iron in order to increase the strength of the magnetic field that is produced by the windings.

Illustration 9 g01073461

A field winding is a stationary insulated wire that is wrapped in a circular shape, which creates a strong magnetic field around the motor armature. When current flows through the field winding, the magnetic field that is between the pole pieces becomes vary large. The magnetic field can be 5 to 10 times that of a permanent magnet. As the magnetic field between the pole shoes acts against the field that is developed by the armature, the motor spins with extra power.

Starting Motor Characteristics

Starters are high capacity intermittent duty electric motors that tend to behave with the followign specific characteristics:

- If starting motors are required to power a certain mechanical component (load), the starting motor will consume a specific amount of power in watts.
- If the load is removed, speed increases and current draw will go down.
- If the load is increased, speed decreases and current draw will go up.

The amount of torque that is developed by an electric motor increases as the current flowing through the motor increases. The starting motor is designed to operate for short periods of time under an extreme load. The starting motor produces a very high horsepower for the size.

Counter Electromotive Force (CEMF) is responsible for changes in current flow as the starter speed changes. CEMF increases the resistance to current flow from the battery, through the starter, as the starter speed increases. This occurs because, as the conductors in the armature are forced to spin, the conductors are cutting through the magnetic field that is created by the field windings. This induces a counter voltage in the armature that acts against battery voltage. This counter voltage increases as the armature speed increases. This acts as a speed control, and prevents high free running speeds.

Although, most electric motors have some form of current protection device in the circuit, most starter motors do not. Some starters have thermal protection. This is provided by a heat sensitive thermostatic switch. The thermostatic switch will open when the starter temperature rises due to excessive cranking. The switch will automatically reset when the starter temperature cools. The electric motor is classified as an intermittent operating motor. If the electric motor were a continuous operating motor, the electric motor would need to be almost as large as the engine. Because of the high torque demands on the starter motor, a great deal of heat is produced during operation. Extended operation of the starter motor will cause internal damage due to this high heat. All the parts of the starter motor's electrical circuit are very heavy. This enables the handling of the heavy current flow that is associated with the operation.

If higher loads require more power to operate, then each starter motor must have sufficient torque in order to provide turning speed that is necessary to crank the engine. This power is directly related to the strength of the magnetic field, since the strength of the field is what creates the power.

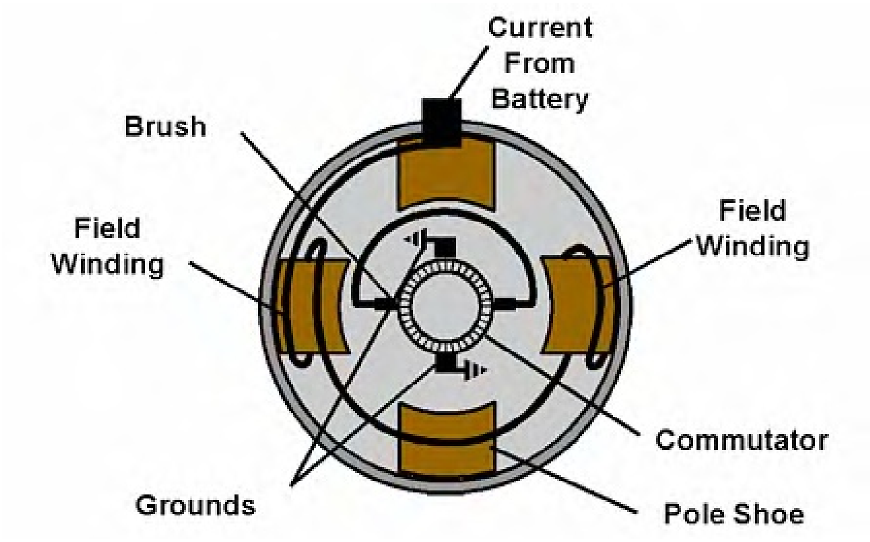

Illustration 10 g01073464

As previously described, starting motors have a stationary member (field windings) and a rotating member (armature). The field windings and the armature are usually connected together so that all current that enters the motor passes both the field and the armature. This is the motor circuit.

The brushes are a means of carrying the current from the external circuit (field windings) to the internal circuit (armature windings).

The brushes are contained in brush holders. Normally, half the brushes are grounded to the end frame. The other half of the brushes are insulated and connected to the field windings.

Starter motor fields can be wired together in four different configurations in order to provide the necessary field strength:

- Series
- Compound (shunt)
- Parallel
- Series-parallel

Series wound starters (Illustration 9) are capable of producing a very high initial torque output when the starters are first engaged. This torque then decreases as the starters operate due to counter-electromotive force. This decreases the current flow since all the windings are in series.

Compound motors have three windings in series and one winding in parallel. This produces good initial torque for starting and the benefit of some load adjustment due to the parallel winding. This type of starter also has the added benefit of speed control due to the parallel field.

Parallel wound motors provide higher current flow and greater torque, by dividing the series windings into two parallel circuits.

Series-parallel motors combine the benefits of both the series and the parallel motors.

Many starters have four fields and four brushes. Starters that are required to produce very high torque, may have up to six fields and brushes. Some light duty starters may have only two fields.

Many heavy-duty starter motors are not grounded through the case of the starter. This type of starter motor is grounded through an insulated terminal that must be connected to the battery ground for the starter to work. A ground wire for the solenoid and other engine electrical devices must also be attached to the starter ground terminal for proper electrical operation.

Illustration 11 g01073469

After electrical power is transmitted to the starting motor, some type of connection is needed to put this energy to work. The starting motor drive makes it possible to use the mechanical energy that is produced by the starting motor.

Although torque that is produced by the starter motor is high, the torque does not have the ability to crank the engine directly. Other means must be used to provide both adequate cranking speed and the necessary torque.

To provide adequate torque for cranking the engine, the speed of the starter is altered by the ratio between the pinion gear on the starter and the engine flywheel. This ratio varies from 15:1 to 20:1. For example, if the starter drive gear had 10 teeth, the ring gear might have 200 to provide a ratio of 200:10 or 20:1.

Starter drive mechanisms

If the starter were left engaged to the flywheel after the engine started, damage would occur to the armature due to very high speeds that are created as the engine rpm increased. At high speed, the armature would throw the windings due to centrifugal force.

The gear that engages and drives the flywheel is called a pinion gear. The gear on the flywheel is called a ring gear. How the starter pinion gear engages with the flywheel ring gear depends on the type of drive that is used.

Starter pinion gears and starter drive mechanisms can be of two different types:

- Inertia drive
- Overrunning clutch

Inertia drives are actuated by rotational force when the armature turns. This type engages after the motor begins to move. The drive sleeve has a very coarse screw thread that is cut into the drive sleeve, which corresponds to threads that are on the inside of the pinion.

As the motor begins to turn, the inertia that is created at the drive causes the pinion to move up the threads until the pinion engages with the ring gear on the flywheel. You can recreate this action by spinning a heavy nut on a bolt and watch the rotary motion change to linear motion as the nut moves up or down.

One disadvantage of inertia starters is that the pinion is not positively engaged before the starter begins to turn. If the drive does not engage with the flywheel, the starter will spin at a high speed without cranking the engine. If the pinion lags the pinion will strike the gear with heavy force. This will damage the teeth.

Illustration 12 g01073470

The overrunning clutch drive is the most common type of clutch drive. The overrunning clutch drive requires a lever to move the pinion into mesh with the flywheel ring gear. The pinion is engaged with the flywheel ring gear before the armature starts to rotate.

With this type of drive system, a different method must be used in order to prevent armature overspeeding. A lever pulls the drive out of engagement while an overrunning clutch prevents overspeeding.

The overrunning clutch locks the pinion in one direction and releases the pinion in the other direction. This allows the pinion gear to turn the flywheel ring gear for starting. The overrunning clutch also allows the pinion gear to freewheel when the engine begins to run.

The overrunning clutch consists of rollers that are held in position by springs against a roller clutch. This roller clutch has tapered ramps that allow the roller to lock the pinion to the shaft during cranking.

The torque travels through the clutch housing. The torque is transferred by the rollers to the pinion gear. When the engine starts and the speed of the drive pinion exceeds the speed of the armature shaft, the rollers are pushed down the ramps. This permits the pinion to rotate independently from the armature shaft. Once the starter drive pinion is disengaged from the flywheel and is not operating, spring tension will force the rollers into contact with the ramps in preparation for the next starting sequence. There are various heavy duty designs of this drive.

Starting Circuit Controls

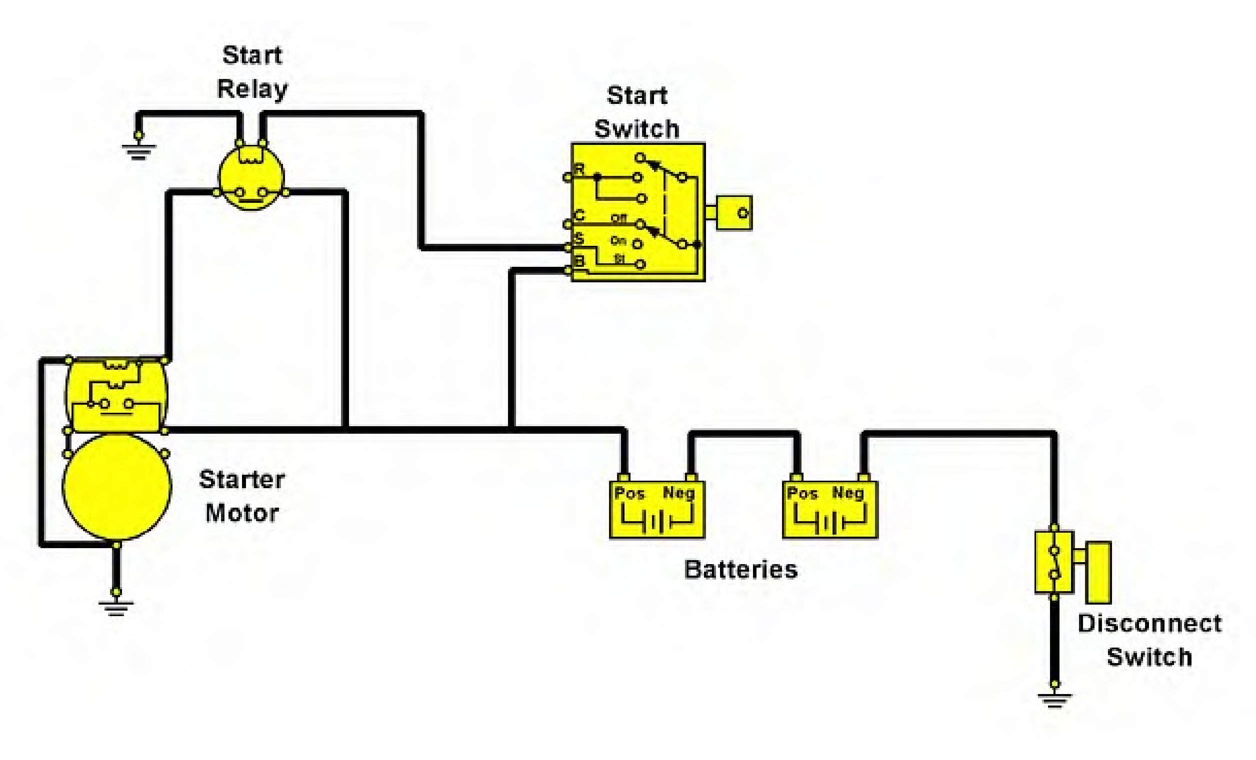

Illustration 13 g01073471

The starting circuit contains control and protection devices. The control and protection devices are necessary to allow the intermittent operation of the starter motor and to prevent operation during some machine operation modes for safety reasons.

The starter electrical circuit may consist of the following devices:

- Battery
- Cables and wires
- Key start switch
- Neutral safety switch and clutch safety switch (if equipped)
- Starter relay
- Starter solenoid

Battery

The battery supplies all of the electrical energy to the starter which enables the battery to crank the engine. It is important that the battery be fully charged and in good condition if the starting system is to operate at full potential.

Cables and Wires

The high current flow through the starter motor requires cables that must be large enough to have low resistance. In a series circuit, any added resistance in the circuit will affect the operation of the load due to a reduction in the total current flow in the circuit.

In some systems, the cables will connect the battery to the relay and the relay to the starter motor. In other systems the cable will go directly from the battery to the starter.

Ground cables must also be large enough to handle the current flow. All connectors and connections in the starting system must have as little resistance as possible.

Key Start Switch

The key start switch activates the starter motor by providing power to the starter relay from the battery. The key start switch can be operated directly by a key, a button, or remotely by linkage from a key activated control. The key start switch can be mounted in the dashboard assembly or on the steering column.

Illustration 14 g01073473

Neutral Safety Switch or Clutch Safety Switch

All vehicles that are equipped with a power shift or an automatic transmission require a neutral safety switch that will only permit starter operation in park or in neutral. This switch can be mounted on the transmission, at the shifter or in the linkage. The switch contacts are closed when the transmission selector is in park or in neutral. The switch contacts are open when the transmission selector is in any gear.

Some vehicles may use a clutch safety switch that is open when the clutch is in the engaged position and closed when the operator depresses the clutch pedal. This prevents starter operation as long as the clutch is engaged. Some transmissions also use a neutral gear switch that will prevent starter operation, unless the transmission is placed in the neutral position.

All safety switches of this type should be maintained in good operating condition. All safety switches should never be bypassed or removed.

Starter relay

Illustration 15 g01073474

The starter relay (magnetic switch) may be used in some starting systems. The starter relay is located between the key start switch and starter solenoid. The starter relay is a magnetic switch that is activated by power from the battery that is supplied through the key start switch. Relays are usually placed so that the cables between the starter and the battery are as short as possible.

The starter relay uses a small current from the key start switch to control the larger current to the starter solenoid, which reduces the load on the key start switch. Energizing the relay windings will cause the plunger to be pulled up due to the magnetism that is caused by the current flow through the windings. The contact disk will also be pulled up and will contact the battery and starter terminal ends. Current will flow from the battery to the starter solenoid.

Illustration 16 g01073475

Solenoids combine the operation of a magnetic switch (relay) with the ability to perform a mechanical task (engage the drive). The starter solenoid produces a magnetic field that pulls the solenoid plunger and disc into the coil windings, which completes the starting system circuit. The solenoid is mounted on the starter motor so that linkage may be attached to the overrunning clutch drive in order to engage the drive.

Solenoids contain two different windings for effective operation. When the ignition switch is turned to the start position, current from the battery flows through a pull-in winding and a hold-in winding. These windings contain many coils of wire and produce a strong magnetic field to pull the heavy plunger forward and engage the starter drive.

When a plunger reaches the end of the travel through the solenoid, the plunger engages a contact disk that will operate like a relay and allow current to flow to the starter motor from the battery. This also serves to disconnect the series pull-in winding from the circuit and allows current to flow through a shunt hold-in winding only. Only the lighter magnetic field that is created by the hold-in winding is required to hold the plunger in position. This reduces the amount of control current that is required to eliminate heat buildup and provides more current for the starter motor.

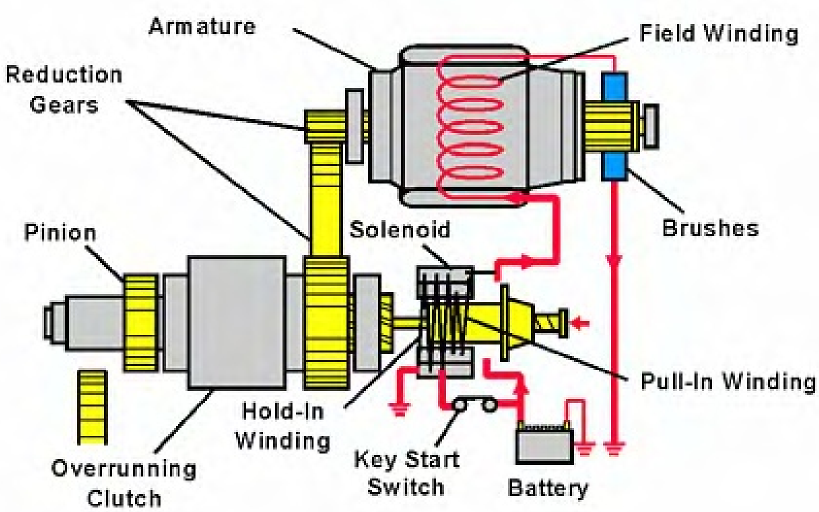

Illustration 17 g01073476

When the ignition switch is closed, battery current flows in two directions. Current flows from the battery to the start switch and then through the pull-in winding, field winding, armature, brushes and to ground.

The activation of the pull-in winding and the hold-in winding produces a magnetic force. The magnetic force pulls the plunger to the left, which moves the overrunning clutch and the pinion toward the flywheel ring gear.

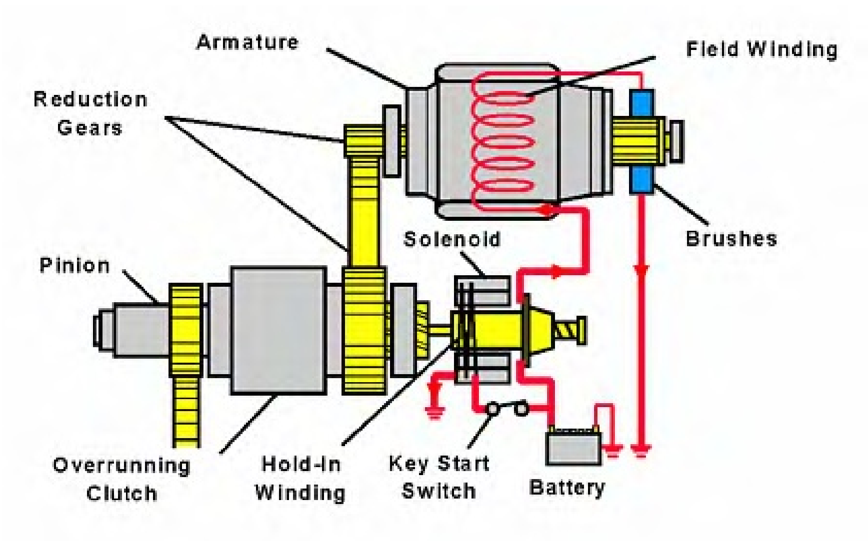

Illustration 18 g01073477

When the plunger is pulled to the left, the solenoid contacts close. At this point the pinion begins to mesh with the flywheel ring gear and the pull-in winding is shorted. This causes current flow through the solenoid contacts to the field winding, armature, brushes and to ground. Current still flows through the hold-in winding to ground. The starting motor is energized. The pinion engages the flywheel ring gear. The engine begins to crank. At this time the plunger is kept in the pull-in position only by the magnetic force of the hold-in winding.

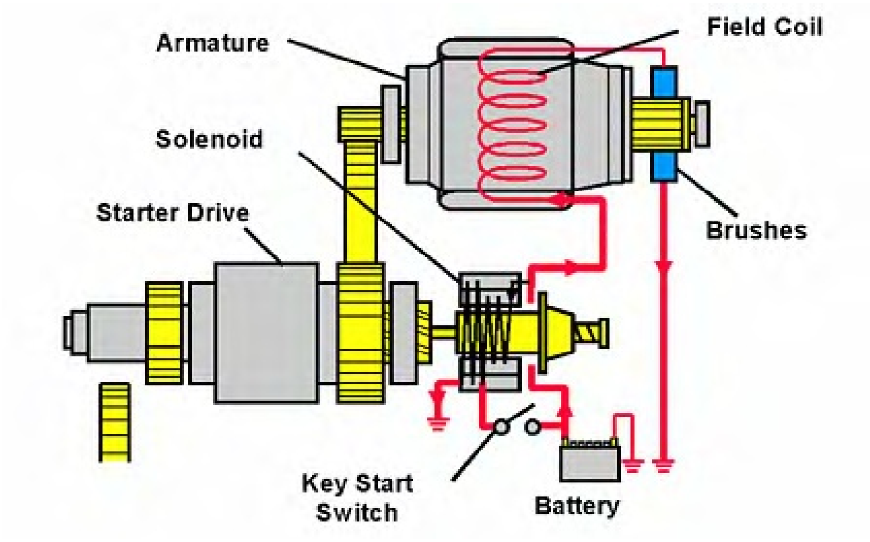

Illustration 19 g01073478

As soon as the engine starts, the flywheel ring gear turns the pinion faster than the starting motor is rotating. The overrunning clutch breaks the mechanical connection between the clutch and the starting motor. When the ignition switch is released, current flow through the hold-in winding and the pull-in winding is in the same direction, which causes the hold-in winding magnetic force to be reduced. The solenoid contacts are opened. The plunger and overrunning clutch are pulled back to the original position by the return spring force. The armature stops and the motor is OFF.

Series-Parallel Systems

Machines with larger diesel engines require high power starters to provide adequate cranking speed for the engine. To achieve this some machines use 24V starters. Using 24V allows the starter to produce the same power with less current flow.

In a series-parallel system the starter operates on 24V but the rest of the machine electrical system operates on 12V. A special series-parallel switch is used that connects two or more batteries in parallel for normal accessory and charging operation and then connects the batteries in series with the starter when cranking. 12V accessories are preferred because they are much less expensive than 24V lights and accessories.

12/24V Electrical Systems

In another system of this type, the starter is connected in series with two 12V batteries. The alternator charges the batteries with 24V.

Starter System Testing

Accurate testing of a starting system begins with an understanding of how the system functions. If your knowledge of the operation is complete, you can logically determine the fault through visual inspection and electrical testing.

Inspecting and Troubleshooting

An organized procedure for testing and inspection is necessary to prevent the replacement of good parts or the unnecessary repair of operational components.

Verify the Complaint

Operate the system yourself to see how the system functions. Starter system problems will normally fall into the following categories:

- The starter spins but does not crank the engine.
- The engine cranks very slowly.
- The engine does not crank at all.
- The starter motor is too noisy.

Do not crank the engine for more than 30 seconds at a time. Allow the starter motor to cool between cranking periods in order to prevent damage.

Define the Problem

Determine whether the problem is mechanical or electrical. For instance, if the starter rotates but does not crank the engine, the problem is most likely mechanical, since the drive does not seem to be engaging.

Mechanical problems can be corrected by repairing the component or by replacing parts.

Electrical problems require additional testing to determine the cause of the fault and the repair that will be required.

Isolate the Problem

Regardless of whether the problem is mechanical or electrical, you will have to determine where the problem is occurring, so that you can quickly and accurately make your repairs.

The steps involved in testing and isolating a starting circuit are:

1. Test the battery in order to determine if the battery is fully charged and capable of delivering sufficient current.
2. Test the wiring and switches to determine if both are in good operating condition.
3. If the engine, battery and wiring are all OK, but the starter is not operating correctly, the fault must be with the starter.

Visual Inspection

Begin all starting system testing with a thorough visual inspection. Check for the following problems:

- Loose or corroded battery terminals
- Worn or frayed insulation on the battery cables

- Corroded solenoid or relay connections
- A damaged starter solenoid or relay
- Cracked or broken insulators on the starter relay
- Loose engine or chassis grounds
- Damaged neutral safety switches
- Damaged ignition switch or actuating mechanisms
- Loose starter

Battery test

Continue the inspection with a complete test and service of the battery.

Preform all required tests in order to verify that the battery is in good operating condition. Correct battery output is vital for good starting system operation and for correct diagnosis of the starting system.

Starting System Tests

On machine starting motor tests should be performed first in order to determine whether the starter must be removed and tested further.

The following test should be preformed while the starting motor is still on the machine:

- Starting system voltage during cranking
- Current draw during cranking
- Voltage drops during cranking
- Engine rotation
- Starter motor pinion and flywheel ring gear inspection

Bench tests will determine if the starter must be repaired or replaced. Bench tests include a no load test and starting motor component tests.

Technical Library

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