



Ingersoll Rand

Drilling Solutions

Basic Electrical Training Level 1

Table of Contents

CHAPTER 1 - SAFETY

CHAPTER 2 - FUNDAMENTALS OF ELECTRICITY

CHAPTER 3 - DIRECT CURRENT

CHAPTER 4 - BATTERIES

CHAPTER 5 - INDUCTANCE

CHAPTER 6 - CIRCUIT MEASUREMENT

CHAPTER 7 - CIRCUIT PROTECTION DEVICES

CHAPTER 8 - CIRCUIT CONTROL DEVICES

CHAPTER 9 - BELT-DRIVEN ALTERNATORS

CHAPTER 10 - DIRECT CURRENT MOTORS

CHAPTER 11 - WIRING AND ELECTRICAL DISTRIBUTION

**CHAPTER 12 - THE ELECTRICAL CIRCUIT AND SCHEMATIC
EXAMPLES**

**CHAPTER 13 – T3W ELECTRICAL SYSTEM AND MURPHY
SHUTDOWN SCHEME**

APPENDIX - ELECTRICAL SYMBOLS

GLOSSARY

INTRODUCTION

Successfully completing everyday activities depends on safe execution. Preparation and conduct during these activities reflects on performance.

Current is the measure of shock intensity. The passage of even a very small current through a vital part of the human body can kill. At about 100 milliamperes (0.1 ampere), the shock is fatal if it lasts for one second or more. Fatalities have resulted from voltages as low as 30 volts.

Conditions while servicing the machine add to the chance of receiving an electrical shock. The body is likely to be in contact with the metal structure of the drill. The body's resistance may be low because of perspiration or damp clothing. Personnel must be aware that electrical shock hazards exist.

Accidentally placing or dropping a metal tool, ruler, flashlight case, or other conducting articles across an energized terminal can cause short circuits. The resulting arc and fire, even on relatively low-voltage circuits, may extensively damage equipment and seriously injure personnel.

Touching one conductor of an ungrounded electrical system while the body is in contact with the frame or deck of the drill or other metal equipment enclosures could be fatal.

WARNING

Treat all energized electric circuits as potential hazards at all times.

DANGER SIGNALS

Be constantly alert for any signs that might indicate a malfunction of electrical equipment. When any danger signals are noted, report them immediately to the maintenance department of your supervisor. The following are examples of danger signals:

- Fire, smoke, sparks, arcing, or an unusual sound from an electric motor, conduit or control.
- Frayed and damaged wires, conduits or enclosures.
- Conduits, wires, and devices that feel warm to the touch.
- Slight shocks felt when handling electrical equipment.
- Unusually hot running electric motors and other electrical equipment.
- An odor of burning or overheated insulation.
- Electrical equipment that either fails to operate or operates irregularly.
- Electrical equipment that produces excessive vibrations.

CAUTION

Do not operate faulty equipment. Stand clear of any suspected hazard, and instruct others to do likewise.

ELECTRIC SHOCK

Electric shock is a jarring, shaking sensation. Usually it feels like receiving a sudden blow. If the voltage and current are sufficiently high, unconsciousness occurs. Electric shock may severely burn the skin. Muscular spasms may cause the hands to clasp the apparatus or wire making it impossible to let go.

Rescue and Care of Shock Victims

For complete coverage of cardiopulmonary resuscitation (CPR) and treatment of burn and shock victims, refer to the mines safety department for instructions and training.

The following procedures are recommended for the rescue and care of shock victims:

- Remove the victim from electrical contact at once, but do not endanger yourself. Touching a shock victim who is still in contact with the energized circuit will make you another shock victim. Help the shock victim by de-energizing the affected circuit. Then use a dry stick, rope, belt, coat, blanket, shirt, or any other nonconductor of electricity to drag or push the victim to safety.
- Determine the cardiopulmonary status of the casualty. (A trained individual should start CPR, if spontaneous respiration or circulation is absent.)
- Once the person is stabilized, tend to the physical injuries, as they would normally be treated. Lay the victim face up in a prone position. The feet should be about 12 inches higher than the head. Chest or head injuries require the head to be slightly elevated. If there is vomiting or if there are facial injuries that cause bleeding into the throat, place the victim on his stomach with his head turned to one side. The head should be 6 to 12 inches lower than the feet.
- Keep the victim warm. The injured person's body heat must be conserved. Cover the victim with one or more blankets, depending on the weather and the person's exposure to the elements. Avoid artificial means of warming, such as hot water bottles.
- Do not give drugs, food and liquids if medical attention will be available within a short time. If necessary, liquids may be administered. Use small amounts of water, tea, or coffee. Never give alcohol, opiates, and other depressant substances.

- Send for medical personnel (a doctor, if available) at once, but do not under any circumstances leave the victim until medical help arrives.

Safety Precautions for Preventing Electric Shock

Observe the following safety precautions when working on electrical equipment:

- When work must be done in the immediate vicinity of electrical equipment, check with the senior engineer responsible for maintaining the equipment to avoid any potential hazards. Never work alone. Another person could save your life if you receive an electric shock.
- Never work on energized circuits. The power source should be tagged out at the nearest source of electricity for the component being serviced.
- Keep covers for all fuse boxes, junction boxes, switch boxes, and wiring accessories closed. Report any cover that is not closed or that is missing to the senior engineer responsible for its maintenance. Failure to do so may result in injury to personnel or damage to equipment if an accidental contact is made with exposed live circuits.
- Discharge capacitors before working on de-energized equipment. Take special care to discharge capacitors properly. Injury or damage to equipment could result if improper procedures are used.
- When working on energized equipment, stand on a rubber mat to insulate yourself from the steel deck.
- When working on an energized circuit, wear approved electrical insulating rubber gloves. Cover as much of your body as practical with an insulating material, such as shirtsleeves. This is especially important when working in a warm space where you may perspire.
- If possible, de-energize equipment before hooking up or removing test equipment.
- When working on energized electrical equipment, work with only one hand inside the equipment. Keep the other hand clear of all conductive materials that may provide a path for current flow.
- Wear safety goggles. Sparks could injure or damage your eyes. The sulfuric acid contained in batteries and the oils in electrical components can cause blindness.
- Ensure that all tools are adequately insulated when working on electrical equipment.
- Never work on electrical equipment while wearing rings, watches, identification tags, or other jewelry.

- Never work on electrical equipment while wearing loose-fitting clothing. Be careful of loose sleeves and shirttails.
- Ensure guards adequately protect all rotating and reciprocating parts of the electric motors.
- Remain calm and consider the possible consequences before performing any action.

DAMAGE AND FIRE

Turn off (eliminate) power to the affected circuits if there is an electrical fire on a drill rig. If critical systems are involved that prevent power from being secured, extinguish the fire using a non-conducting agent, such as dry chemical, carbon dioxide (CO₂), or halon.

WARNING

The use of water in any form is not permitted.

Carbon dioxide is the choice for fighting electrical fires. It has a nonconductive extinguishing agent and does not damage equipment. However, the ice that forms on the horn of the extinguisher will conduct electricity.

WARNING

Personnel exposed to a high concentration of CO₂ will suffocate.

Burning electrical insulation is toxic and can kill in a matter of moments. Use the oxygen breathing apparatus (OBA) when fighting electrical fires. For more information, refer to your mine safety department for specific training.

PORTABLE AND TEMPORARY ELECTRICAL EQUIPMENT

Ensure either the chief electrical engineer or the safety department approves all electrical extension cords. Never use an extension cord or power hand tool without it being properly grounded. Regularly inspect all extension cords and portable electrical equipment. Where possible, ground all metal multi-meters and test equipment to the machine. Some meters have a grounding jack for this connection.

WARNING

An ungrounded portable power tool can kill.

REPAIR SAFETY

Battery design forces the electrolyte to explode upwards. Never service batteries without proper eye protection. If battery electrolyte gets in your eyes, flush them immediately for 15 minutes and seek medical attention.

Before starting any electrical work, secure (turn off) the power to the circuit and affix a "Lock Out" tag (temporary warning tag) to the affected circuit breaker or power source. Check the de-energized circuit with a multi-meter. If you must leave the repair and return at a later time, always ensure that the circuit is de-energized before resuming work.

Do not remove a lock out tag unless you installed it. The person tagging or "locking out" a circuit, machine, or device is the only person approved to remove the tag.

Figure 1-1 shows an example of a temporary warning tag. Any tag can be used as long as it contains the following minimum amount of information:

- Time and date work is started.
- The person performing the work.
- The affected circuits.
- The approval and signature of the chief engineer or electrical supervisor.
- The required position of the affected switch, breaker, or fuse, such as closed, open, or removed.

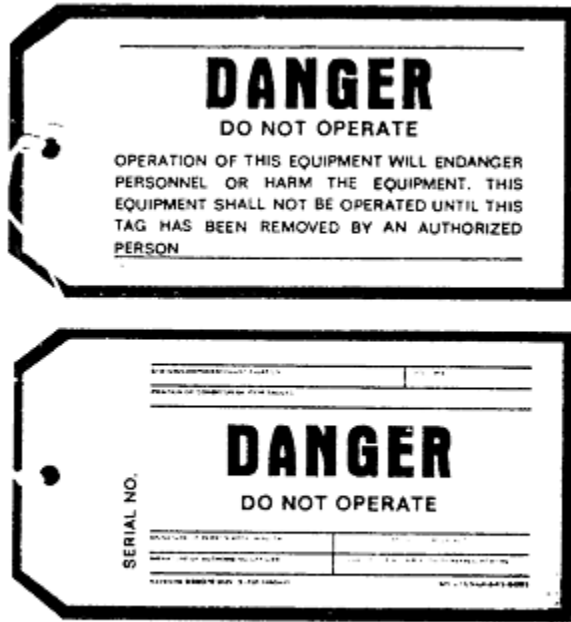


FIGURE 1-1. Temporary Warning Tag (NAVSIPS 9890/8).

When you are engaged in electrical repairs on a drill, (esp. High Voltage operated Drills) it is recommended always to work in teams of two or more. Never start working on an electrical system until the maintenance chief or the immediate supervisor has been informed. A drills operational status reflects on the machine and production status, and its ability to meet production demands. All hydraulic and electrical systems are interrelated. What may appear to be a minor repair may ultimately determine whether or not the drill is fully operational.

Introductions

Electricity is a fundamental entity of nature. It consists mainly of negatively and positively charged particles commonly found in the atom. Through man-made influence and natural phenomena, it is possible to observe how the electron (negatively charged) and the proton (positively charged) interact magnetically.

The attraction and repulsion principles of magnetism are used to make electricity perform work. Magnetic principles determine certain reactions; for example, the attraction or repulsion of two magnetically charged objects. These principles can be used in a motor to cause motion and to turn a water pump. Electricity, in other words, uses the magnetic properties of subatomic particles to develop magnetic fields at a given place and time to perform work.

Taking a magnetically neutral atom and artificially separating the electron from the rest of the atom leaves a positive ion. Exciting this atom through mechanical or chemical means prevents the electron and positive ion from returning to its natural state. Nature seeks equilibrium or a natural balance and order.

A battery or generator forces all the electrons to one terminal and positive ions to the other terminal. As long as the atoms are stimulated, this imbalance or difference between the terminals remains. If excitation of the atoms is stopped nature will cause the negative electrons to return to their positive ions through the principles of magnetism.

If excitation of the atoms continues and a complete path of conductive material connects the two terminals (where the negative electrons and positive ions have gathered), a complete circuit is created. Because positive and negative polarities attract, the electron follows this path from its terminal to the positive ion terminal seeking equilibrium. In doing so, a magnetic field from the electron is developing in the entire circuit.

An electron is surrounded by a magnetic field. Wherever an electron is present there is also the magnetic field. The more electrons, the greater the magnetic field in the circuit. The greater the magnetic field in the circuit, the greater the ability to attract or repel other magnets or ferrometallic objects.

Current is measured in amperes and is known mathematically as a quantity of electrons passing a specific point in a circuit in a given time period (coulomb per second).

Voltage is the force that allows the electron to be available to be attracted to the positive ion. Initially, when the electrically neutral atom was excited, a difference in potential was created. This produced negative electrons at one terminal and positive ions at the other terminal. The greater the difference in potential, the greater the number of electrons gathered at one terminal and positive ions at the other terminal. The greater this difference, the greater the potential to do work as the electrons move throughout the circuit carrying their magnetic field. As long as

an imbalance at the terminals results from the exciting of atoms artificially, there will be a difference in potential, which is another term for voltage. The greater the difference in potential, the greater the voltage. The greater the negative and positive attraction, the greater the force to attract electrons back to the positive ions seeking equilibrium.

All the electrons (current) will move through the circuit at once, unless impeded or slowed down by some outside force. Wire size or an electrical light filament will restrict or resist the flow of the electrons returning to the positive ions. Everything that prevents or resists the maximum flow of electrons in their natural desire to seek out their positive ions is called resistance. If there is no resistance, a short circuit, which is a very dangerous condition, exists.

CONDUCTORS, SEMICONDUCTORS, AND INSULATORS

Since every electrical device is constructed of parts made from ordinary matter, the effects of electricity on matter must be well understood. Depending on their ability to conduct an electric current, all elements of matter fit into one of three categories: conductors, semiconductors, and insulators. Conductors are elements that transfer electrons very readily. Insulators have an extremely high resistance to the flow of electrons. All material between these two extremes is referred to as a semiconductor.

The electron theory states that all matter is composed of atoms and the atoms are composed of smaller particles called protons, electrons, and neutrons. The electrons orbit the nucleus, which contains the protons and neutrons. Electricity is most concerned with the valence electrons. These electrons break loose from their parent atom the easiest. Normally, conductors have no more than three valence electrons; insulators have five or more, and semiconductors have four.

The electrical conductivity of matter depends on the atomic structure of the material from which the conductor is made. In any solid material, such as copper, the atoms that make up the molecular structure are bound firmly together. At room temperature, copper contains a large amount of heat energy. Since heat energy is one method of removing electrons from their orbits, copper contains many free electrons that can move from atom to atom. When not under the influence of an external force, these electrons move in a haphazard manner within the conductor. This movement is equal in all directions so that electrons are not lost or gained by any part of the conductor. When controlled by an external force, the electrons move generally in the same direction. The effect of this movement is felt almost instantly from one end of the conductor to the other. This electron movement is called an electric current.

Some metals are better conductors of electricity than others. Silver, copper, gold, and aluminum exchange valence electrons readily and make good conductors. Silver is the best conductor, followed by copper, gold, and aluminum. Copper is used more often than silver because of cost. Aluminum is used where weight is a major consideration, such as in high-tension power lines with long spans

between supports. Gold is used where oxidation or corrosion is a consideration and good conductivity is required. The ability of a conductor to handle current also depends on its physical dimensions. Conductors are usually found in the form of wire, but may be bars, tubes, or sheets.

Nonconductors fail to exchange valence electrons because their outer shells are completed with tightly bound valence electrons of their own. These materials are called insulators. Some examples of these materials are rubber, plastic, enamel, glass, dry wood, and mica. Just as there is no perfect conductor, neither is there a perfect insulator.

Some materials are neither good conductors nor good insulators, since their electrical characteristics fall between those of conductors and insulators. These in-between materials are semiconductors. Germanium and silicon are two common semiconductors used in solid-state devices.

Magnetic Fields

The space surrounding a magnet where magnetic forces act is the magnetic field. Magnetic forces have a pattern of directional force observed by performing an experiment with iron filings. Place a piece of glass over a bar magnet. Then sprinkle iron filings on the surface of the glass. The magnetizing force of the magnet will be felt through the glass, and each iron filing becomes a temporary magnet. Tap the glass gently. The iron particles will align themselves with the magnetic field surrounding the magnet just as the compass needle did previously. The filings form a definite pattern, which is a visible representation of the forces comprising the magnetic field. The arrangements of iron filings in Figure 2-13 indicate that the magnetic field is very strong at the poles and weakens as the distance from the poles increases. They also show that the magnetic field extends from one pole to the other in a loop around the magnet.

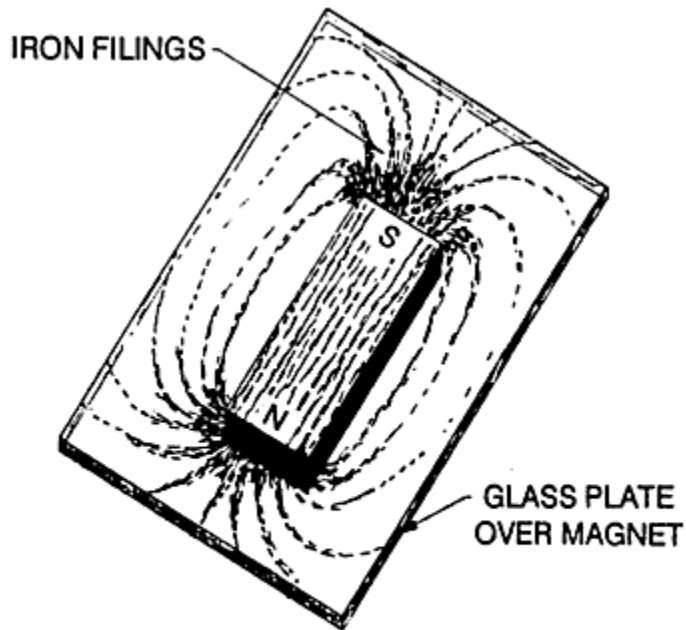


FIGURE 2-13. Pattern Formed by Iron Filings.

Lines of Force

To further describe and work with magnetic phenomena, lines are used to represent the force existing in the area surrounding a magnet ([Figure 2-14](#)). These magnetic lines of force are imaginary lines used to illustrate and describe the pattern of the magnetic field. The magnetic lines of force are assumed to emanate from the north pole of a magnet, pass through the surrounding space, and enter the south pole. They then travel inside the magnet from the south pole to the north pole, thus completing a closed loop.

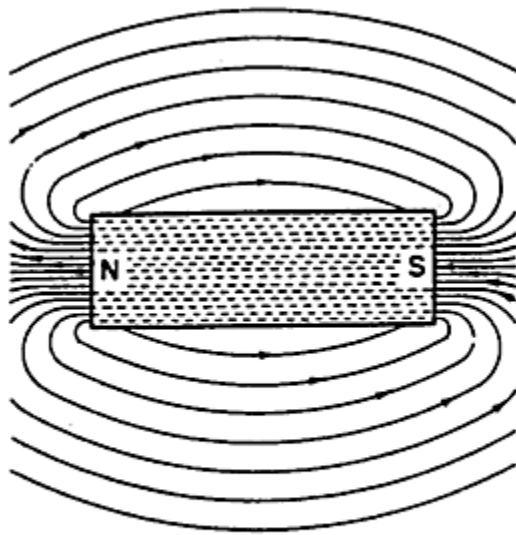


FIGURE 2-14. Bar Magnet Showing Lines of Force.

When two magnetic poles are brought close together, the mutual attraction or repulsion of the poles produces a more complicated pattern than that of a single magnet. These magnetic lines of force can be plotted by placing a compass at various points throughout the magnetic field, or they can be roughly illustrated using iron filings as before. [Figure 2-15](#) shows a diagram of magnetic poles placed close together.

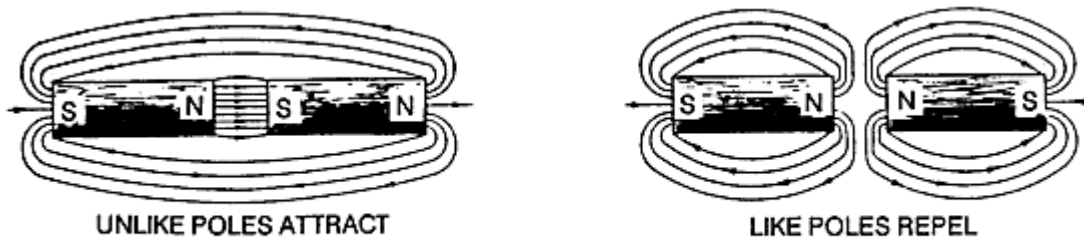


FIGURE 2-15. Magnetic Poles in Close Proximity.

Although magnetic lines of force are imaginary a simplified version of many magnetic phenomena can be explained by assuming they have certain real properties. The lines of force are similar to rubber bands which stretch outward when a force is exerted on them and contract when the force is removed. Characteristics of magnetic lines of force are as follows:

- Magnetic lines of force are continuous and will always form closed loops.
- Magnetic lines of force will never cross one another.

- Parallel magnetic lines of force traveling in the same direction repel one another. Parallel magnetic lines of force traveling in opposite directions extend to unite with each other and form single lines traveling in a direction determined by the magnetic poles creating the lines of force.
- Magnetic lines of force tend to shorten themselves. Therefore, the magnetic lines of force existing between two unlike poles cause the poles to be pulled together.
- Magnetic lines of force pass through all materials, both magnetic and nonmagnetic.
- Magnetic lines of force always enter or leave a magnetic material at right angles to the surface.

Magnetic Effects

Magnetic Flux. The total number of magnetic lines of force leaving or entering the pole of a magnet is called magnetic flux. The number of flux lines per unit area is called flux density.

Field Intensity. The intensity of a magnetic field is directly related to the magnetic force exerted by the field.

Attraction/Repulsion. The intensity of attraction or repulsion between magnetic poles may be described by a law almost identical to Coulomb's Law of Charged Bodies. The force between two poles is directly proportional to the product of the pole strengths and inversely proportional to the square of the distance between the poles.

Magnetic Induction

All substances that are attracted by a magnet can become magnetized. The fact that a material is attracted by a magnet indicates the material must itself be a magnet at the time of attraction. Knowing about magnetic fields and magnetic lines of force simplifies the understanding of how a material becomes magnetized when brought near a magnet. As an iron nail is brought close to a bar magnet (Figure 2-16), some flux lines emanating from the north pole of the magnet pass through the iron nail in completing their magnetic path. Since magnetic lines of force travel inside a magnet from the south pole to the north pole, the nail will be magnetized so its south pole will be adjacent to the north pole of the bar magnet.

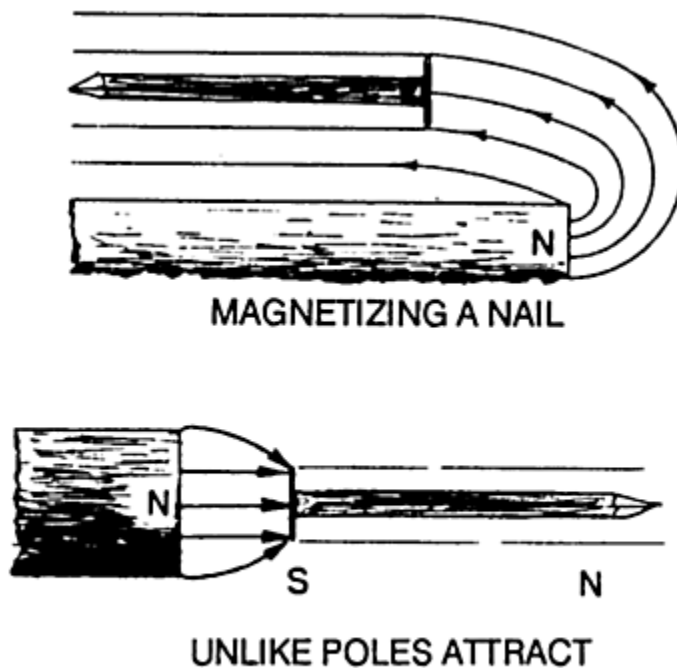


FIGURE 2-16. Magnetized Nail.

If another nail is brought in contact with the end of the first nail, it is magnetized by induction. This process can be repeated until the strength of the magnetic flux weakens as distance from the bar magnet increases. However, as soon as the first iron nail is pulled away from the bar magnet, all the nails will fall. Each nail had become a temporary magnet, but once the magnetizing force was removed, the nails' domains once again assumed a random distribution.

Magnetic induction always produces a pole polarity on the material being magnetized opposite that of the adjacent pole of the magnetizing force. It is sometimes possible to bring a weak north pole of a magnet near a strong magnet north pole and note attraction between the poles. The weak magnet, when placed within the magnetic field of the strong magnet, has its magnetic polarity reversed by the field of the stronger magnet. Therefore, it is attracted to the opposite pole. For this reason, keep a very weak magnet, such as a compass needle, away from a very strong magnet.

Magnetism can be induced in a magnetic material by several means. The magnetic material may be placed in the magnetic field, brought into contact with a magnet, or stroked by a magnet. Stroking and contact both indicate actual contact with the material but are considered in magnetic studies as magnetizing by induction.

Magnetic Shielding

Magnetic flux has no known insulator. If a nonmagnetic material is placed in a magnetic field, there is no appreciable change in flux. That is, the flux penetrates the nonmagnetic material. For example, a glass plate placed between the poles of a horseshoe magnet will have no appreciable effect on the field, although glass itself is a good insulator in an electric circuit. If a magnetic material such as soft iron is placed in a magnetic field, the flux may be redirected to take advantage of the greater permeability of the magnetic material ([Figure 2-17](#)). Permeability is the quality of a substance that determines the ease with which it can be magnetized.

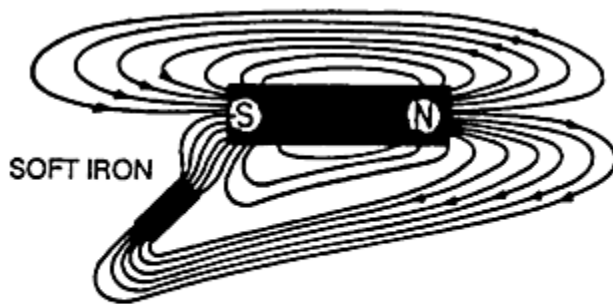


**FIGURE 2-17. Effects of a Magnetic Substance
in a Magnetic Field.**

Stray magnetic fields can influence the sensitive mechanisms of electric instruments and meters causing errors in their readings. Instrument mechanisms cannot be insulated against magnetic flux. Therefore, the flux must be directed around the instrument by placing a soft-iron case, called a magnetic screen or magnetic shield, about the instrument. Because the flux is established more readily through the iron (even though the path is larger) than through the air inside the case, the instrument is effectively shielded. [Figure 2-18](#) shows a soft iron magnetic shield around a watch.

ENERGY AND WORK

In the field of physical science, work is defined as the product of force and displacement. That is, the force applied to move an object and the distance the object is moved are the factors of work performed. No work is accomplished unless the force applied causes a change in position of a stationary object or a change in the velocity of a moving object. For example, a worker may tire by pushing against a heavy wooden crate, but unless the crate moves, no work will be accomplished.

In the study of energy and work, energy is defined as the ability to do work. To perform any kind of work, energy must be expended (converted from one form to another). Energy supplies the required force or power whenever any work is accomplished.

One form of energy is that contained by an object in motion. When a hammer is set in motion in the direction of a nail, it possesses energy of motion. As the hammer strikes the nail, the energy of motion is converted into work as the nail is driven into the wood. The distance the nail is driven into the wood depends on the velocity of the hammer at the time it strikes the nail. Energy contained in an object due to its motion is called kinetic energy.

If a hammer is suspended one meter above a nail by a string, gravity will pull the hammer downward. If the string is suddenly cut, the force of gravity will pull the hammer down against the nail, driving it into the wood. While the hammer is suspended above the nail, it has the ability to do work because of its elevated position in the earth's gravitational field. Since energy is the ability to do work, the hammer contains energy.

Energy contained in an object because of its position is called potential energy. The amount of potential energy available equals the product of the force required to elevate the hammer and the height to which it is elevated.

Another example of potential energy is that contained in a tightly coiled spring. The amount of energy released when the spring unwinds depends on the amount of force required to wind the spring initially.

ELECTRICAL CHARGES

The study of electrostatics shows that a field of force exists in the space surrounding any electrical charge. The strength of the field depends directly on the force of the charge.

The charge of one electron might be used as a unit of electrical charge since displacing electrons creates charges. However, the charge of one electron is so small that it is impractical to use. The practical unit adopted for measuring charges is the coulomb, named after the scientist Charles Coulomb. A coulomb equals the charge 6,242,000,000,000,000,000 (six quintillion, two hundred forty-two quadrillion or 6.242 times 10 to the 18th power) electrons.

When a charge of 1 coulomb exists between two bodies, one unit of electrical potential energy exists. This difference in potential between the two bodies is called electromotive force (EMF) or voltage. The unit of measure is the volt.

Electrical charges are created by the displacement of electrons, so that there is an excess of electrons at one point and a deficiency at another point. Therefore, a charge must always have either a negative or positive polarity. A body with an excess of electrons is negative; a body with a deficiency of electrons is positive.

A difference in potential can exist between two points or bodies only if they have different charges. In other words, there is no difference in potential between two bodies if both have a deficiency of electrons to the same degree. If, however, one body is deficient by 6 coulombs (6 volts) and the other is deficient by 12

coulombs (12 volts), the difference in potential is 6 volts. The body with the greater deficiency is positive with respect to the other.

In most electrical circuits only the difference in potential between two points is important. The absolute potentials of the points are of little concern. Often it is convenient to use one standard reference for all of the various potentials throughout a piece of equipment. For this reason, the potentials at various points in a circuit are generally measured with respect to the metal chassis on which all parts of the circuit are mounted. The chassis is considered to be at zero potential and all other potentials are either positive or negative with respect to the chassis. When used as the reference point, the chassis is said to be at ground potential.

Sometimes rather large values of voltage may be encountered and the volt becomes too small a unit for convenience. In this situation, the kilovolt (kV), meaning 1,000 volts, is used. For example, 20,000 volts would be written as 20 kV. Sometimes the volt may be too large a unit when dealing with very small voltages. For this purpose, the millivolt (mV), meaning one-thousandth of a volt, and the microvolt (μ V), meaning one-millionth of a volt, are used. For example, 0.001 volt would be written as 1 mV, and 0.000025 volt would be written as 25 μ V.

When a difference in potential exists between two charged bodies connected by a conductor, electrons will flow along the conductor. This flow is from the negatively charged body to the positively charged body until the two charges are equalized and the potential difference no longer exists.

Figure 2-19 shows an analogy of this action in the two water tanks connected by a pipe and valve. At first, the valve is closed and all the water is in tank A. Thus, the water pressure across the valve is at maximum. When the valve is opened, the water flows through the pipe from A to B until the water level becomes the same in both tanks. The water then stops flowing in the pipe because there is no longer a difference in water pressure between the two tanks.

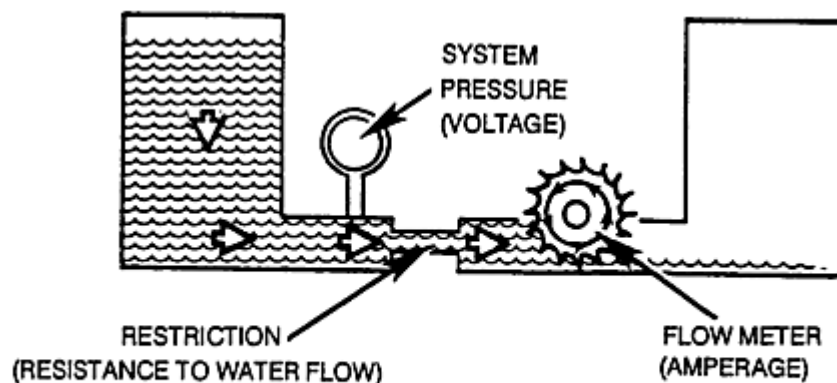


FIGURE 2-19. Water Analogy of Electric Difference in Potential.

Electron movement through an electric circuit is directly proportional to the difference in potential or EMF across the circuit, just as the flow of water through the pipe in Figure 2-19 is directly proportional to the difference in water level in the two tanks.

A fundamental law of electricity is that the electron flow is directly proportional to the applied voltage. If the voltage is increased, the flow is increased. If the voltage is decreased, the flow is decreased.

VOLTAGE PRODUCTION

It has been demonstrated that a charge can be produced by rubbing a rubber rod with fur. Because of the friction involved, the rod acquires electrons from the fur, making it negative. The fur becomes positive due to the loss of electrons. These quantities of charge constitute a difference in potential between the rod and the fur. The electrons that make up this difference in potential are capable of doing work if a discharge is allowed to occur.

To be a practical source of voltage, the potential difference must not be allowed to dissipate. It must be maintained continuously. As one electron leaves the concentration of negative charge, another must be immediately provided to take its place or the charge will eventually diminish to the point where no further work can be accomplished. A voltage source, therefore, is a device that can supply and maintain voltage while an electrical apparatus is connected to its terminals. The internal action of the source is such that electrons are continuously removed from one terminal to keep it positive and simultaneously supplied to the second terminal to keep it negative.

Presently, six methods for producing a voltage or electromotive force are known. Some are more widely used than others, and some are used mostly for specific applications. The six known methods of producing a voltage are --

- Friction. Voltage is produced by rubbing certain materials together.
- Pressure (piezoelectricity). Voltage is produced by squeezing crystals of certain substances.
- Heat (thermoelectricity). Voltage is produced by heating the joint (junction) where two unlike metals are joined.
- Light (photoelectricity). Voltage is produced by light striking photosensitive (light sensitive) substances.
- Chemical action. Voltage is produced by chemical reaction in a battery cell.
- Magnetism. Voltage is produced in a conductor when the conductor moves through a magnetic field, or a magnetic field moves through the conductor so that the magnetic lines of force of the field are cut.

Voltage Produced by Friction

The first method discovered for creating a voltage was generation by friction. The development of charges by rubbing a rod with fur is a prime example of the way friction generates voltage. Because of the nature of the materials producing this voltage, it cannot be conveniently used or maintained. Therefore, this method has very little practical use.

While searching for ways to produce larger amounts of voltage with more practical nature, machines were developed that transferred charges from one terminal to another by rotating glass discs or moving belts. The most notable of these machines is the Van de Graaff generator. It is used today to produce potentials in the order of millions of volts for nuclear research. As these machines have little value outside the field of research, their theory of operation will not be described here.

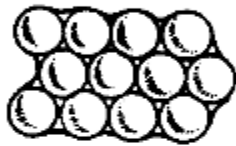
Voltage Produced by Pressure

One specialized method of generating an EMF uses the characteristics of certain ionic crystals such as quartz, Rochelle salts, and tourmaline. These crystals can generate a voltage whenever stresses are applied to their surfaces. Thus, if a crystal of quartz is squeezed, charges of opposite polarity appear on two opposite surfaces of the crystal. If the force is reversed and the crystal is stretched, charges again appear but are of the opposite polarity from those produced by squeezing. If a crystal of this type is vibrated, it produces a voltage of reversing polarity between two of its sides. Quartz or similar crystals can thus be used to convert mechanical energy into electrical energy. Figure 2-20 shows this phenomenon, called the piezoelectric effect. Some of the common devices that use piezoelectric crystals are microphones, phonograph cartridges, and oscillators used in radio transmitters, radio receivers, and sonar equipment. This method of generating an EMF is not suitable for applications having large voltage or power requirements. But it is widely used in sound and communications systems where small signal voltages can be effectively used.

- (A) Noncrystallized Structure.
- (B) Crystallized Structure.
- (C) Compression of a Crystal.
- (D) Decompression of a Crystal.



MOLECULES OF NON-CRYSTALLIZED MATTER
(A)



MOLECULES OF CRYSTALLIZED MATTER
(B)

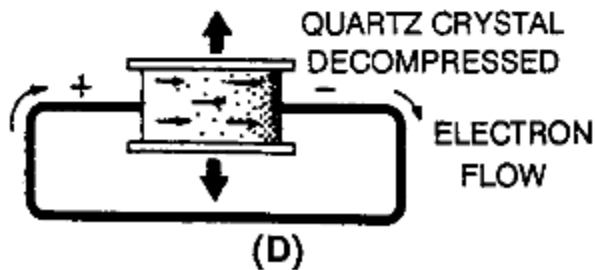
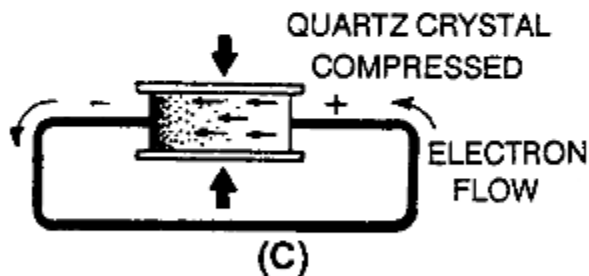


FIGURE 2-20. Piezoelectric Effect.

Crystals of this type also possess another interesting property, the converse piezoelectric effect. They can convert electrical energy into mechanical energy. A voltage impressed across the proper surfaces of the crystal will cause it to expand or contract its surfaces in response to the voltage applied.

Voltage Produced by Heat

When a length of metal, such as copper, is heated at one end, valence electrons tend to move away from the hot end toward the cooler end. This is true of most metals. However, in some metals such as iron, the opposite takes place and electrons tend to move toward the hot end. Figure 2-21 illustrates these characteristics. The negative charges (electrons) are moving through the copper away from the heat and through the iron toward the heat. They cross from the iron to the copper through the current meter to the iron at the cold junction. This device is called a thermocouple.

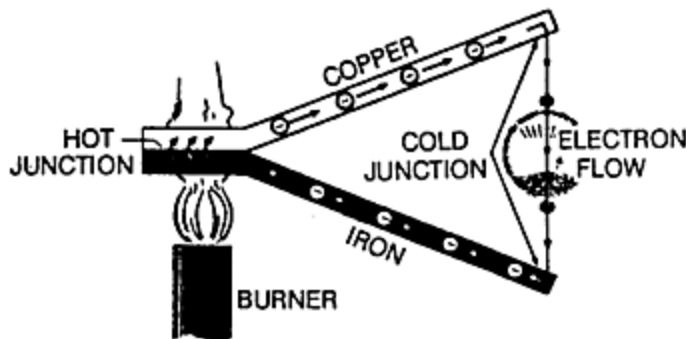


FIGURE 2-21. Voltage Produced by Heat.

Thermocouples have a greater power capacity than crystals, but it is still very small compared to some other sources. The thermoelectric voltage in a thermocouple depends mainly on the difference in temperature between the hot and cold junctions. They are therefore widely used to measure temperature and are used in heat-sensing devices in automatic temperature control equipment. Thermocouples generally can be subjected to much greater temperatures than ordinary thermometers, such as mercury or alcohol types.

ELECTRIC CURRENT

Electrons move through a conductor in response to a magnetic field. Electron current is the directed flow of electrons. The direction of electron movement is from a region of negative potential to a region of positive potential. Therefore, electron current flow in a material is determined by the polarity of the applied voltage.

Magnitude of Current Flow

Electric current is the directed movement of electrons. Directed drift, therefore, is current, and the terms can be used interchangeably. The term "directed drift" helps distinguish the random and directed motion of electrons. However, "current flow" is the term most commonly used to indicate a directed movement of electrons.

The magnitude of current flow is directly related to the amount of energy that passes through a conductor as a result of the drift action. An increase in the number of energy carriers (moving free electrons) or an increase in the energy of the existing valence electrons increases the current flow. When an electric potential is impressed across a conductor, the velocity of the free electrons increases, causing an increase in the energy of the carriers. An increased number of electrons is also generated, providing added carriers of energy. The additional number of free electrons is relatively small. Thus, the magnitude of current flow depends mainly on the velocity of the existing moving electrons.

The difference in potential affects the magnitude of current flow. Initially, free electrons are given additional energy because of the repelling and attracting electrostatic field. If the difference in potential (voltage) is increased, the electric field will be stronger, the amount of energy imparted to a valence electron will be greater, and the current will be increased. If the potential difference is decreased, the strength of the field is reduced, the energy supplied to the electron is diminished, and the current is decreased.

Measurement of Current

The magnitude of current is measured in amperes. A current of 1 ampere is said to flow when 1 coulomb of charge passes a point in one second (1 coulomb equals the charge of 6.242 times 10 to the 18th power electrons). Often the ampere is much too large a unit for measuring current. Therefore, the milliampere (mA), one-thousandth of an ampere, or the microampere (uA), one-millionth of an ampere, is used. The device that measures current is called an ammeter.

ELECTRICAL RESISTANCE

The directed movement of electrons constitutes a current flow. Electrons do not move freely through a conductor's crystalline structure. Some materials offer little opposition to current flow, while other materials greatly oppose current flow. This opposition to current flow is resistance (R), and the unit of measure is the ohm. The greater the resistance in the circuit, the smaller the current will be from the power supply. Resistance is essential in a circuit. If all the resistance in a circuit was eliminated, a short circuit would result. If not prevented, this maximum current flow will damage the electrical system. The standard of measure for 1 ohm is the resistance provided at 0 degrees Celsius by a column of mercury having a cross-sectional area of 1 square millimeter and a length of 106.3 centimeters. A conductor has 1 ohm of resistance when an applied potential of 1 volt produces a current of 1 ampere. The symbol used to represent the ohm is the Greek letter omega (Ω).

Resistance, although an electrical property, is determined by the physical structure of a material. Many of the same factors that control current flow govern the resistance of a material. Therefore, the factors that affect current flow will help explain the factors affecting resistance.

The magnitude of resistance is determined in part by the number of free electrons available within the material. Since a decrease in the number of free electrons will decrease the current flow, the opposition to current flow (resistance) is greater in a material with fewer free electrons. Thus, the resistance of a material is determined by the number of free electrons available in a material. The conditions that limit current flow also affect resistance. The type of material, physical dimensions, and temperature affect the resistance of a conductor.

CONDUCTANCE

Electricity is often explained in terms of opposites. The opposite of resistance is conductance. Conductance is the ability of a material to pass electrons. The same factors that affect the magnitude of resistance affect conductance, but in the opposite manner. Conductance is directly proportional to area and inversely proportional to the length of the material. The temperature of the material is also a factor. With a constant temperature, the conductance of a material can be calculated.

The unit of conductance is the mho, which is ohm spelled backwards, or siemens. Whereas the symbol used to represent resistance (R) is the Greek letter omega (Ω), the symbol used to represent conductance is (U). The relationship between resistance and conductance is a reciprocal one. A reciprocal of a number is 1 divided by the number. In terms of resistance and conductance, $R = 1/G$ and $G = 1/R$.

ELECTRICAL RESISTORS

Resistance is a property of every electrical component. At times, its effects will be undesirable. However, resistance is used in many varied ways. Resistors are components manufactured in many types and sizes to possess specific values of resistance. In a schematic representation, a resistor is drawn as a series of jagged lines (Figure 2-29).

TYPICAL RESISTOR	TYPE	SYMBOL
A 	FIXED CARBON	
B 	FIXED WIREWOUND (TAPPED)	
C 	ADJUSTABLE WIREWOUND	
D 	POTENTIOMETER	
E 	RHEOSTAT	

FIGURE 2-29. Types of Resistors.

Types of Resistors

The two kinds of resistors are fixed and variable. The fixed resistor will have one value and will never change, other than through temperature, age, and so forth. The resistors in views A and B are fixed resistors. The tapped resistor in view B has several fixed taps which make more than one resistance value available. The sliding contact resistor or in view C has an adjustable collar that can be moved to tap off any resistance within the ohmic value range of the resistor.

There are two types of variable resistors: the potentiometer and the rheostat (views D and E). An example of the potentiometer is the volume control on your radio. An example of the rheostat is the dimmer control for the dash lights in an automobile. There is a slight difference between them. Rheostats usually have two connections: one fixed and the other movable. Any variable resistor can properly be called a rheostat. The potentiometer always has three connections: two fixed and one movable. Generally, the rheostat has a limited range of values and high current-handling capability. The potentiometer has a wide range of values, but it usually has a limited current-handling capability. Potentiometers are always connected as voltage dividers.

WATTAGE RATING

When a current is passed through a resistor, heat develops within the resistor. The resistor must be able to dissipate this heat into the surrounding air. Otherwise, the temperature of the resistor rises causing a change in resistance or possibly causing the resistor to burn out.

The resistor's ability to dissipate heat depends on the design of the resistor. It depends on the amount of surface area exposed to the air. A resistor designed to dissipate a large amount of heat therefore must be large. The heat dissipating capability of a resistor is measured in watts. Some of the more common wattage ratings of carbon resistors are 1/8 watt, 1/4 watt, 1/2 watt, 1 watt, and 2 watts. In some of the newer state-of-the-art circuits, much smaller wattage resistors are used. Generally, the type that can be physically worked with are of the values above. The higher the wattage rating of the resistor, the larger its physical size. Resistors that dissipate very large amounts of power (watts) are usually wirewound resistors. Wirewound resistors with wattage ratings up to 50 watts are not uncommon. Figure 2-30 shows some resistors with different wattage ratings.

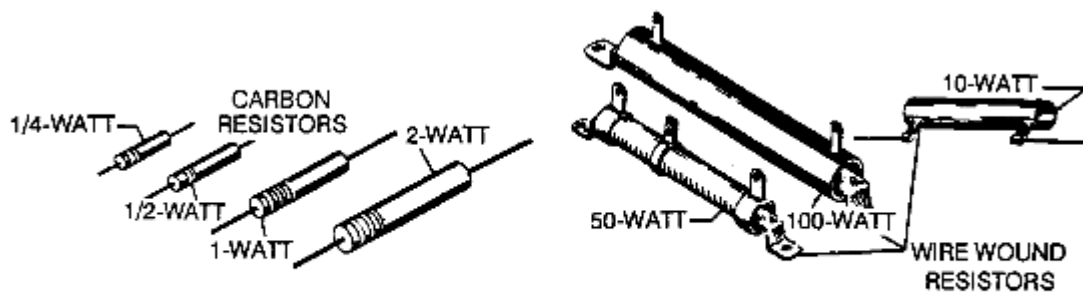


FIGURE 2-30. Resistors of Different Wattage Ratings.

INTRODUCTION

This chapter describes the basic direct current (DC) circuit and the basic schematic diagram of that circuit. The schematic diagram is used when working in electricity and electronics. This chapter also describes the series DC circuit and the parallel DC circuit. It explains how to determine the total resistance, current, voltage, and power in a series, parallel, or series-parallel network through the use of Ohm's and Kirchhoff's Laws.

BASIC ELECTRIC CIRCUIT

The flashlight is an example of a basic electric circuit. It contains a source of electrical energy (the dry cells in the flashlight), a load (the bulb) that changes the electrical energy into a more useful form of energy (light), and a switch to control the energy delivered to the load.

A load is any device through which an electrical current flows and which changes this electrical energy into a more useful form. The following are common examples of loads:

- A light bulb (changes electrical energy to light energy).
- An electric motor (changes electrical energy into mechanical energy).
- A speaker in a radio (changes electrical energy into sound).

A source is the device that furnishes the electrical energy used by the load. It may be a simple dry cell (as in a flashlight), a storage battery (as in an automobile), or a power supply (such as a battery charger). A switch permits control of the electrical device by interrupting the current delivered to the load.

SCHEMATIC REPRESENTATION

The technician's main aid in troubleshooting a circuit in a piece of equipment is the schematic diagram. This is a picture of the circuit that uses symbols to represent the various circuit components. A relatively small diagram can show large or complex circuits. Before studying the basic schematic, review the appendix, which shows the symbols used in the schematic diagram. These symbols and others like them are used throughout the study of electricity and electronics.

The schematic in Figure 3-1 represents a flashlight. In the de-energized state, the switch (S1) is open. There is not a complete path for current (I) through the circuit, so the bulb (DS1) does not light. In the energized state, the switch (S1) is closed. Current flows from the negative terminal of the battery (BAT), through the switch (S1), through the lamp (DS1), and back to the positive terminal of the battery. With the switch closed, the path for current is complete. Current will continue to flow until the switch (S1) is moved to the open position or the battery is completely discharged.

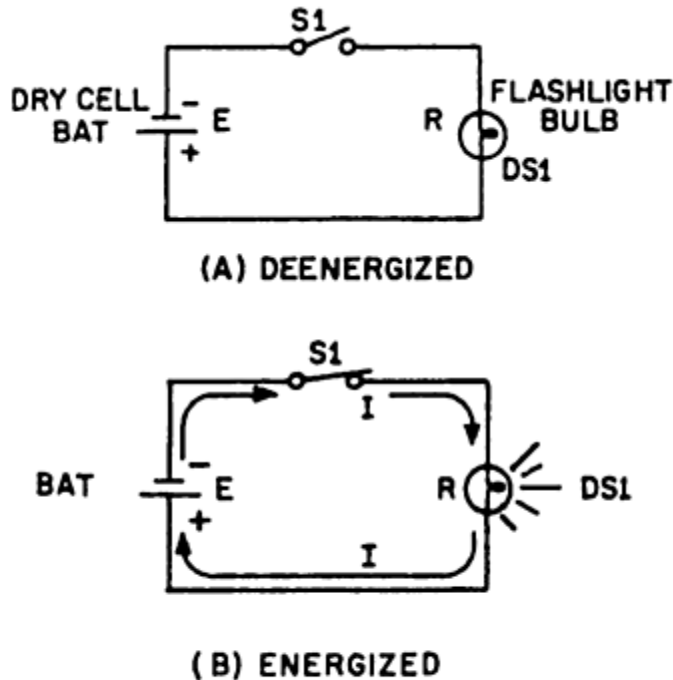


FIGURE 3-1. Schematic of a Flashlight.

OHM'S LAW

In the early part of the 19th century, George Simon Ohm proved by experiment that a precise relationship exists between current, voltage, and resistance. This relationship, called Ohm's Law, is stated as follows: The current in a circuit is directly proportional to the applied voltage and inversely proportional to the circuit resistance. Ohm's Law may be expressed as an equation.

$$I = \frac{E}{R}$$

Where:

I = current in amperes

E = voltage in volts

R = resistance in ohms

As stated in Ohm's Law, current is inversely proportional to resistance. As the resistance in a circuit increases, the current decreases proportionately.

In the equation $I = E/R$, if any two quantities are known, you can determine the third one. Refer to [Figure 3-1 view B](#), the schematic of the flashlight. If the battery (BAT) supplies a voltage of 1.5 volts and the lamp (DS1) has a resistance of 5

ohms, then you can determine the current in the circuit by using these values in the equation:

$$I = \frac{1.5 \text{ volts}}{5 \text{ ohms}}$$

$$I = .3 \text{ amp}$$

If the flashlight were a two-cell flashlight, twice the voltage or 3.0 volts would be applied to the circuit. You can determine the current in the circuit using this voltage in the equation:

$$I = \frac{3.0 \text{ volts}}{5 \text{ ohms}}$$

$$I = .6 \text{ amp}$$

As the applied voltage is doubled, the current flowing through the circuit doubles. This demonstrates that the current is directly proportional to the applied voltage.

If the value of resistance of the lamp is doubled, you can determine the current in the circuit:

$$I = \frac{3.0 \text{ volts}}{10 \text{ ohms}}$$

$$I = .3 \text{ amp}$$

The current has been reduced to one-half of the value of the previous equation, or .3 ampere. This demonstrates that the current is inversely proportional to the resistance. Doubling the value of the resistance of the load reduces circuit current value to one-half of its former value.

Figures 3-2 and 3-3 are diagrams for determining resistance and voltage in a basic circuit, respectively.

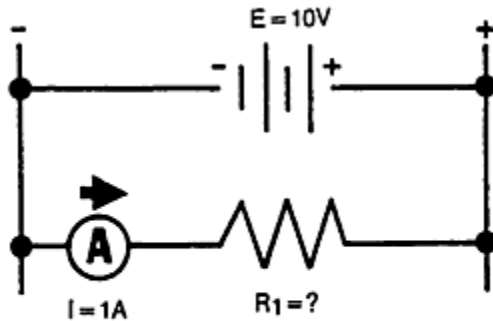


FIGURE 3-2. Determining Resistance in a Basic Circuit.

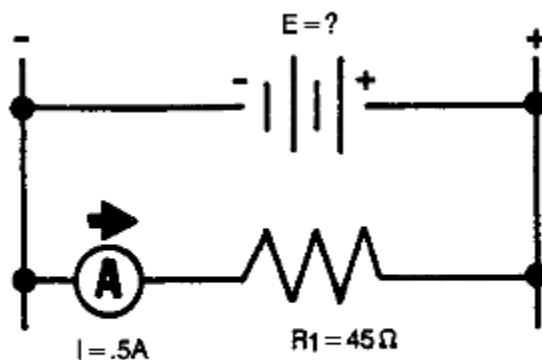


FIGURE 3-3. Determining Voltage in a Basic Circuit.

Using Ohm's Law, the resistance of a circuit can be determined knowing only the voltage and the current in the circuit. In any equation, if all the variables (parameters) are known except one, that unknown can be found. For example, using Ohm's Law, if current (I) and voltage (E) are known, you can determine resistance (R), the only parameter not known:

Basic formula: $I = \frac{E}{R}$

The formula may also be expressed as -

$E = I \times R$ or $R = \frac{E}{I}$

The Ohm's Law equation and its various forms may be obtained readily using Figure 3-4. The circle containing E, I, and R is divided into two parts, with E above the line and I and R below the line. To determine the unknown quantity, first cover that quantity with a finger. The position of the uncovered letters in the circle will indicate the mathematical operation to be performed.

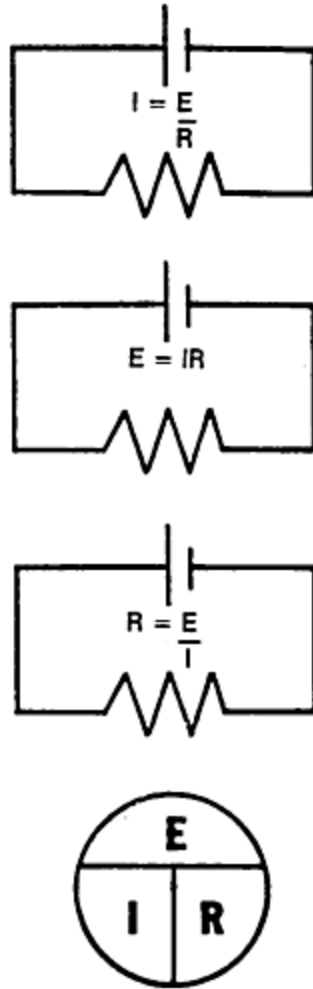


FIGURE 3-4. Ohm's Law in Diagram Form.

For example, to find I , cover I with a finger. The uncovered letters indicate that E is to be divided by R , or --

$$I = \frac{E}{R}$$

To find the formula for E , cover E with your finger. The result indicates that I is to be multiplied by R , or --

$$E = IR$$

To find the formula for R , cover R . The result indicates that E is to be divided by I , or --

$$R = \frac{E}{I}$$

POWER

Power, whether electrical or mechanical, pertains to the rate at which work is being done. Work is done whenever a force causes motion. When a mechanical force is used to lift or move a weight, work is done. However, force exerted without causing motion, such as the force of a compressed spring acting between two freed objects, does not constitute work.

Voltage is an electrical force that forces current to flow in a closed circuit. However, when voltage exists but current does not flow because the circuit is open, no work is done. This is similar to the spring under tension that produced no motion. The instantaneous rate at which this work is done is called the electric power rate and is measured in watts.

A total amount of work may be done in different lengths of time. For example, a given number of electrons may be moved from one point to another in 1 second or in 1 hour, depending on the rate at which they are moved. In both cases, total work done is the same. However, when the work is done in a short time, the wattage, or instantaneous power rate, is greater than when the same amount of work is done over a longer period of time.

The basic unit of power is the watt. Power in watts equals the voltage across a circuit multiplied by current through the circuit. This represents the rate at any given instant at which work is being done. The symbol P indicates electrical power. The basic power formula is --

$$P = I \times E$$

Where:

I = current in the circuit

E = voltage

The amount of power changes when either voltage or current or both are changed.

In practice, the only factors that can be changed are voltage and resistance. In explaining the different forms that formulas may take, current is sometimes presented as a quantity that is changed. Remember, if current is changed it is because either voltage or resistance has been changed.

Four of the most important electrical quantities are voltage (E), current (I), resistance (R), and power (P). The relationships among these quantities are used throughout the study of electricity. Previously, P was expressed in terms of alternate pairs of the other three basic quantities (E, I, and R). In practice, any one of these quantities can be expressed in terms of any two of the others.

Figure 3-5 is a summary of 12 basic formulas. The four quantities E, I, R, and P are at the center of the figure. Next to each quantity are three segments. In each

segment, the basic quantity is expressed in terms of two other basic quantities and no two segments are alike.

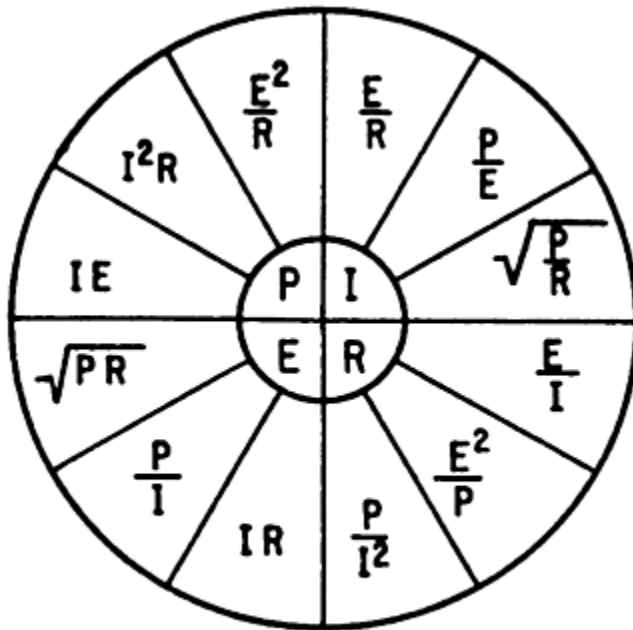


FIGURE 3-5. Summary of Basic Formulas.

For example, you can use the formula wheel in [Figure 3-5](#) to find the formula to solve this problem. A circuit has a source voltage of 24 volts and a measured current of 10 amperes. What would the power rate be? Find P in the center of the wheel. IE or current multiplied by voltage fits the supplied information.

Given:

I = 10 amps E = 24 volts

Solution:

P = IE = 10 x 24 = 240 watts

Power Rating

Electrical components are often given a power rating. The power rating, in watts, indicates the rate at which the device converts electrical energy into another form of energy, such as light, heat, or motion. An example of such a rating is noted when comparing a 150-watt lamp to a 100-watt lamp. The higher wattage rating of the 150-watt lamp indicates it can convert more electrical energy into light energy than the lamp of the lower rating. Other common examples of devices with power ratings are soldering irons and small electric motors.

In some electrical devices, the wattage rating indicates the maximum power the device is designed to use rather than the normal operating power. A 150-watt lamp, for example, uses 150 watts when operated at the specified voltage printed

on the bulb. In contrast, a device such as a resistor is not normally given a voltage or a current rating. A resistor is given a power rating in watts and can be operated at any combination of voltage and current as long as the power rating is not exceeded. In most circuits, the actual power a resistor uses is considerably less than the power rating of the resistor because a 50 percent safety factor is used. For example, if a resistor normally used 2 watts of power, a resistor with a power rating of 3 watts would be selected.

Resistors of the same resistance value are available in different wattage values. Carbon resistors, for example, are commonly made in wattage ratings of 1/8, 1/4, 1/2, 1, and 2 watts. The larger the physical size of a carbon resistor, the higher the wattage rating. This is true because a larger surface area of material radiates a greater amount of heat more easily.

When resistors with wattage ratings greater than 5 watts are needed, wirewound resistors are used. Wirewound resistors are made in values between 5 and 200 watts, with special types being used for power in excess of 200 watts.

As with other electrical quantities, prefixes may be attached to the word "watt" when expressing very large or very small amounts of power. Some of the more common of these are the megawatt (1,000,000 watts), the kilowatt (1,000 watts), and the milliwatt (1/1,000 of a watt).

SERIES DC CIRCUITS

When two unequal charges are connected by a conductor, a complete pathway for current exists. An electric circuit is a complete conducting pathway. It consists of the conductor and the path through the voltage source. Inside the voltage source, current flows from the positive terminal, through the source, and emerges at the negative terminal.

Characteristics

A series circuit is a circuit that contains only one path for current flow. Figure 3-6 shows the basic circuit and a more complex series circuit. The basic circuit has only one lamp, and the series circuit has three lamps connected in series.

Resistance in a Series Circuit. The current in a series circuit must flow through each lamp to complete the electrical path in the circuit (Figure 3-6). Each additional lamp offers added resistance. In a series circuit, the total circuit resistance (R_t) equals the sum of the individual resistances ($R_t = R_1 + R_2 + R_3 + R_n$).

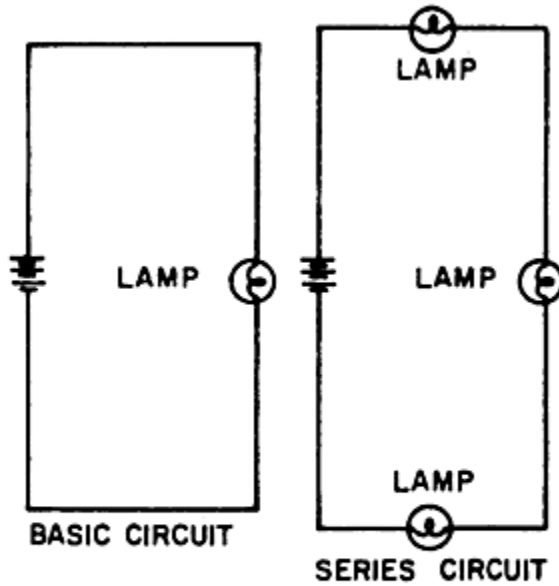


FIGURE 3-6. Comparison of Basic and Series Circuits.

NOTE: The subscript n denotes any number of additional resistances that might be in the equation.

Example: Figure 3-7 shows a series circuit consisting of three resistors (10 ohms, 1.5 ohms, and 30 ohms). What is the total resistance?

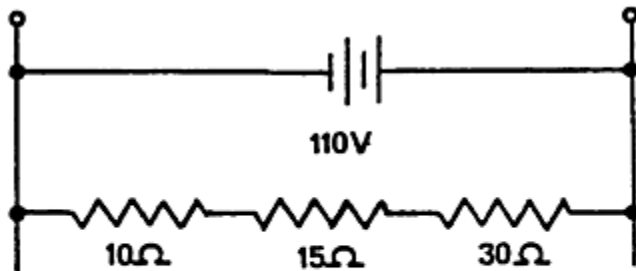


FIGURE 3-7. Calculating Total Resistance in a Series Circuit.

Given:

$R_1 = 10 \text{ ohms}$ $R_2 = 15 \text{ ohms}$ $R_3 = 30 \text{ ohms}$

Solution:

$R_t = R_1 + R_2 + R_3 = 10 \text{ ohms} + 15 \text{ ohms} + 30 \text{ ohms} = 55 \text{ ohms}$

In some circuit applications, the total resistance is known and the value of one of the circuit resistors has to be determined. The equation $R_t = R_1 + R_2 + R_3$ can be transposed to solve for the value of the unknown resistance (Figure 3-8).

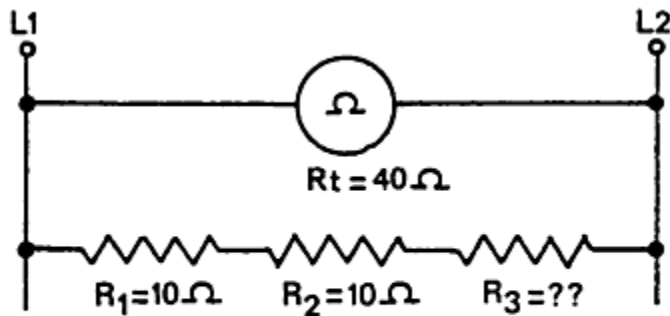


FIGURE 3-8. Calculating the Value of One Resistance in a Series Circuit.

$$R_t - R_1 - R_2 = R_3$$

$$40 \text{ ohms} - 10 \text{ ohms} - 10 \text{ ohms} = 20 \text{ ohms}$$

Current in a Series Circuit. Since there is only one path for current in a series circuit, the same current must flow through each component of the circuit. To determine the current in a series circuit, only the current through one of the components need be known.

The fact that the same current flows through each component of a series circuit can be verified by inserting meters into the circuit at various points (Figure 3-9). If this were done, each meter would be found to indicate the same value of current.

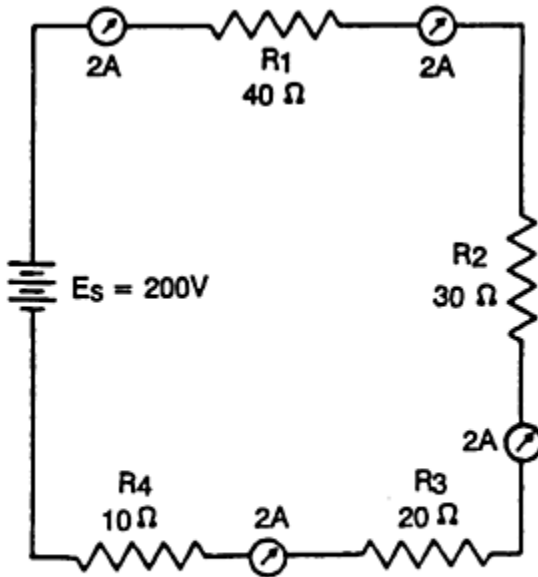


FIGURE 3-9. Current in a Series Circuit.

Voltage in a Series Circuit, The loads in a circuit consume voltage (energy). This is called a voltage drop. Voltage drop across the resistor in a circuit, consisting of a single resistor and a voltage source, is the total voltage across the circuit and equals the applied voltage. The total voltage across a series circuit that consists of more than one resistor is also equal to the applied voltage but consists of the sum of the individual resistor voltage drops. In any series circuit, the sum of the resistor voltage drops must equal the source voltage. An examination of the circuit in [Figure 3-10](#) proves this. In this circuit, a source potential (E_t) of 20 volts is consumed by a series circuit consisting of two 5-ohm resistors. The total resistance of the circuit (R_t) equals the sum of the two individual resistance or 10 ohms. Using Ohm's Law, calculate the circuit current (I) as follows:

Given:

$$E_t = 20 \text{ volts} \quad R_t = 10 \text{ ohms}$$

Solution:

$$I_t = \frac{E_t}{R_t}$$

$$I_t = \frac{20 \text{ Volts}}{10 \text{ ohms}}$$

$$I_t = 2 \text{ amps}$$

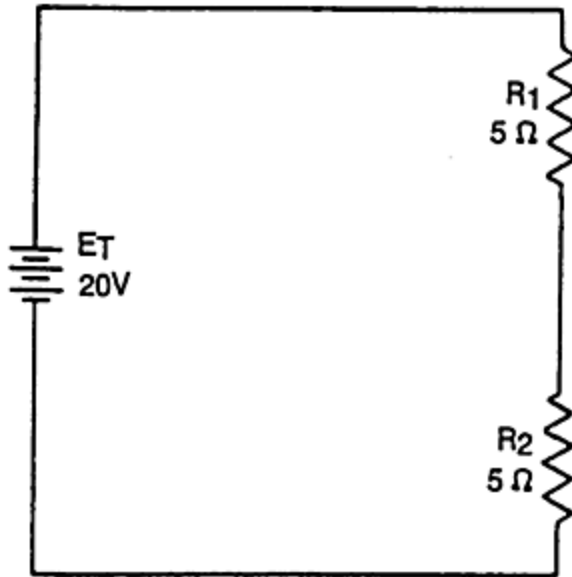


FIGURE 3-10. Calculating Individual Voltage Drops in a Series Circuit.

The value of the resistors is 5 ohms each, and the current through the resistors is 2 amperes. With these values known, you can calculate the voltage drops across the resistors. Calculate the voltage (E_I) across R_1 as follows:

Given:

$$I_1 = 2 \text{ amps} \quad R_1 = 5 \text{ ohms}$$

Solution:

$$E_1 = I_1 \times R_1 = 2 \text{ amps} \times 5 \text{ ohms} = 10 \text{ volts}$$

R_2 is the same ohmic value as R_1 and carries the same current. Therefore, the voltage drop across R_2 is also equal to 10 volts. Adding these two 10-volt drops together gives a total drop of 20 volts, equal to the applied voltage. For series circuit, then --

$$E_t = E_1 + E_2 + E_3 + \dots E_n$$

Example: A series circuit consists of three resistors having values of 20 ohms, 30 ohms, and 50 ohms, respectively. Find the applied voltage if the current through the 30-ohm resistor is 2 amperes. To solve the problem, first draw and label a circuit diagram ([Figure 3-11](#)).

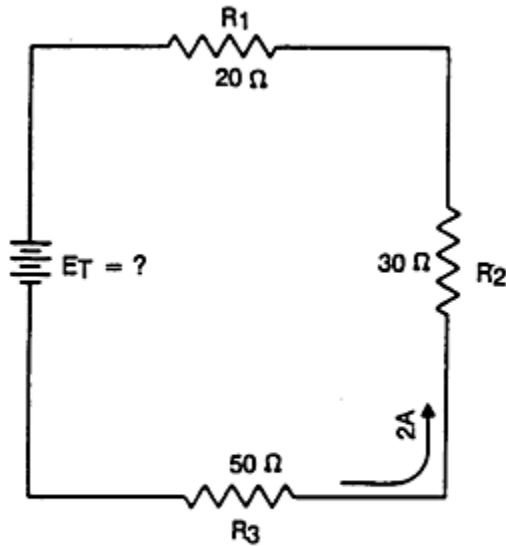


FIGURE 3-11. Calculating Applied Voltage in a Series Circuit.

Given:

$$R1 = 20 \text{ ohms} \quad R2 = 30 \text{ ohms} \quad R3 = 50 \text{ ohms} \quad I = 2 \text{ amps}$$

Solution:

$$E_t = E_1 + E_2 + E_3$$

$$E_1 = R_1 \times I_1 \text{ (} I_1 = \text{the current through resistor } R_1 \text{)}$$

$$E_2 = R_2 \times I_2$$

$$E_3 = R_3 \times I_3$$

Substituting:

$$E_t = (R_1 \times I_1) + (R_2 \times I_2) + (R_3 \times I_3)$$

$$E_t = (20 \text{ ohms} \times 2 \text{ amps}) + (30 \text{ ohms} \times 2 \text{ amps}) + (50 \text{ ohms} \times 2 \text{ amps})$$

$$E_t = 40 \text{ volts} + 60 \text{ volts} + 100 \text{ volts}$$

$$E_t = 200 \text{ volts}$$

NOTE: When you use Ohm's Law, the quantities for the equation must be taken from the same part of the circuit. In the above example, the voltage across R_2 was computed using the current through R_2 and the resistance of R_2 .

The applied voltage determines the value of the voltage dropped by a resistor. It is in proportion to the circuit resistances. The voltage drops that occur in a series circuit are in direct proportion to the resistances. This is the result of having the same current flow through each resistor. The larger the ohmic value of the resistor, the larger the voltage drop across it.

Power in a Series Circuit. Each of the loads in a series circuit consumes power that is dissipated in the form of heat. Since this power must come from the source, the total power supplied must be equal to the power consumed by the circuit's loads. In a series circuit, the total power equals the sum of the power dissipated by the individual loads. Total power (P_t) equals --

$$P_t = P_1 + P_2 + P_3 + \dots P_n$$

Example: A series circuit consists of three resistors having values of 5 ohms, 10 ohms, and 15 ohms. Find the total power when 120 volts is applied to the circuit (Figure 3-12).

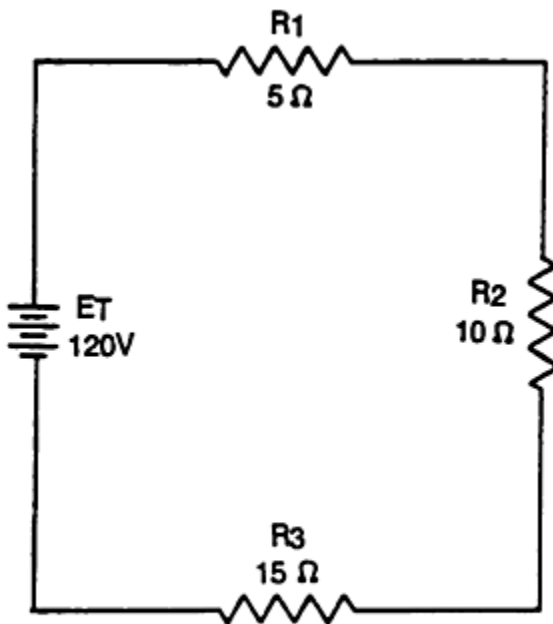


FIGURE 3-12. Calculating Total Power in a Series Circuit.

Given:

$$R_1 = 5 \text{ ohms} \quad R_2 = 10 \text{ ohms} \quad R_3 = 15 \text{ ohms} \quad E_t = 120 \text{ volts}$$

Solution: (The total resistance is found first.)

$$R_t = R_1 + R_2 + R_3 = 5 \text{ ohms} + 10 \text{ ohms} + 15 \text{ ohms} = 30 \text{ ohms}$$

Calculate the circuit current by using the total resistance and the applied voltage:

$$I = E_t / R_t = 120\text{volts} / 30 \text{ ohms} = 4 \text{ amps}$$

Calculate the power for each resistor using the power formulas:

For R_1 --

$$P_1 = I^2 \times R_1 = (4 \text{ amps})^2 \times 5 \text{ ohms} = 80 \text{ watts}$$

For R2 --

$$P_2 = I^2 \times R_2 = (4 \text{ amps})^2 \times 10 \text{ ohms} = 160 \text{ watts}$$

For R3 --

$$P_3 = I^2 \times R_3 = (4 \text{ amps})^2 \times 15 \text{ ohms} = 240 \text{ watts}$$

To obtain total power --

$$P_t = P_1 + P_2 + P_3 = 80 \text{ watts} + 160 \text{ watts} + 240 \text{ watts} = 480 \text{ watts}$$

To check the answer, calculate the total power delivered by the source:

$$P_{\text{source}} = I_{\text{source}} \times E_{\text{source}} = 4 \text{ amps} \times 120 \text{ volts} = 480 \text{ watts}$$

The total power equals the sum of the power used by the individual resistors.

Rules for Series DC Circuits

Listed below are the important factors governing the operation of a series circuit. For ease of study, they are set up as a group of rules. They must be completely understood before studying more advanced circuit theory.

1. The same current flows through each part of a series circuit.

$$I_t = I_1 = I_2 = I_3 = I_n$$

2. The total resistance of a series circuit equals the sum of the individual resistances.

$$R_t = R_1 + R_2 + R_3 + R_n$$

3. The total voltage across a series circuit equals the sum of the individual voltage drops.

$$E_t = E_1 + E_2 + E_3 + E_n$$

4. The voltage drop across a resistor in a series circuit is proportional to the ohmic value of the resistor.

5. The total power in a series circuit equals the sum of the individual powers used by each circuit component.

$$P_t = P_1 + P_2 + P_3 + P_n$$

Series Circuit Analysis

The following sample problems show the procedure for solving series circuits:

Example: Three resistors of 5 ohms, 10 ohms, and 15 ohms are connected in series with a power source of 90 volts (Figure 3-13).

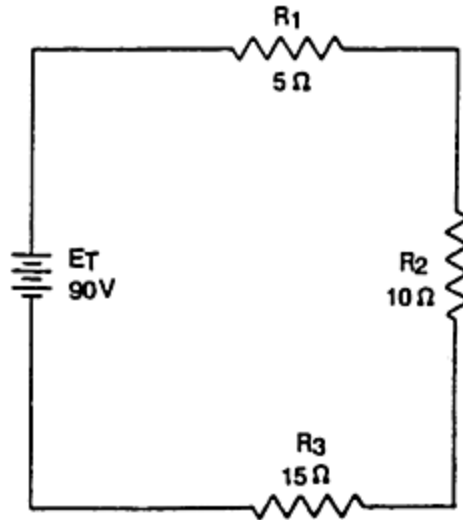


FIGURE 3-13. Solving for Various Values in a Series Circuit.

- What is the total resistance?
- What is the circuit current?
- What is the voltage drop across each resistor?
- What is the power of each resistor?
- What is the total power of the circuit?

In solving the circuit, find the total resistance first. Next, calculate the circuit current. Once the current is known, calculate the voltage drops and power dissipations.

Given:

$R_1 = 5 \text{ ohms}$ $R_2 = 10 \text{ ohms}$ $R_3 = 15 \text{ ohms}$ $E_t = 90 \text{ volts}$

Solution (a):

$R_t = R_1 + R_2 + R_3 = 5 \text{ ohms} + 10 \text{ ohms} + 15 \text{ ohms} = 30 \text{ ohms}$

Solution (b):

$$I = \frac{E_t}{R_t}$$

$$I = \frac{90 \text{ volts}}{30 \text{ ohms}}$$

$I = 3 \text{ amps}$

Solution (c):

$$E_1 = (I)(R_1) = 3 \text{ amps} \times 5 \text{ ohms} = 15 \text{ volts}$$

$$E_2 = (I)(R_2) = 3 \text{ amps} \times 10 \text{ ohms} = 30 \text{ volts}$$

$$E_3 = (I)(R_3) = 3 \text{ amps} \times 15 \text{ ohms} = 45 \text{ volts}$$

Solution (d):

$$P_1 = (I)(E_1) = 3 \text{ amps} \times 15 \text{ volts} = 45 \text{ watts}$$

$$P_2 = (I)(E_2) = 3 \text{ amps} \times 30 \text{ volts} = 90 \text{ watts}$$

$$P_3 = (I)(E_3) = 3 \text{ amps} \times 45 \text{ volts} = 135 \text{ watts}$$

Solution (e):

$$P_t = (E_t)(I) = 90 \text{ volts} \times 3 \text{ amps} = 270 \text{ watts}$$

or

$$P_t = P_1 + P_2 + P_3 = 45 \text{ watts} + 90 \text{ watts} + 135 \text{ watts} = 270 \text{ watts}$$

Example: Four resistors ($R_1 = 10 \text{ ohms}$, $R_2 = 10 \text{ ohms}$, $R_3 = 50 \text{ ohms}$, and $R_4 = 30 \text{ ohms}$) are connected in series with a power source ([Figure 3-14](#)). The current through the circuit is $1/2$ ampere.

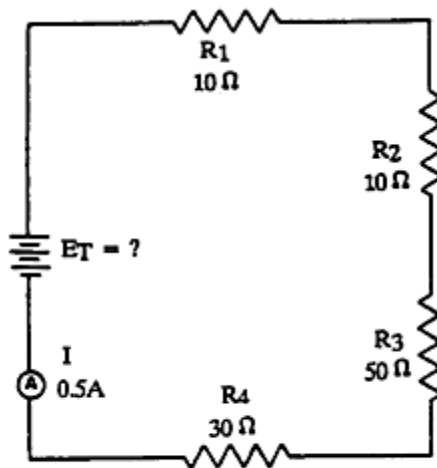


FIGURE 3-14. Computing Series Circuit Values.

- What is the battery voltage?
- What is the voltage across each resistor?
- What is the power expended in each resistor?
- What is the total power?

Given:

$$R1 = 10 \text{ ohms}$$

$$R2 = 10 \text{ ohms}$$

$$R3 = 50 \text{ ohms}$$

$$R4 = 30 \text{ ohms}$$

$$I = 0.5 \text{ amp}$$

Solution (a):

$$E_t = (I)(R_t)$$

$$R_t = R1 + R2 + R3 + R4 = 10 \text{ ohms} + 10 \text{ ohms} + 50 \text{ ohms} + 30 \text{ ohms} = 100 \text{ ohms}$$

$$E_t = 0.5 \text{ amp} \times 100 \text{ ohms} = 50 \text{ volts}$$

Solution (b):

$$E1 = (I)(R1) = 0.5 \text{ amp} \times 10 \text{ ohms} = 5 \text{ volts}$$

$$E2 = (I)(R2) = 0.5 \text{ amp} \times 10 \text{ ohms} = 5 \text{ volts}$$

$$E3 = (I)(R3) = 0.5 \text{ amp} \times 50 \text{ ohms} = 25 \text{ volts}$$

$$E4 = (I)(R4) = 0.5 \text{ amp} \times 30 \text{ ohms} = 15 \text{ volts}$$

Solution (c):

$$P1 = (I)(E1) = 0.5 \text{ amp} \times 5 \text{ volts} = 2.5 \text{ watts}$$

$$P2 = (I)(E2) = 0.5 \text{ amp} \times 5 \text{ volts} = 2.5 \text{ watts}$$

$$P3 = (I)(E3) = 0.5 \text{ amp} \times 25 \text{ volts} = 12.5 \text{ watts}$$

$$P4 = (I)(E4) = 0.5 \text{ amp} \times 15 \text{ volts} = 7.5 \text{ watts}$$

Solution (d):

$$P_t = P1 + P2 + P3 + P4 = 2.5 \text{ watts} + 2.5 \text{ watts} + 12.5 \text{ watts} + 7.5 \text{ watts}$$

$$P_t = 25 \text{ watts}$$

or

$$P_t = \frac{E_t^2}{R_t}$$

$$P_t = \frac{(50 \text{ volts})^2}{100 \text{ ohms}}$$

$$P_t = \frac{2,500 \text{ volts}}{100 \text{ ohms}}$$

$$P_t = 25 \text{ watts}$$

When applying Ohm's Law to a series circuit, consider whether the values used are component values or total values. When the information available enables the use of Ohm's Law to find total resistance, total voltage, and total current, total values must be inserted into the formula.

To find total resistance --

$$R_t = \frac{E_t}{I_t}$$

To find total voltage --

$$E_t = I_t \times R_t$$

To find total current --

$$I_t = \frac{E_t}{R_t}$$

NOTE: In a series circuit, I_t equals I . However, the distinction between I_t and I in the formula should be noted because future circuits may have several currents. Then it would be necessary to differentiate between I_t and other currents.

To compute any quantity (E , I , R , or P) associated with a single given resistor, obtain the values used in the formula from that particular resistor. For example, to find the value of an unknown resistance, use the voltage across and the current through that particular resistor.

To find the value of a resistor --

$$R_x = \frac{E_x}{I_x}$$

To find the voltage drop across a resistor --

$$E_x = (I_x)(R_x)$$

To find current through a resistor --

$$I_x = \frac{E_x}{R_x}$$

PARALLEL DC CIRCUITS

The series circuit has only one path for current. Another basic type of circuit is the parallel circuit. While the series circuit has only one path for current, the parallel circuit has more than one path for current. Ohm's Law and Kirchhoff's Law apply to all electrical circuits, but the characteristics of a parallel DC circuit are different than those of a series DC circuit.

Characteristics

A parallel circuit has more than one current path connected to a common voltage source. Parallel circuits, therefore, must contain two or more resistances that are not connected in series. Figure 3-20 shows an example of a basic parallel circuit.

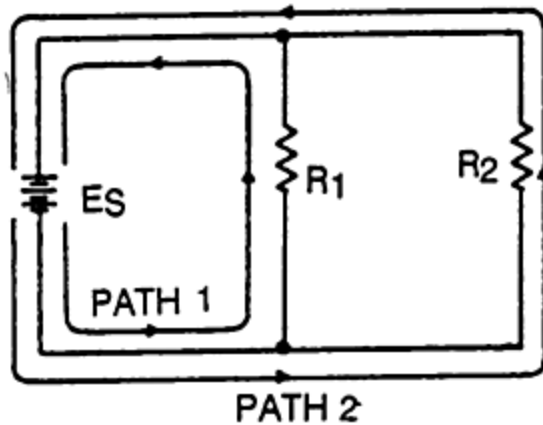


FIGURE 3-20. Example of a Basic Parallel Circuit.

Start at the voltage source (E_t) and trace counterclockwise around the circuit in [Figure 3-20](#). Two complete and separate paths can be identified in which current can flow. One path is traced from the source, through resistance R_1 , and back to the source. The other path is from the source, through resistance R_2 , and back to the source.

Voltage in a Parallel Circuit. The source voltage in a series circuit divides proportionately across each resistor in the circuit. In a parallel circuit, the same voltage is present in each branch (section of a circuit that has a complete path for current). In [Figure 3-20](#), this voltage equals the applied voltage (E_t). This can be expressed in equation form:

$$E_t = E_1 = E_2 = E_n$$

Voltage measurements taken across the resistors of a parallel circuit verify this equation ([Figure 3-21](#)). Each meter indicates the same amount of voltage. Notice that the voltage across each resistor is the same as applied voltage.

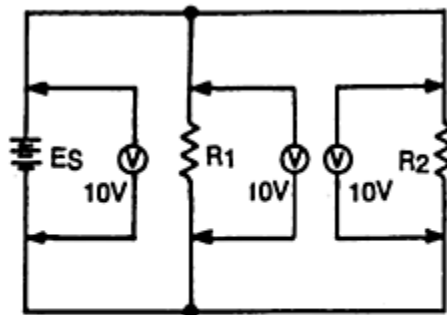


FIGURE 3-21. Voltage Comparison in a Parallel Circuit.

Example: The current through a resistor of a parallel circuit is 12 amperes and the value of the resistor is 10 ohms. Determine the source voltage. Figure 3-22 shows the circuit.

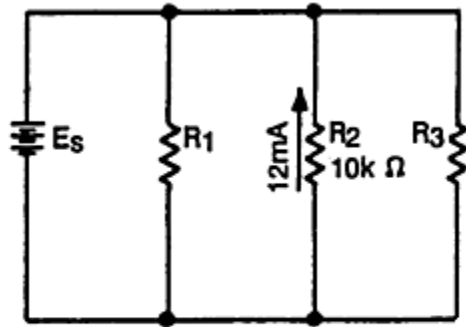


FIGURE 3-22. Example Problem of a Parallel Circuit.

Given:

$$R_2 = 10 \text{ ohms} \quad I_2 = 12 \text{ amps}$$

Solution:

$$E_2 = (I_2)(R_2) = 12 \text{ amps} \times 10 \text{ ohms} = 120 \text{ volts}$$

$$E_t = E_2 = 120 \text{ volts}$$

Current in a Parallel Circuit. Ohm's Law states that the current in a circuit is inversely proportional to the circuit resistance. This is true in both series and parallel circuits.

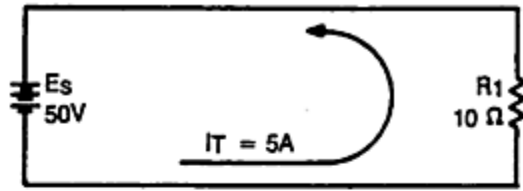
There is a single path for current in a series circuit. The amount of current is determined by the total resistance of the circuit and the applied voltage. In a parallel circuit the source current divides among the available paths.

The following illustrations show the behavior of current in parallel circuits using example circuits with different values of resistance for a given value of applied voltage.

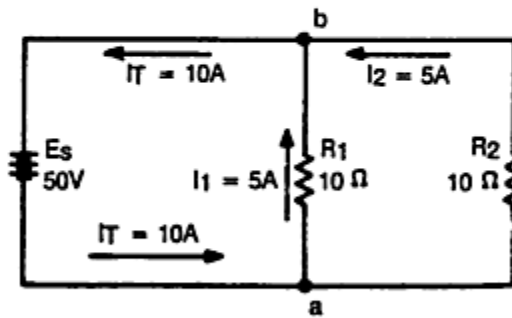
Figure 3-23 view A shows a basic series circuit. Here, the total current must pass through the single resistor. The amount of current can be determined as follows:

Given:

$$E_t = 50 \text{ volts} \quad R_1 = 10 \text{ ohms}$$



(A)



(B)

FIGURE 3-23. Analysis of Current in a Parallel Circuit.

Solution:

$$I = \frac{E}{R}$$

$$I_t = \frac{E_t}{R_1}$$

$$I_t = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_t = 5 \text{ amps}$$

View B shows the same resistor (R1) with a second resistor (R2) of equal value connected in parallel across the voltage source. When Ohm's Law is applied, the current flow through each resistor is found to be the same as the current through the single resistor in view A.

Given:

$E_t = 50 \text{ volts}$

$R_1 = 10 \text{ ohms}$

$R_2 = 10 \text{ ohms}$

Solution:

$$I = \frac{E}{R}$$

$$E_t = E_1 = E_2$$

$$I_1 = \frac{E_1}{R_1}$$

$$I_1 = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_1 = 5 \text{ amps}$$

$$I_2 = \frac{E_2}{R_2}$$

$$I_2 = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_2 = 5 \text{ amps}$$

If 5 amperes of current flow through each of the two resistors, there must be a total current of 10 amperes drawn from the source. The total current of 10 amperes leaves the negative terminal of the battery and flows to point a (view B). Point a, called a “node”, is a connecting point for the two resistors. At node a, the total current divides into two currents of 5 amperes each. These two currents flow through their respective resistors and rejoin at node b. The total current then flows from node b back to the positive terminal of the source. The source supplies a total current of 10 amperes, and each of the two equal resistors carries one-half of the total current.

Each individual current path in the circuit of view B is a branch. Each branch carries a current that is a portion of the total current. Two or more branches form a network.

The characteristics of current in a parallel circuit can be expressed in terms of the following general equation:

$$I_t = I_1 + I_2 + \dots I_n$$

Compare Figure 3-24 view A with the circuit in Figure 3-23 view B. Notice that doubling the value of the second branch resistor (R2) has no effect on the current in the first branch (I1). However, it does reduce the second branch current (I2) to one-half its original value. The total circuit current drops to a value equal to the sum of the branch currents. These facts are verified by the following equations:

Given:

$E_t = 50 \text{ volts}$

$R_1 = 10 \text{ ohms}$

$R_2 = 20 \text{ ohms}$

Solution:

$$I = \frac{E}{R}$$

$$E_t = E_1 = E_2$$

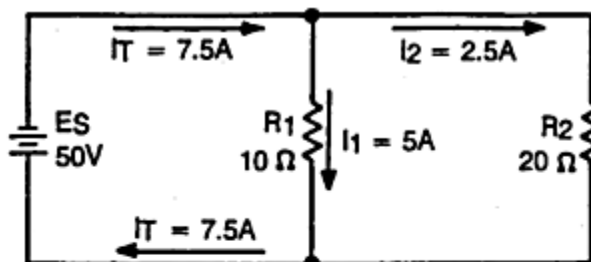
$$I_1 = \frac{E_1}{R_1}$$

$$I_1 = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

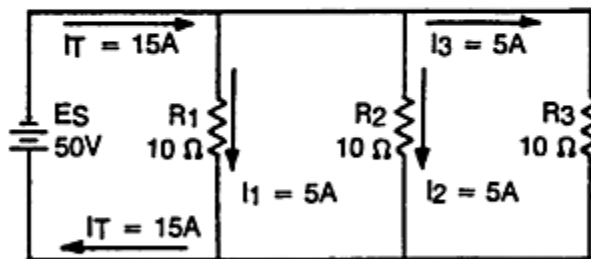
$$I_1 = 5 \text{ amps}$$

$$I_2 = \frac{E_2}{R_2}$$

$$I_2 = \frac{50 \text{ volts}}{20 \text{ ohms}}$$



(A)



(B)

FIGURE 3-24. Current Behavior in a Parallel Circuit.

$$I_2 = 2.5 \text{ amps}$$

$$I_t = I_1 + I_2 = 5 \text{ amps} + 2.5 \text{ amps} = 7.5 \text{ amps}$$

The amount of current flow in the branch circuits and the total current in the circuit in Figure 3-24 view B are determined by the following computations:

Given:

$$E_t = 50 \text{ volts} \quad R_1 = 10 \text{ ohms} \quad R_2 = 10 \text{ ohms} \quad R_3 = 10 \text{ ohms}$$

$$I = \frac{E}{R}$$

$$E_s = E_1 = E_2 = E_3$$

$$I_1 = \frac{E_1}{R_1}$$

$$I_1 = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_1 = 5 \text{ amps}$$

$$I_2 = \frac{E_2}{R_2}$$

$$I_2 = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_2 = 5 \text{ amps}$$

$$I_3 = \frac{E_3}{R_3}$$

$$I_3 = \frac{50 \text{ volts}}{10 \text{ ohms}}$$

$$I_3 = 5 \text{ amps}$$

$$I_t = I_1 + I_2 + I_3 = 5 \text{ amps} + 5 \text{ amps} + 5 \text{ amps} = 15 \text{ amps}$$

Notice that the sum of the ohmic values of the resistors in both circuits in Figure 3-24 is equal (30 ohms) and that the applied voltage is the same value (50 volts). However, the total current in Figure 3-24 view B (15 amperes) is twice the amount in Figure 3-24 view A (7.5 amperes). It is apparent, therefore, that the

manner in which resistors are connected in a circuit, as well as their actual ohmic values, affect the total current.

The division of current in a parallel network follows a definite pattern. This pattern is described by Kirchhoff's Current Law which states, "The algebraic sum of the currents entering and leaving any node of conductors is equal to zero."

This law stated mathematically is --

$$I_a + I_b + \dots I_n = 0$$

Where: $I_a, I_b, \dots I_n$ = the current entering and leaving the node.

Currents entering the node are considered positive, and currents leaving the node are negative. When solving a problem using Kirchhoff's Current Law, the currents must be placed into the equation with the proper polarity signs attached.

Example: Solve for the value of I_3 in Figure 3-25.

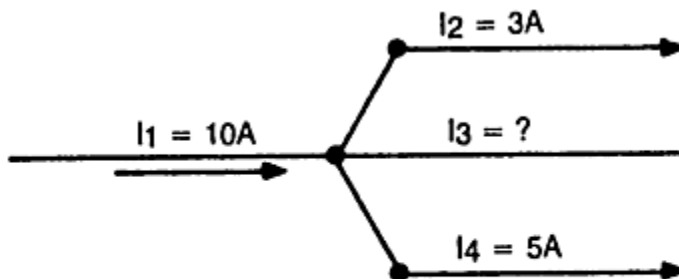


FIGURE 3-25. Circuit for Example Problem 1.

Given:

$$I_1 = 10 \text{ amps} \qquad I_2 = 3 \text{ amps} \qquad I_4 = 5 \text{ amps}$$

Solution:

$$I_a + I_b + \dots I_n = 0$$

The currents are placed into the equation with the proper signs:

$$I_1 + I_2 + I_3 + I_4 = 0$$

$$10 \text{ amps} + (-3 \text{ amps}) + I_3 + (-5 \text{ amps}) = 0$$

$$I_2 + 2 \text{ amps} = 0$$

$$I_2 = -2 \text{ amps}$$

I_2 has a value of 2 amperes. The negative sign shows it to be a current leaving the node.

Resistance in a Parallel Circuit. The example diagram (Figure 3-26) has two resistors connected in parallel across a 5-volt battery. Each has a resistance value of 10 ohms. A complete circuit consisting of two parallel paths is formed, and current flows as shown.

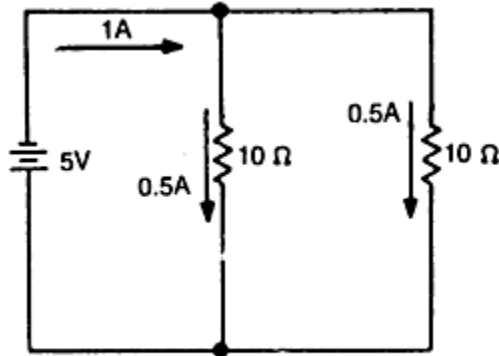


FIGURE 3-26. Two Equal Resistors Connected

Computing the individual currents shows that there is 1/2 ampere of current through each resistance. The total current flowing from the battery to the node of the resistors and returning from the resistors to the battery equals 1 ampere.

The total resistance of the circuit is calculated using the values of total voltage (E_t) and total current (I_t):

Given:

$$E_t = 5 \text{ volts} \quad I_t = 1 \text{ amp}$$

Solution:

$$R = \frac{E}{I}$$

$$R_t = \frac{E_t}{I_t}$$

$$R_t = \frac{5 \text{ volts}}{1 \text{ amp}}$$

$$R_t = 5 \text{ ohms}$$

This computation shows the total resistance to be 5 ohms, one-half the value of either of the two resistors.

The total resistance of a parallel circuit is smaller than any one of the individual resistors. Thus, the total resistance of a parallel circuit is not the sum of the

individual resistor values as was the case in a series circuit. The total resistance of resistors in parallel is also referred to as equivalent resistance (R_{eq}).

Several methods are used to determine the equivalent resistance of parallel circuits. The best method for a given circuit depends on the number and value of the resistors. For the circuit described above, where all resistors have the same value, the following simple equation is used:

$$R_t = \frac{R}{N}$$

Where: R_t = total parallel resistance

R = ohmic value of one resistor

N = number of resistors

This equation is valid for any number of parallel resistors of equal value.

Example: Four 40-ohm resistors are connected in parallel. What is their equivalent resistance?

Given:

$$R_1 = R_2 = R_3 = R_4$$

$$R_1 = 40 \text{ ohms}$$

Solution:

$$R_t = \frac{R}{N}$$

$$R_t = \frac{40 \text{ ohms}}{4}$$

$$R_t = 10 \text{ ohms}$$

Figure 3-27 shows two resistors of unequal value in parallel. Since the total current is shown, the equivalent resistance can be calculated.

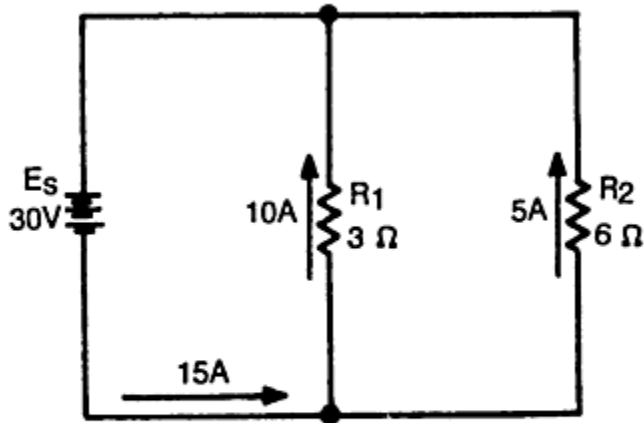


FIGURE 3-27. Example Circuit With Unequal Parallel Resistors.

Given:

$$E_t = 30 \text{ volts} \quad I_t = 15 \text{ amps}$$

Solution:

$$R_t = \frac{E_t}{I_t}$$

$$R_t = \frac{30 \text{ volts}}{15 \text{ amps}}$$

$$R_t = 2 \text{ ohms}$$

The total resistance of the circuit in Figure 3-27 is smaller than either of the two resistors (R_1 , R_2). An important point to remember is that the total resistance of a parallel circuit is always less than the resistance of any branch.

Reciprocal Method. This method is based on taking the reciprocal of each side of the equation. This presents the general formula for resistors in parallel as --

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}}$$

This formula is generally used to solve for the equivalent resistance of any number of unequal parallel resistors. Unlike the equal value or the product-over-the-sum method, the reciprocal method is the only formula that can be used to determine the equivalent resistance in any combination of parallel resistances. You must find the lowest common denominator in solving these problems.

Example: Three resistors are connected in parallel as shown in Figure 3-28. The resistor values are $R_1 = 20 \text{ ohms}$, $R_2 = 30 \text{ ohms}$, and $R_3 = 40 \text{ ohms}$. What is the equivalent resistance? Use the reciprocal method.

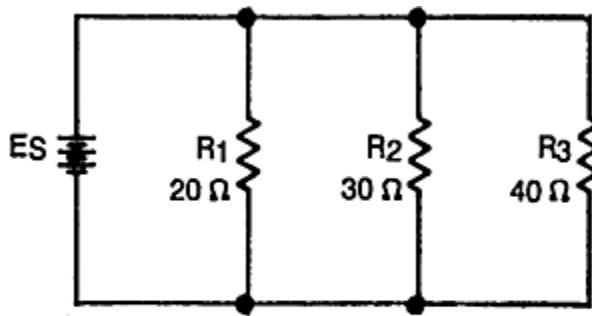


FIGURE 3-28. Example of a Parallel Circuit With Unequal Branch Resistors.

Given:

$R_1 = 20 \text{ ohms}$ $R_2 = 30 \text{ ohms}$ $R_3 = 40 \text{ ohms}$

Solution:

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

$$R_t = \frac{1}{\frac{1}{20 \text{ ohms}} + \frac{1}{30 \text{ ohms}} + \frac{1}{40 \text{ ohms}}}$$

$$R_t = \frac{1}{\frac{6}{120 \text{ ohms}} + \frac{4}{120 \text{ ohms}} + \frac{3}{120 \text{ ohms}}}$$

$$R_t = \frac{1}{\frac{13}{120 \text{ ohms}}}$$

$$R_t = \frac{120 \text{ ohms}}{13}$$

$$R_t = 9.23 \text{ ohms}$$

Product-Over-the-Sum Method. A convenient method for finding the equivalent, or total, resistance of two parallel resistors is by using the product-over-the-sum formula:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

Example: What is the equivalent resistance of a 20-ohm and a 30-ohm resistor connected in parallel, as in Figure 3-29?

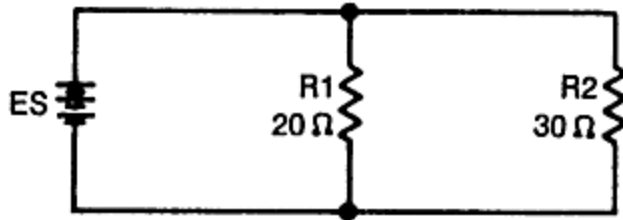


FIGURE 3-29. Parallel Circuit with Two Unequal Resistors.

Given:

$$R_1 = 20 \qquad R_2 = 30$$

Solution:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_t = \frac{20 \text{ ohms} \times 30 \text{ ohms}}{20 \text{ ohms} + 30 \text{ ohms}}$$

$$R_t = \frac{600 \text{ ohms}}{50 \text{ ohms}}$$

$$R_t = 12 \text{ ohms}$$

The product-over-the-sum method can only be used with two resistance values at a time. If three or more resistors are to be calculated, combine any two ohmic values into an equivalent resistance using the formula. Repeat the formula again, and this time, combine the remaining ohmic value with the recently derived equivalent resistance. Combining additional resistance values with equivalent resistance may be continued throughout the parallel circuit.

Power in a Parallel Circuit. Power computations in a parallel circuit are basically the same as those used for the series circuit. Since power dissipation in resistors consists of a heat loss, power dissipations are additive regardless of how the resistors are connected in the circuit. The total power equals the sum of the

power dissipated by the individual resistors. Like the series circuit, the total power consumed by the parallel circuit is

$$P_t = P_1 + P_2 + \dots P_n$$

Example Find the total power consumed by the circuit in Figure 3-30.

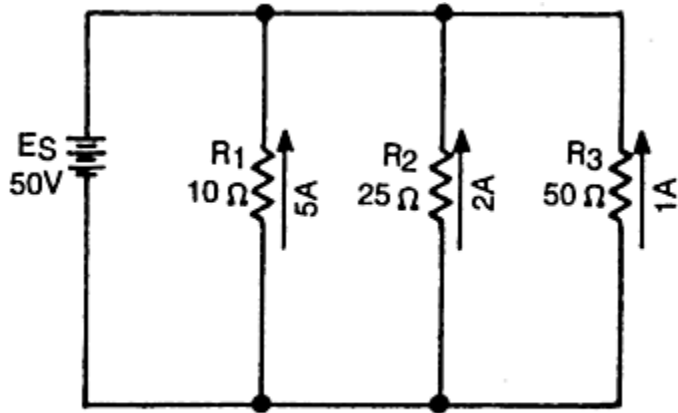


FIGURE 3-30. Example of a Parallel Circuit.

Given:

$$\begin{array}{llll} R_1 = 10 \text{ ohms} & I_1 = 5 \text{ amps} & R_2 = 25 \text{ ohms} & I_2 = 2 \text{ amps} \\ R_3 = 50 \text{ ohms} & I_3 = 1 \text{ amp} & & \end{array}$$

Solution:

$$P = I^2 R$$

$$P_1 = (I_1)^2 \times R_1 = (5 \text{ amps})^2 \times 10 \text{ ohms} = 250 \text{ watts}$$

$$P_2 = (I_2)^2 \times R_2 = (2 \text{ amps})^2 \times 25 \text{ ohms} = 100 \text{ watts}$$

$$P_3 = (I_3)^2 \times R_3 = (1 \text{ amp})^2 \times 50 \text{ ohms} = 50 \text{ watts}$$

$$P_t = P_1 + P_2 + P_3 = 250 \text{ watts} + 100 \text{ watts} + 50 \text{ watts} = 400 \text{ watts}$$

Since the total current and source voltage are known, the total power can also be computed:

Given:

$$E_t = 50 \text{ volts} \quad I_t = 8 \text{ amps}$$

Solution:

$$P_t = E_t \times I_t = 50 \text{ volts} \times 8 \text{ amps} = 400 \text{ watts}$$

INTRODUCTION

A battery consists of a number of cells assembled in a common container and connected together to function as a source of electrical power. This chapter introduces the basic theory and characteristics of batteries. The batteries discussed are representative of the many models and types used in the mobile equipment industry.

The cell is the building block of all batteries. This chapter explains the physical makeup of the cell and the methods used to combine cells to provide useful voltage, current, and power. The chemistry of the cell and how chemical action is used to convert chemical energy to electrical energy are also discussed. In addition, this chapter addresses the care, maintenance, and operation of batteries, as well as some of the safety precautions that should be followed while working around batteries.

Batteries are widely used as sources of direct current electrical energy in automobiles, boats, aircraft, shops, portable electric/electronic equipment, and lighting equipment. In some instances, batteries are used as the only source of power. In others, they are used as a secondary or emergency power source.

BATTERY COMPONENTS

The Cell

A cell is a device that transforms chemical energy into electrical energy. Figure 4-1 shows the simplest cell, known as a galvanic or voltaic cell. It consists of a piece of carbon (C) and a piece of zinc (Zn) suspended in a jar that contains a sulfuric acid solution (H_2SO_4), called the electrolyte.

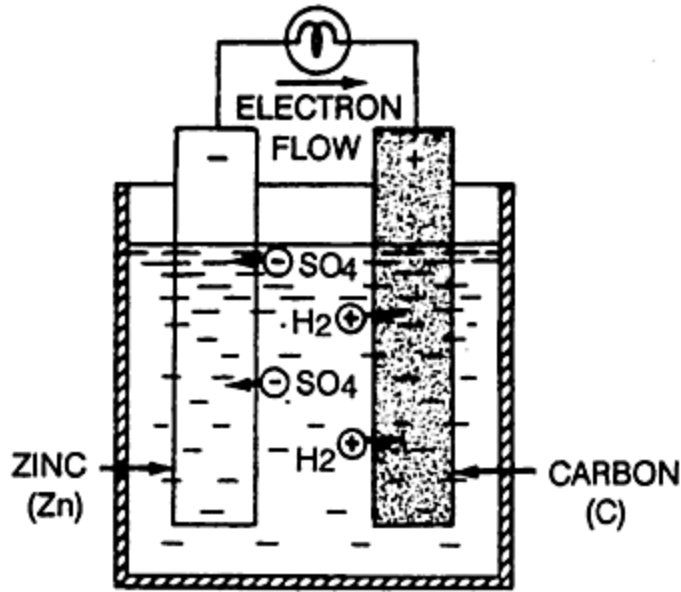


FIGURE 4-1. Simple Voltaic or Galvanic Cell.

The cell is the fundamental unit of the battery. A simple cell consists of two electrodes placed in a container that holds the electrolyte. In some cells, the container acts as one of the electrodes and is acted upon by the electrolyte.

Electrodes

The electrodes are the conductors by which the current leaves or returns to the electrolyte. In the simple cell, they are carbon and zinc strips placed in the electrolyte. In the dry cell ([Figure 4-2](#)), they are the carbon rod in the center and zinc container in which the cell is assembled.

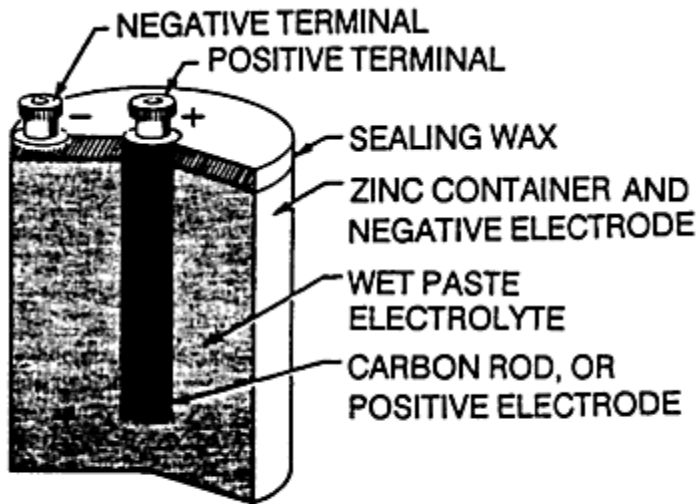


FIGURE 4-2. Dry Cell, Cross-Sectional View.

Electrolyte

The electrolyte is the solution that reacts with the electrodes. The electrolyte provides a path for electron flow. It may be a salt, an acid, or an alkaline solution. In the simple galvanic cell, the electrolyte is a liquid. In the dry cell, the electrolyte is a paste.

Container

The container provides a means of holding (containing) the electrolyte. It is also used to mount the electrodes. The container may be constructed of one of many different materials. In the voltaic cell, the container must be constructed of a material that will not be acted upon by the electrolyte.

Secondary Wet Cells

Secondary cells are sometimes known as wet cells. There are four basic types of wet cells: lead-acid, nickel-cadmium, silver-zinc, and silver-cadmium. Different combinations of materials are used to form the electrolyte, cathode, and anode of different cells. These combinations provide the cells with different qualities for many varied applications.

Lead-Acid Cell. The lead-acid cell is the most widely used secondary cell. The previous explanation of the secondary cell describes how the lead-acid cell provides electrical power. The discharging and charging action presented in Electrochemical Action describes the lead-acid cell. The lead-acid cell has an anode of lead peroxide, a cathode of sponge lead, and an electrolyte of sulfuric acid and water.

Nickel-Cadmium Cell. The nickel-cadmium (NICAD) cell is far superior to the lead-acid cell. In comparison to lead-acid cells, these cells generally require less maintenance throughout their service life regarding the addition of electrolyte or water. The major difference between the nickel-cadmium cell and the lead-acid cell is the material used in the cathode, anode, and electrolyte. In the nickel-cadmium cell, the cathode is cadmium hydroxide; the anode is nickel hydroxide; and the electrolyte is potassium hydroxide and water.

The nickel-cadmium and lead-acid cells have capacities that are comparable at normal discharge rates. However, at higher discharge rates, the nickel-cadmium cell can deliver a large amount of power. Also, the nickel-cadmium cell can --

- Be charged in a shorter time.
- Stay idle longer in any state of charge and keep a full charge when stored for a longer period of time.
- Be charged and discharged any number of times without any appreciable damage.

Because of their superior capabilities, nickel-cadmium cells are used extensively in many *military* applications that require a cell with a high discharge rate.

Silver-Zinc Cells. The silver-zinc cell is used extensively to power emergency equipment. However, it is relatively expensive and can be charged and discharged fewer times than other types of cells. When compared to lead-acid or nickel-cadmium cells, these disadvantages are outweighed by the light weight, small size, and good electrical capacity of the silver-zinc cell. The silver-zinc cell uses the same electrolyte as the nickel-cadmium cell (potassium hydroxide and water), but the anode and cathode differ. The anode is made of silver oxide, and the cathode is made of zinc.

Silver-Cadmium Cell. The silver-cadmium cell is a recent development for use in storage batteries. The silver-cadmium cell combines some of the better features of the nickel-cadmium and silver-zinc cells. It has more than twice the shelf life of the silver-zinc cell and can be recharged many more times. The disadvantages of the silver-cadmium cell are high cost and low voltage production. The electrolyte of the silver-cadmium cell is potassium hydroxide and water as in the nickel-cadmium and silver-zinc cells. The anode is silver oxide as in the silver-zinc cell, and the cathode is cadmium hydroxide as in the NICAD cell.

BATTERIES AS POWER SOURCES

A battery is a voltage source that uses chemical action to produce a voltage. The term "battery" is often applied to a single cell, such as the flashlight battery. In a flashlight that uses a battery of 1.5 volts, the battery is a single cell. The flashlight that is operated by 6 volts uses four cells in a single case. This is a battery composed of more than one cell. Cells can be combined in series or in parallel.

In many cases, a battery-powered device may require more electrical energy than one cell can provide. The device may require a higher voltage or more current, or, in some cases, both. To meet the higher requirements, a sufficient number of cells must be combined or interconnected. Cells connected in series provide a higher voltage, while cells connected in parallel provide a higher current capacity.

Series-Connected Cells

Assume that a load requires a power supply of 6 volts and a current capacity of 1/8 ampere. Since a single cell normally supplies a voltage of only 1.5 volts, more than one cell is needed. To obtain the higher voltage, the cells are connected in series, as shown in Figure 4-5. Figure 4-5 view B is a schematic representation of the circuit in view A. The load is shown by the lamp symbol, and the battery is indicated by one long and one short line per cell.

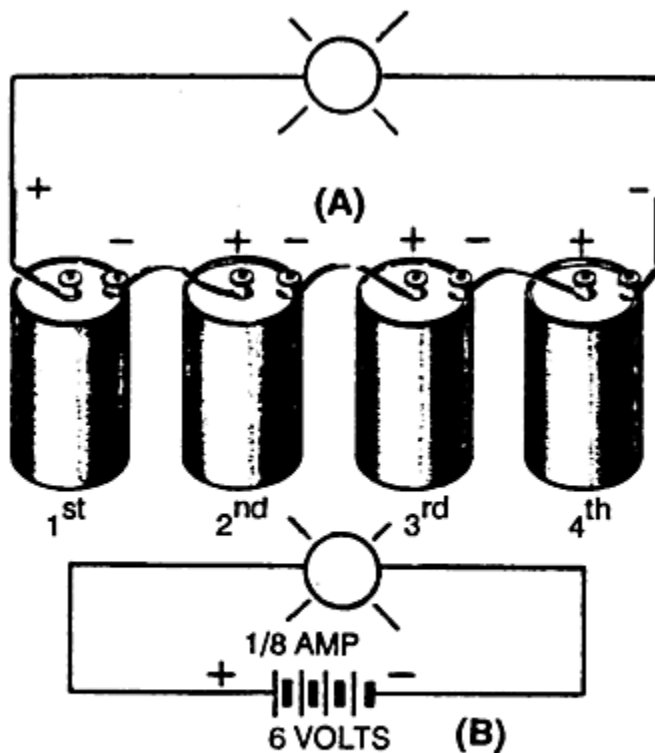


FIGURE 4-5. Series-Connected Cells.

In a series hookup, the negative electrode (cathode) of the first cell is connected to the positive electrode (anode) of the second cell, the negative electrode of the second to the positive of the third, and so on. The positive electrode of the first cell and negative electrode of the last cell then serve as the terminals of the battery. In this way, the voltage is 1.5 volts for each cell in the series line. There are four cells, so the output terminal voltage is 1.5 x 4 or 6 volts. When

connected to the load, 1/8 ampere flows through the load and each cell of the battery. This is within the capacity of each cell. Therefore, only four series-connected cells are needed to supply this particular load.

WARNING

When connecting cells in series, there MUST ALWAYS be two unconnected terminals remaining. These two terminals must be connected to each side of a load. NEVER connect the final two remaining terminals together unless a load is placed between them. Physical harm or equipment damage will result.

Parallel-Connected Cells

Assume an electrical load requires only 1.5 volts but will require 1/2 ampere of current. (Assume that a single cell will supply only 1/8 ampere.) To meet this requirement, the cells are connected in parallel, as shown in Figure 4-6 view A and schematically represented in view B. In a parallel connection, all positive cell electrodes are connected to one line, and all negative electrodes are connected to the other. No more than one cell is connected between the lines at any one point, so the voltage between the lines is the same as that of one cell, or 1.5 volts. However, each cell may contribute its maximum allowable current of 1/8 ampere to the line. There are four cells, so the total line current is $1/8 \times 4$, or 1/2 ampere. In this case, four cells in parallel have enough capacity to supply a load requiring 1/2 ampere at 1.5 volts.

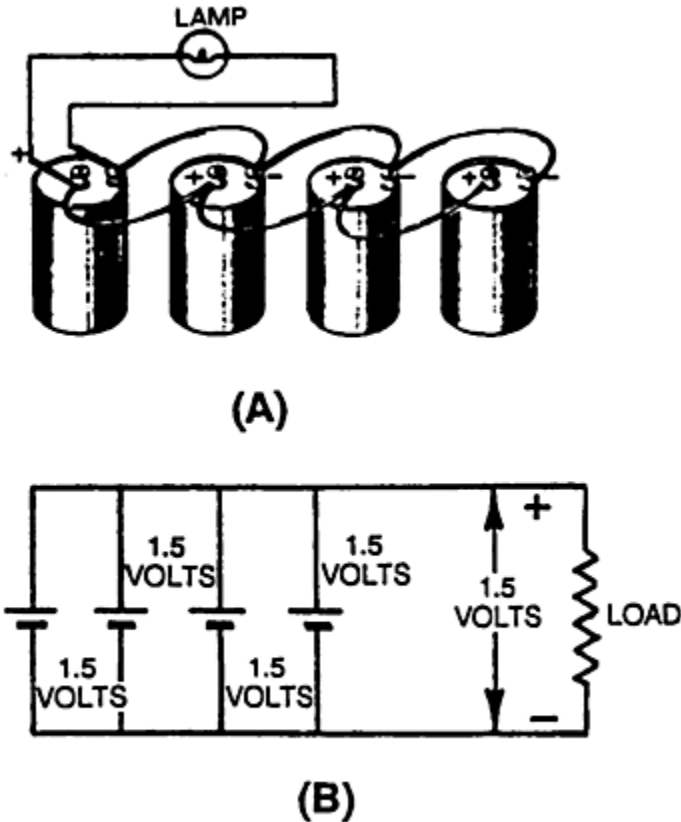


FIGURE 4-6. Parallel-Connected Cells.

BATTERY CONSTRUCTION

Secondary cell batteries are constructed using the various secondary cells already described. The lead-acid battery, one of the most common batteries, will be used to explain battery construction. The nickel-cadmium battery, which is being used with increasing frequency, will also be discussed.

Figure 4-7 shows the makeup of a lead-acid battery. The container houses the separate cells. Most containers are hard rubber, plastic, or some other material that is resistant to the electrolyte and mechanical shock and can withstand extreme temperatures. The container (battery case) is vented through vent plugs to allow the gases that form within the cells to escape. The plates in the battery are the cathodes and anodes. In Figure 4-8, the negative plate group is the cathode of the individual cells, and the positive plate group is the anode. The plates are interlaced with a terminal attached to each plate group. The terminals of the individual cells are connected together by link connectors, as shown in Figure 4-7. The cells are connected in series in the battery and the positive terminal of the battery. The negative terminal of the opposite end cell becomes the negative terminal of the battery.

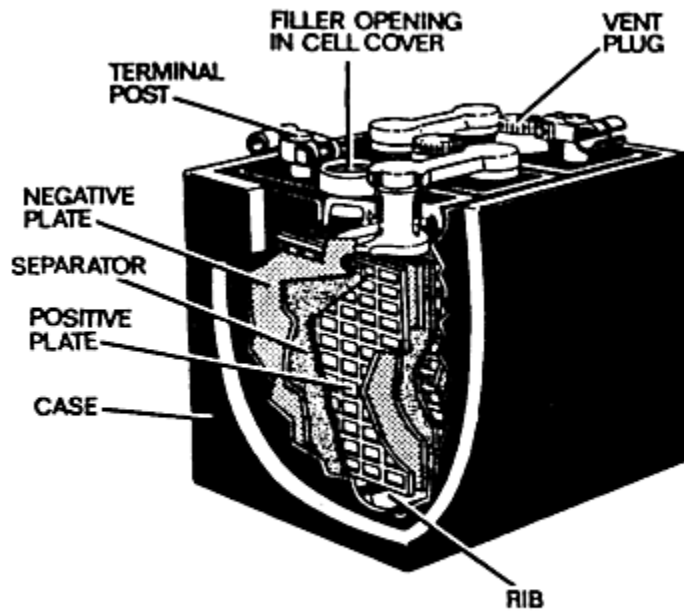


FIGURE 4-7. Lead-Acid Battery Construction.

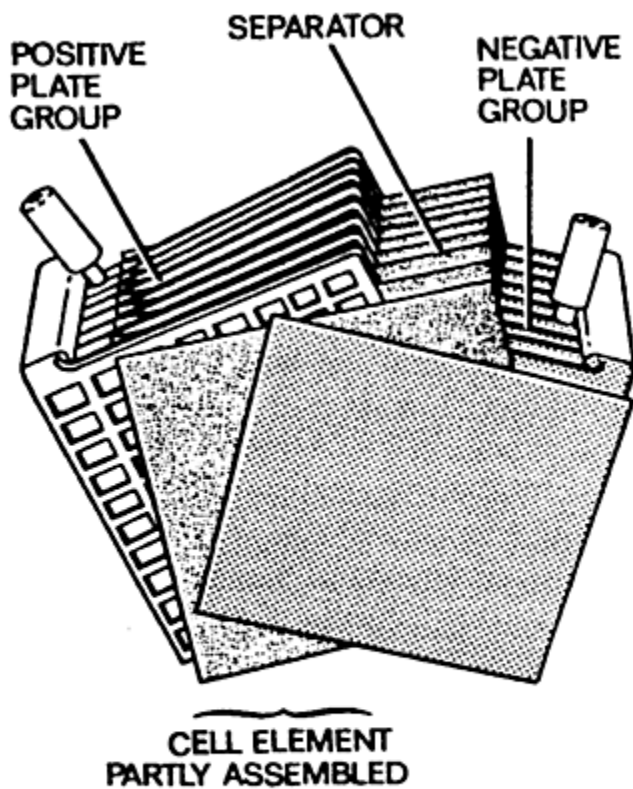


FIGURE 4-8. Lead-Acid Battery Plate Arrangement.

The terminals of a lead-acid battery are usually identified from one another by their size and markings. The positive terminal, marked (+), is some times colored red and is physically larger than the negative terminal, marked (-). The individual cells of the lead-acid battery are not replaceable; so if one cell fails, the battery must be replaced.

The nickel-cadmium battery is similar in construction to the lead-acid battery, except that it has individual cells that can be replaced. Figure 4-9 shows the cell of the NICAD battery.

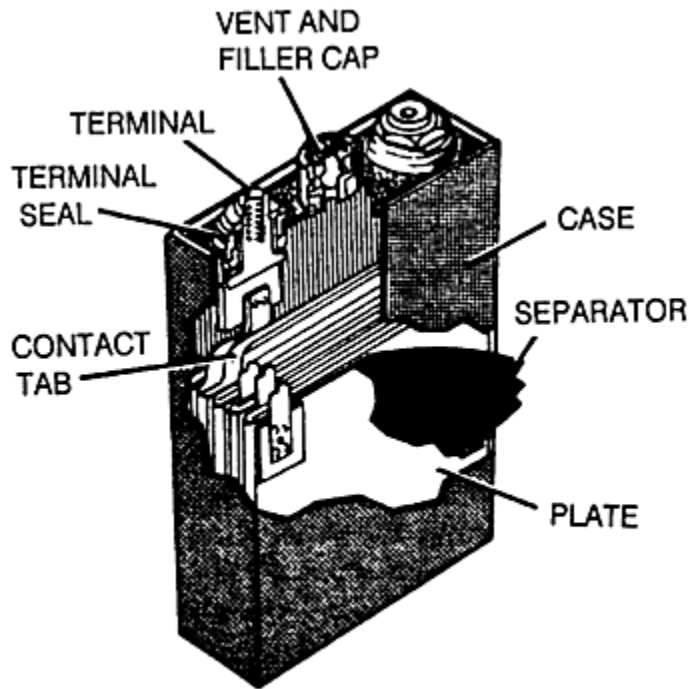


FIGURE 4-9. Nickel-Cadmium Cell.

The construction of secondary cell batteries is so similar that it is difficult to distinguish the type of battery by simply looking at it. The type of battery must be known to properly check or recharge the battery. Each battery should have a nameplate that gives a description of its type and electrical characteristics.

BATTERY MAINTENANCE

The transportation field relies on the battery's ability to store electrical power until such time as the power is needed.

The general information below concerns the maintenance of secondary-cell batteries, in particular the lead-acid battery. Refer to the appropriate technical manual before engaging in any other battery maintenance.

Leak Test

Cleanliness of the lead-acid battery is a primary concern because moisture and dirt are conductors. Batteries that are allowed to gas excessively add additional conductive liquid to the top and sides of the battery. Damp battery surfaces retain conductive dirt and debris.

A simple test, known as the leak test, provides a visual and authoritative point of view for battery cleanliness. Figure 4-10 illustrates the procedure.

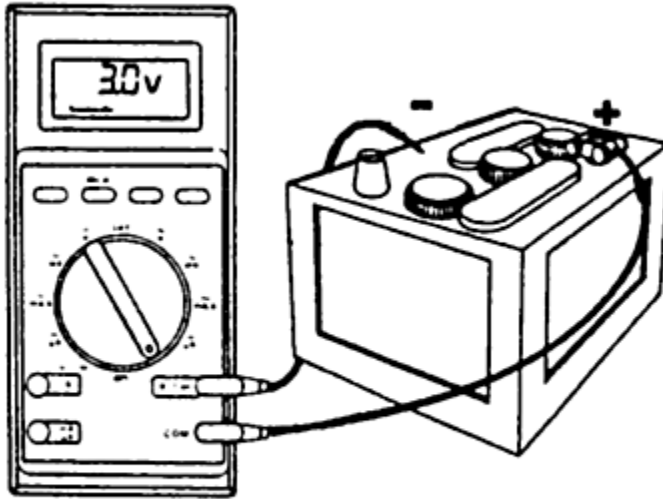


FIGURE 4-10. Leak Test.

- (1) Select a DC voltage scale at or above battery voltage.
- (2) Connect the negative meter lead to the negative battery post (the smaller battery post).
- (3) Use the positive meter lead to probe the housing of the battery.
- (4) Measure the voltage leaking across the two battery terminals using the multimeter.

In effect, electrolyte, dirt, and other foreign matter become a parallel circuit that continuously discharges the battery. Standard grease is not an acceptable battery terminal preservative. The heat from the battery compartment often melts the grease, which in turn covers the top and sides of the battery with a thin coating of lubricant. Dirt and dust adhere easily to this surface. Use a non-conducting high temperature grease or compound to protect the connections from contamination.

Idle Winter Batteries

Battery maintenance becomes even more critical during the winter months. The cold weather increases the already difficult task of starting diesel engines. Since the starter motor rotates slower than normal, less counter EMF is developed, and the current to the starter motor remains high. This increased current depletes the storage batteries rapidly. Problems are readily observed after extended winter weekends. To ensure the batteries are maintained at a high state of readiness --

- Always service and charge batteries thoroughly whenever the batteries are to enter an idle period. A discharged battery will freeze at about 18 degrees Fahrenheit. A frozen battery greatly increases the chance of a battery detonation. Detonation occurs during excessive charging or prolonged efforts to jump start equipment under these severe conditions.
- After the batteries are serviced and charged, disconnect the cables. Always disconnect the negative battery post first. Many small electrical problems in the starting or charging system can conduct current and discharge the batteries. When the equipment is operated regularly, small electrical deficiencies may not be noted. However, when equipment is left idle, even for a short time, these electrical deficiencies become apparent.

Battery Maintenance Tools

The most acceptable manner to clean battery terminals and clamps is to use the cutter or straightedge type of battery terminal and clamp cleaner. Wire-type battery terminal and clamp cleaners can damage the battery posts and clamps. Figure 4-11 shows the physical differences between the two cleaners.

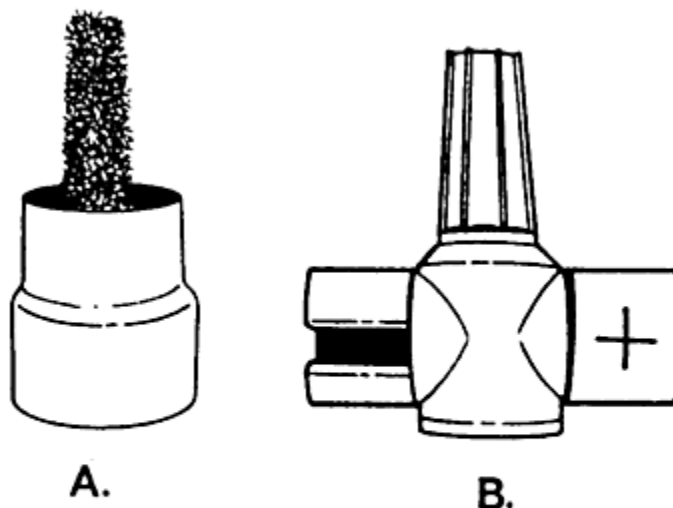


FIGURE 4-11. Battery Terminal and Clamp Cleaners.

Figure 4-12 view A shows a battery terminal in dire need of cleaning. The main concern for cleaning is to provide a large, clean contact surface area for the unimpeded flow of current. In view B, a cutter-type terminal cleaner is used. The cutter-type cleaner ensures a concentric post surface uniform in contact area. The cutter leaves some of the surface area soiled and dull because it is designed to maintain the original taper of both the post and the clamp. The cutter can only remove a small amount of the outer post surface area each time. The low pitted areas grow smaller in dimension as the tool is used.

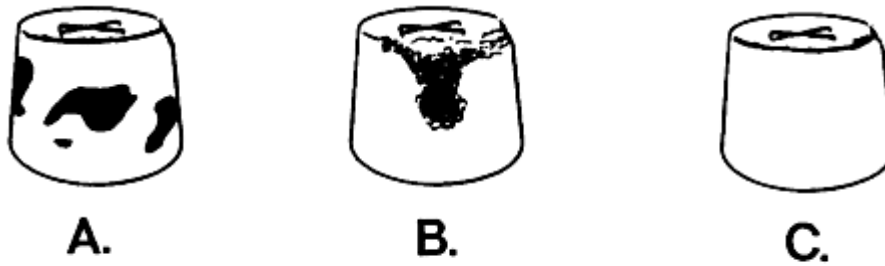


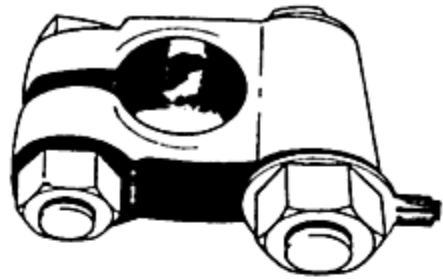
FIGURE 4-12. Cleaning a Dirty Battery Terminal.

(A) Dirty Battery Terminal.

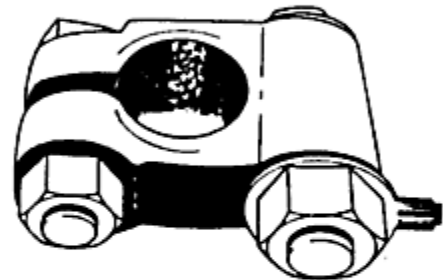
(B) Battery Terminal Partly Cleaned With Cutter-Type Terminal Cleaner.

(C) Battery Terminal Cleaned With Cutter-Type Terminal Cleaner.

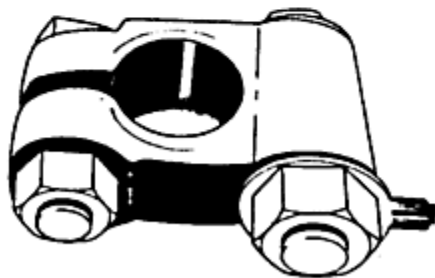
When the inside of the terminal clamp is cleaned with the cutter-type cleaner, a similar condition results (Figure 4-13). Pits are visible and continually reduced in size. The cutting can continue until a uniform and properly tapered clean surface results.



A.



B.



C.

FIGURE 4-13. Cleaning a Dirty Battery Clamp.

(A) Dirty Battery Clamp.

(B) Partly Cleaned Battery Clamp With Cutter-Type Cleaner.

(C) Cleaned Battery Clamp With Cutter-Type Cleaner.

The wire-type cleaner cannot restore the surface of the post or clamp. It will clean the entire area, but it cannot restore any irregularities in the surfaces. It actually increases the surface distortions. Pits get bigger, and the necessary contact surface area is decreased. The original taper is lost. The surface area is eventually reduced to a point where excessive heat from current flow can melt the post and clamp. A spark may result, detonating the battery. As [Figure 4-14](#) shows, reduced contact area equals increased heating.

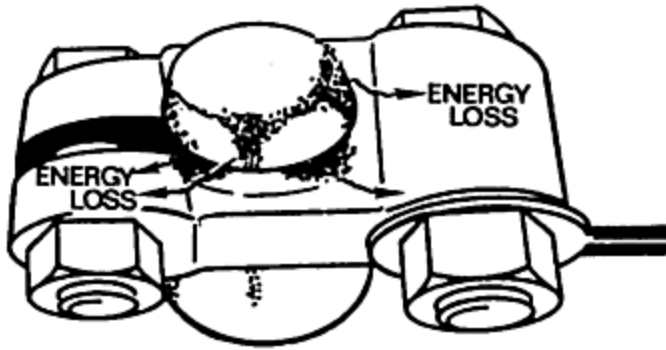


FIGURE 4-14. Reduced Contact Area Equals Increased Heating.

Use a battery terminal clamp puller to remove battery clamps from the terminals. Prying the clamp from the terminal with a screwdriver will damage the terminal.

Battery Log

Keep weekly specific gravity readings and overall battery bank voltage readings in a battery logbook. This will provide an accurate and complete operational status of each battery to forecast any cells that are becoming deficient. Figure 4-15 is an example of a battery logbook.

Date Serviced: _____			
Battery No. 1: _____		Battery No. 2: _____	
Date Installed: _____		Date Installed: _____	
Specific Gravity Readings (negative to positive terminal)			
Cell 1: _____	Cell 4: _____	Cell 1: _____	Cell 4: _____
Cell 2: _____	Cell 5: _____	Cell 2: _____	Cell 5: _____
Cell 3: _____	Cell 6: _____	Cell 3: _____	Cell 6: _____

Battery No. 3: _____		Battery No. 4: _____	
Date Installed: _____		Date Installed: _____	
Cell 1: _____	Cell 4: _____	Cell 1: _____	Cell 4: _____
Cell 2: _____	Cell 5: _____	Cell 2: _____	Cell 5: _____
Cell 3: _____	Cell 6: _____	Cell 3: _____	Cell 6: _____

Battery No. 5: _____		Battery No. 6: _____	
Date Installed: _____		Date Installed: _____	
Cell 1: _____	Cell 4: _____	Cell 1: _____	Cell 4: _____
Cell 2: _____	Cell 5: _____	Cell 2: _____	Cell 5: _____
Cell 3: _____	Cell 6: _____	Cell 3: _____	Cell 6: _____

FIGURE 4-15. Battery Logbook.

The Hydrometer

A hydrometer is the instrument that measures the amount of active ingredients in the electrolyte of the battery. The hydrometer measures the specific gravity of the electrolyte. Specific gravity is the ratio of the weight of the electrolyte to the weight of the same volume of pure water. The active ingredient, such as sulfuric acid or potassium hydroxide, is heavier than water. Therefore, the more active ingredient there is in the electrolyte, the heavier the electrolyte will be. The heavier the electrolyte is, the higher the specific gravity will be.

WARNING

Never mix lead-acid and nickel cadmium servicing tools together. Never store or transport nickel-cadmium and lead-acid batteries together. The combination of potassium hydroxide and sulfuric acid electrolytes generate a toxic gas that can kill!

A hydrometer (Figure 4-16) is a glass syringe with a float inside it. The float is a hollow glass tube weighted at one end and sealed at both ends, with a scale calibrated in specific gravity marked on the side. The electrolyte to be tested is drawn into the hydrometer by using the suction bulb. Enough electrolyte should be drawn into the hydrometer so that the float will rise. However, the hydrometer should not be filled to the extent that the float rises into the suction bulb. Since the weight of the float is at its base, the float will rise to a point determined by the weight of the electrolyte. If the electrolyte contains a large concentration of active ingredient, the float will rise higher than if the electrolyte has a small concentration of active ingredient.

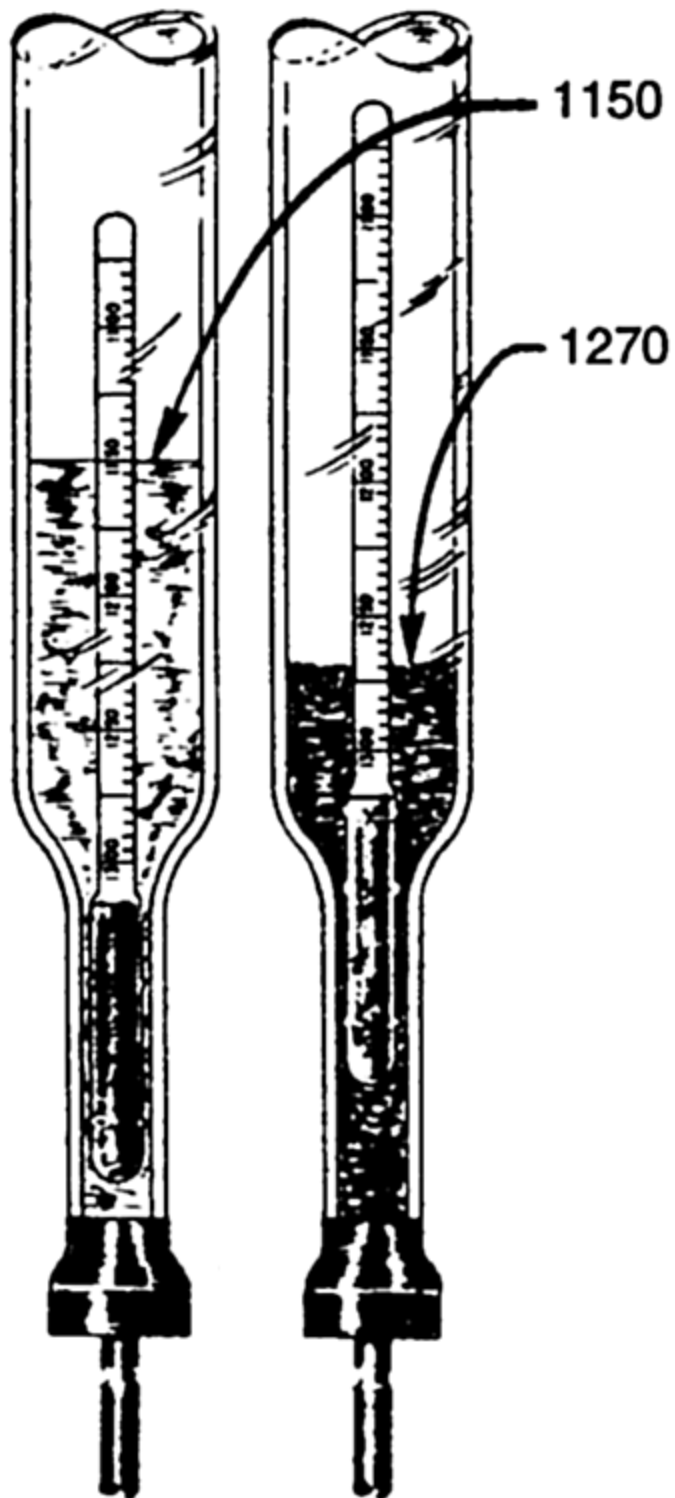


FIGURE 4-16. Hydrometer.

To read the hydrometer, hold it in a vertical position and take the reading at the level of the electrolyte. Refer to the manufacturer's technical manual for battery specifications for the correct specific gravity ranges.

WARNING

Care must be taken to prevent electrolytes from entering the eyes or from splashing on the skin.

NOTE: Hydrometers should be flushed with fresh water after each use to prevent inaccurate readings. Storage battery hydrometers must not be used for any other purpose.

State of Charge

Table 4-1 provides a general guidance for the specific gravity of the lead-acid battery.

TABLE 4-1. Specific Gravity of the Lead -Acid Battery

Specific Gravity Temperate Climates	Specific Gravity Tropical Climates	State of Charge
1.260 - 1.280	1.225	Fully Charged
1.230 - 1.250	1.195	75 Percent Charged
1.200 - 1.220	1.165	50 Percent Charged
1.170 - 1.190	1.135	25 Percent Charged
1.110 - 1.130	1.075	Discharged

All testing of battery-powered equipment must be conducted with fully charged batteries. The manufacturer's technical data is based on the assumption that the power supply (batteries) is fully operational. Any deviation from the fully charged condition will change the testing results. If the batteries are not fully charged, the test results will be erroneous and inconclusive.

Unless otherwise specified, the specific gravity readings between cells should be no greater that 30 points (.030). Any variations outside the specifications indicate an unsatisfactory condition, and the battery should be replaced.

Gassing

When a battery is being charged, a portion of the energy breaks down the water in the electrolyte. Hydrogen is released at the negative plates and oxygen at the positive plates. These gases bubble up through the electrolyte and collect in the air space at the top of the cell. If violent gassing occurs when the battery is first

placed on charge, the charging rate is too high. If the rate is not too high, steady gassing develops as the charging proceeds, indicating that the battery is nearing a fully charged condition.

Avoid excessive gassing. The by-products are hazardous and explosive. Any lost liquid from the battery cell is a combination of water and sulfuric acid. Since the specific gravity changes as the batteries increase in charge, it is impossible to anticipate the exact content of sulfuric acid removed from the cell. Every time the maintenance technician replenishes the cell with water, he is actually reducing the percentage of sulfuric acid within that cell. Eventually the chemical action will become deficient.

Battery Caps

When taking hydrometer readings, avoid contaminating battery cap undersides by placing them upside down on the battery case. This will help keep debris from falling into the cell.

Troubleshooting Battery-Powered Systems

Troubleshooting battery-powered systems can become complex. Unlike many mechanical systems, numerous electrical problems can be identified with a good initial inspection. Burned out electrical components have a distinctive electrical smell, and charred wires and connections are readily identified. Once these areas are identified and corrected, further tests are needed to determine the reason for this condition.

Check all connections, from the battery throughout the entire electrical system, regularly. All connections must be clean and tight. Units operating in the salt air environment are especially prone to oxidation. All mobile units are prone to vibration. Together, vibration and oxidation account for a large percentage of electrical malfunctions.

Any increase in resistance in the circuit reduces the current throughout the entire circuit. When current is reduced, the magnetic properties of the circuit are reduced. Current is a quantity of electrons (with their magnetic field) passing a point in the circuit in a period of time. With fewer electrons, there is a reduction in the magnetic properties available to the circuit components. With a reduction of electrons (and their magnetic influence), motors, solenoids, and other electrical components will function irregularly. Some of the more obvious resistance increases are due to improper or dirty connections and corroded cable ends.

To understand how a small amount of additional resistance can reduce the capability of the electrical system, suppose that a resistance of 1 ohm exists in a poorly made connection in a diesel engine starting system. The 24-volt battery starting system normally provides 240 amps to a starting system with a resistance of .1 ohms. The 24 volts must now supply a starting system with 1.1 ohms resistance.

The additional 1 ohm resistance will consume power (power = amps x volts). The current will be reduced because the total resistance (Rt) is increased. The total amperage for the system is reduced as shown in the following equation:

$$I_t = \frac{E_t}{R_t}$$

$$I_t = \frac{24 \text{ volts}}{1.1 \text{ ohm}}$$

$$I_t = 21.8 \text{ amps}$$

The 240 amps required to turn the starter motor has been reduced to 21.8 amps. The starter cannot turn.

Battery Voltage

A fully charged lead-acid battery has 2.33 volts per cell. It is quite common for a 24-volt battery bank to actually have a voltage of 26.5 volts. The technical manual specifies the term "battery voltage" instead of 24 volts because the actual battery terminal voltage must be observed throughout the entire electrical testing procedure. The manufacturer is concerned with the actual battery bank voltage.

A charged battery that shows an extremely high voltage is suspect of being deficient. Individual 12-volt batteries should not exceed 15.5 volts, and 6-volt batteries should not exceed 7.8 volts. If these voltages are exceeded, the battery is unsatisfactory and probably sulfated. These higher voltage values indicate only a superficial charge and are incapable of delivering the current capacity designed for the battery.

Fully Charged Batteries

Test result standards are based on a fully functioning power supply. Always start troubleshooting the battery-powered electrical system at the batteries. The batteries must be fully operational and completely charged before testing any other electrical component. Charge the existing battery bank or substitute the batteries when other circuit components are suspect.

Other Maintenance

Perform routine maintenance of batteries regularly. Check terminals periodically for cleanliness and good electrical connections. Inspect the battery case for cleanliness and evidence of damage. Check the level of electrolyte. If the electrolyte is low, add distilled water to bring the electrolyte to the proper level. Maintenance procedures for batteries are normally determined by higher authority. Each command will have detailed procedures for battery care and maintenance.

Safety Precautions With Batteries

Observe the following safety precautions when working with batteries:

- Handle all types of batteries with care.
- Never short the terminals of a battery.
- Use carrying straps when transporting batteries.
- Wear chemical splash-proof safety glasses when maintaining batteries.
- Wear protective clothing, such as a rubber apron and rubber gloves when working with batteries. Electrolyte will destroy everyday clothing such as the battle dress uniform.
- Do not permit smoking, electric sparks, or open flames near charging batteries.
- Take care to prevent spilling the electrolyte.
- Never install alkaline and lead-acid batteries in the same compartment.
- Do not exchange battery tools to include hydrometers between lead-acid batteries and nickel-cadmium batteries.

In the event electrolyte is splashed or spilled on a surface, such as the deck or table, immediately dilute it with large quantities of water and clean it up.

If the electrolyte is spilled or splashed on the skin or eyes, immediately flush the area with large quantities of fresh water for a minimum of 15 minutes. If the electrolyte is in the eyes, be sure the upper and lower eyelids are pulled out sufficiently to allow the fresh water to flush under the eyelids. Notify the medical department of the type of electrolyte and the location of the accident as soon as possible.

CAPACITY AND RATING OF BATTERIES

The capacity of a battery is measured in ampere-hours. The ampere-hour capacity equals the product of the current in amperes and the time in hours during which the battery will supply this current. The ampere-hours capacity varies inversely with the discharge current. For example, a 400 ampere-hour battery will deliver 400 amperes for one hour or 100 amperes for four hours.

Storage batteries are rated according to their rate of discharge and ampere-hour capacity. Most batteries are rated according to a 20-hour rate of discharge. That is, if a fully charged battery is completely discharged during a 20-hour period, it is discharged at the 20-hour rate. Thus, if a battery can deliver 20 amperes continuously for 20 hours, the battery has a rating of 20 amperes x 20 hours, or

400 ampere-hours. Therefore, the 20-hour rating equals the average current that a battery can supply without interruption for an interval of 20 hours.

All standard batteries deliver 100 percent of their available capacity if discharged in 20 hours or more, but they will deliver less than their available capacity if discharged at a faster rate. The faster they discharge, the less ampere-hour capacity they have.

The low-voltage limit, as specified by the manufacturer, is the limit beyond which very little useful energy can be obtained from a battery. This low-voltage limit is normally a test used in battery shops to determine the condition of a battery.

BATTERY CHARGING

Adding the active ingredient to the electrolyte of a discharged battery does not recharge the battery. Adding the active ingredient only increases the specific gravity of the electrolyte. It does not convert the plates back to active material, and so does not bring the battery back to a charged condition. A charging current must be passed through the battery to recharge it.

WARNING

A mixture of hydrogen and air can be dangerously explosive. No smoking, electric sparks, or open flames should be permitted near charging.

Types of Charges

The following types of charges may be given to a storage battery, depending on the condition of the battery:

- Initial charge.
- Normal charge.
- Equalizing charge.
- Floating charge.
- Fast charge.

Initial Charge. When a new battery is shipped dry, the plates are in an uncharged condition. After the electrolyte has been added, it is necessary to charge the battery. This is done by giving the battery a long low-rate initial charge. The charge is given according to the manufacturer's instructions, which are shipped with each battery. If the manufacturer's instructions are not available, refer to the detailed instructions for charging batteries found in TM 9-6140-200-14.

Normal Charge. A normal charge is a routine charge given according to the nameplate data during the ordinary cycle of operation to restore the battery to its charged condition.

Equalizing Charge. An equalizing charge is a special extended normal charge that is given periodically to batteries as part of maintenance routine. It ensures that all sulfate is driven from the plates and that all the cells are restored to a maximum specific gravity. The equalizing charge is continued until the specific gravity of all cells, corrected for temperature, shows no change for a four-hour period.

Floating Charge. In a floating charge, the charging rate is determined by the battery voltage rather than by a definite current value. The floating charge is used to keep a battery at full charge while the battery is idle or in light duty. It is sometimes referred to as a trickle charge and is done with low current.

Fast Charge. A fast charge is used when a battery must be recharged in the shortest possible time. The charge starts at a much higher rate than is normally used for charging. It should be used only in an emergency, as this type charge may harm the battery.

Charging Rate

Normally, the charging rate of storage batteries is given on the battery nameplate. If the available charging equipment does not have the desired charging rates, use the nearest available rates. However, the rate should never be so high that violent gassing occurs.

Charging Time

Continue the charge until the battery is fully charged. Take frequent readings of specific gravity during the charge and compare with the reading taken before the battery was placed on charge.

INGERSOLL-RAND **DRILLING SOLUTIONS**

CHAPTER 4 **BATTERIES**

Instrumentation used: Hydrometer, Digital multimeters with MIN/MAX capture capability

Person performing test:

Make and model of instrumentation:

When complete send to Ted Aikman @ Ingersoll-Rand, Rotary Drill, Garland, TX

Rig Model	S/N	Date	Engine make and size	Number of starters	Total cable length, batt-str-batt	Number of batteries	System voltage at the batteries	Voltage of batt #1	Voltage of batt #2	Voltage of batt #3
DM45HP	7443	11/15/99	Cum QSK19C	1	~16" incl.disconnect sw	2	24.8	12.27	12.53	N/A

Example

Voltage of batt #4	Batt. #1 Hi/Lo Specific Gravity, see note 2	Batt. #2 Hi/Lo Specific Gravity, see note 2	Batt. #3 Hi/Lo Specific Gravity, see note 2	Batt. #4 Hi/Lo Specific Gravity, see note 2	MIN starter voltage during start cycle	Voltage drop across pos. cable, MAX	Voltage drop across neg. cable, MAX	Alternator charging voltage
N/A	1.117	1.246	N/A	N/A	17.62	1.091	0.029	27.31

Example

NOTES:

1. Prior to test, examine cable connections for cleanliness and tightness, cables for cuts or nicks in the insulation, and corrosion on the connections. Take test readings, then take corrective action to repair or replace the components as needed and log on this form.

Take another set of readings after corrective action.

2. Batt. 1 has positive starter cable connected. Make sure fluid level is correct. Be careful when handling battery acid.

Measure all cells and write down minimum and maximum, temperature corrected, value for each battery.

If one or more cells have much lower reading than others, evaluate why, repair or replace battery.

3. Normal expected values:

Charge level	Specific gravity, temp corrected	Open circuit voltage per battery
100%	1.27	12.7
75%	1.225	12.4
50%	1.19	12.2
25%	1.155	12

Observation and comments:

INTRODUCTION

The study of inductance is a very challenging but rewarding segment of electricity. It is challenging because at first it seems that new concepts are being introduced. However, these new concepts are merely extensions of the fundamental principles in the study of magnetism and electron physics. The study of inductance is rewarding because a thorough understanding of it will enable you to acquire a working knowledge of electrical circuits more rapidly.

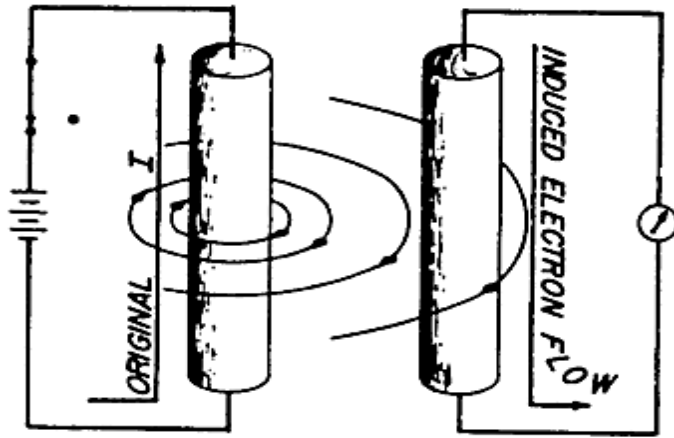
CHARACTERISTICS OF INDUCTANCE

Inductance is the characteristic of an electrical circuit that opposes the starting, stopping, or changing of current flow. The symbol for inductance is L . The basic unit of inductance is the henry (H); 1 henry equals the inductance required to induce 1 volt in an inductor by a change of current of 1 ampere per second.

An analogy of inductance is found in pushing a heavy load, such as a wheelbarrow or car. It takes more work to start the load moving than it does to keep it moving. Once the load is moving, it is easier to keep the load moving than to stop it again. This is because the load possesses the property of inertia. Inertia is the characteristic of mass that opposes a change in velocity. Inductance has the same effect on current in an electrical circuit as inertia has on the movement of a mechanical object. It requires more energy to start or stop current than it does to keep it flowing.

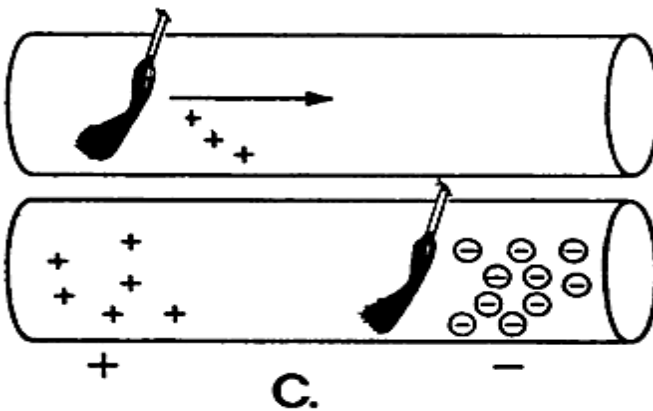
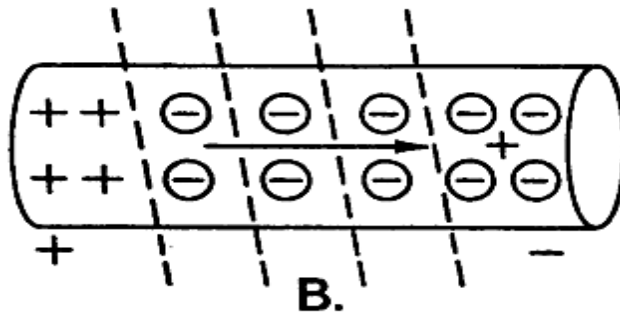
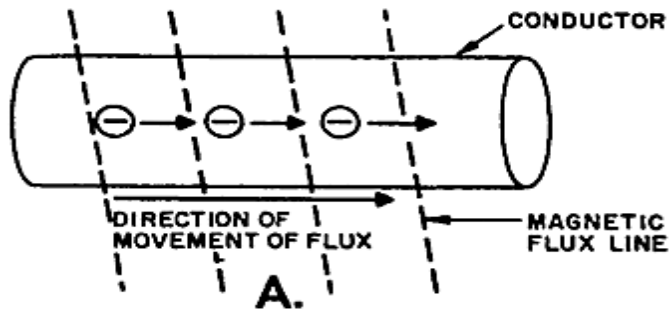
ELECTROMOTIVE FORCE

Electromotive force is developed whenever there is relative motion between a magnetic field and a conductor. EMF is a difference of potential or voltage which exists between two points in an electrical circuit. In generators and inductors, the EMF is developed by the action between the magnetic field and the electrons in a conductor. (An inductor is a wire that is coiled, such as in a relay coil, motor, or transformer.) Below shows EMF generated in an electrical conductor.



Generation of an EMF in an electrical conductor

When a magnetic field moves through a stationary conductor, electrons are dislodged from their orbits. The electrons move in a direction determined by the movement of the magnetic lines of flux, see below.



Current movement and flux direction relationship

The electrons move from one area of the conductor into another area (view A). The area that the electrons moved from has fewer negative charges (electrons) and becomes positively charged (view B). The area the electrons move into becomes negatively charged. The difference between the charges in the conductor equals a difference of potential (or voltage). This voltage caused by the moving magnetic field is called electromotive force.

In simple terms, compare the action of a moving magnetic field on a conductor to the action of a broom. Consider the moving magnetic field to be a moving broom

(view C). As the magnetic broom moves along (through) the conductor, it gathers up and pushes loosely bound electrons before it.

The area from which electrons are moved becomes positively charged, while the area into which electrons are moved becomes negatively charged. The potential difference between these two areas is the electromotive force.

SELF-INDUCTANCE

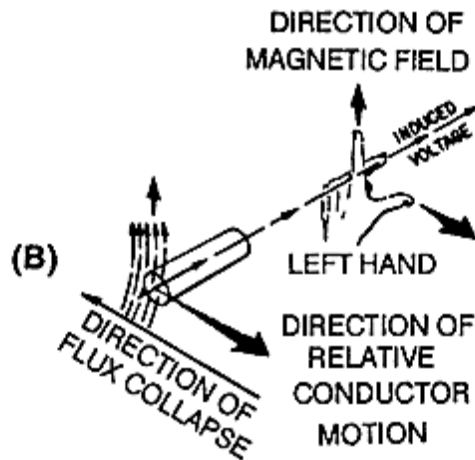
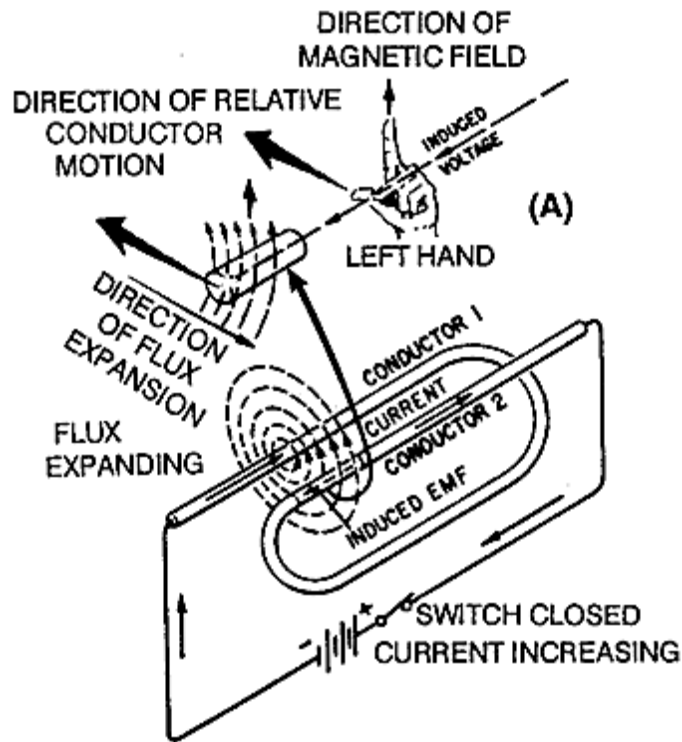
Even a perfectly straight length of conductor has some inductance. Current in a conductor produces a magnetic field surrounding the conductor. When the current changes direction, the magnetic field changes. This causes relative motion between the magnetic field and the conductor, and an EMF is induced in the conductor. This EMF is called a self-induced EMF because it is induced in the conductor carrying the current. It is also called counter electromotive force (CEMF).

COUNTER ELECTROMOTIVE FORCE

To understand what CEMF is and how it develops, first review a basic requirement for the production of voltage. To magnetically produce a voltage or electromotive force, there must be --

- A conductor.
- A magnetic field.
- Relative motion.

Next, review some of the properties of an electrical circuit. If the ends of a length of wire are connected to a terminal of an AC generator, there would be an electrical short, and maximum current would flow. (Do not do this.) Excessive current would flow because there would be only the minimal resistance of the wire to hold back the current. This will damage the electrical system. The figure below illustrates self-inductance.



Self-inductance

If the length of wire is rolled tightly into a coil, the coil would become an inductor. Whenever an inductor is used with AC, a form of power generation occurs. An EMF is created in the inductor because of the close proximity of the coil conductors and the expanding and contracting AC magnetic fields. The inductor creates its own EMF. Since this inductor generator follows the rules of inductance, opposing a change in current, the EMF developed is actually a counter EMF opposing the power source creating it. This CEMF pushes back on

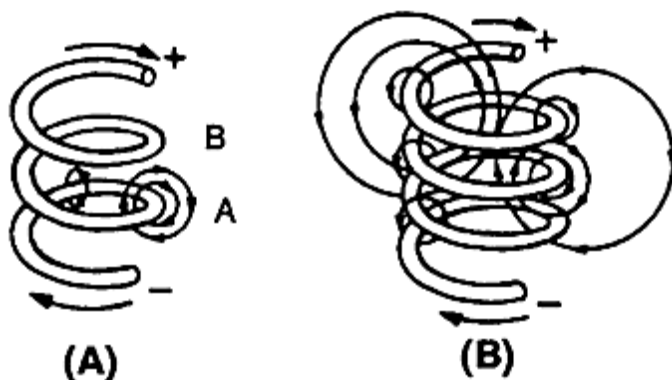
the electrical system as a form of resistance to the normal power source. CEMF is like having another power source connected in series and opposing.

This is an example of an inductive load. Unlike the resistive load, all the power in the circuit is not consumed. This effect is summarized in Lenz's Law which states that the induced EMF in any circuit is always in a direction to oppose the effect that produced it.

The direction of this induced voltage may be determined by applying the left-hand rule for generators. This rule is applied to a portion of conductor 2 that is enlarged for this purpose in the figure above. This rule states that if you point the thumb of your left hand in the direction of relative motion of the conductor and your index finger in the direction of the magnetic field, your middle finger, extended as shown, will indicate the direction of the induced current which will generate the induced voltage (CEMF) as shown.

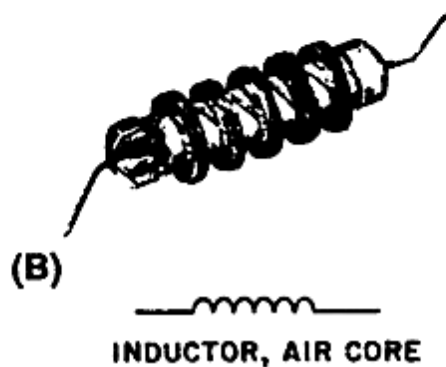
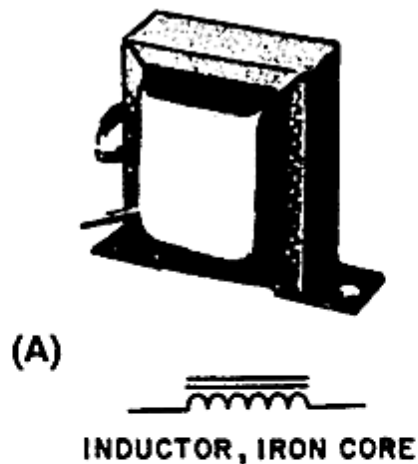
View B shows the same section of conductor 2 after the switch has been opened. The flux field is collapsing. Applying the left-hand rule in this case shows that the reversal of flux movement has caused a reversal in the direction of the induced voltage. The induced voltage is now in the same direction as the battery voltage. The self-induced voltage opposes both changes in current. That is, when the switch is closed, this voltage delays the initial buildup of current by opposing the battery voltage. When the switch is opened, it keeps the current flowing in the same direction by aiding the battery voltage.

Thus, when a current is building up, it produces a growing magnetic field. This field induces an EMF in the direction opposite to the actual flow of current. This induced EMF opposes the growth of the current and the growth of the magnetic field. If the increasing current had not set up a magnetic field, there would have been no opposition to its growth. The whole reaction, or opposition, is caused by the creation or collapse of the magnetic field, the lines of which as they expand or contract cut across the conductor and develop the counter EMF, as seen below.



Inductance

Inductors are classified according to core type. The core is the center of the inductor just as the core of an apple is the center of the apple. The inductor is made by forming a coil of wire around a core. The core material is normally one of two types: soft iron or air. The figure below shows an iron core inductor and its schematic symbol (represented with lines across the top of the inductor to indicate the presence of an iron core). The air core inductor may be nothing more than a coil of wire, but it is usually a coil formed around a hollow form of some nonmagnetic material such as cardboard. This material serves no purpose other than to hold the shape of the coil. View B shows an air core inductor and its schematic symbol.

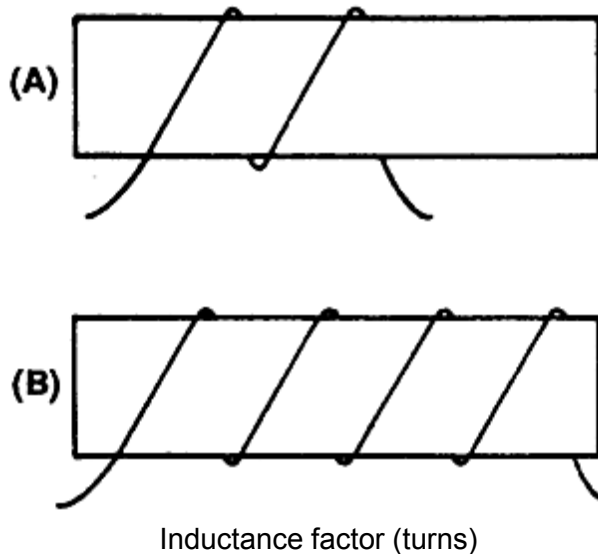


Inductor types and schematic symbols

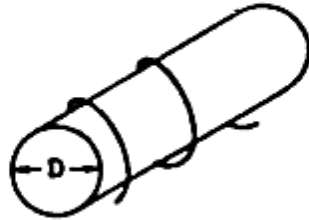
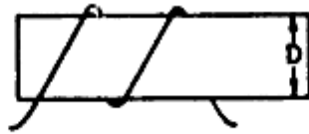
FACTORS AFFECTING COIL INDUCTANCE

Several physical factors affect the inductance of a coil. They are the number of turns, the diameter, the length of the coil conductor, the type of core material, and the number of layers of winding in the coil. Inductance depends entirely on the physical construction of the circuit. It can only be measured with special laboratory instruments.

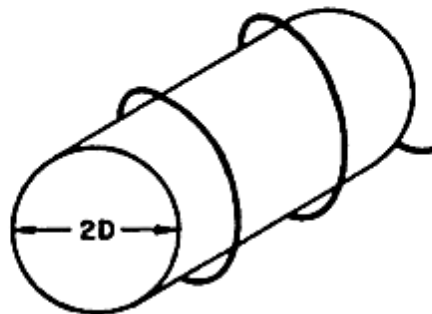
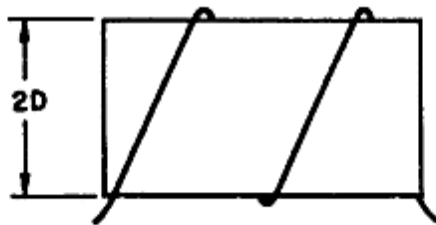
The first factor that affects the inductance of the coil is the number of turns. The figure below shows two coils. Coil A has two turns, and coil B has four turns. In coil A, the flux field setup by one loop cuts one other loop. In coil B, the flux field setup by one loop cuts three other loops. Doubling the number of turns in the coil will produce a field twice as strong; if the same current is used. A field twice as strong, cutting twice the number of turns, will induce four times the voltage. Therefore, inductance varies by the square of the number of turns.



The second factor is the coil diameter. In the below figure, coil B has twice the diameter of coil A. Physically, it requires more wire to construct a coil of larger diameter than one of smaller diameter with an equal number of turns. Therefore, more lines of force exist to induce a counter EMF in the coil with the larger diameter. Actually, the inductance of a coil increases directly as the cross-sectional area of the core increases. Recall the formula for the area of a circle: $A = \pi r^2$ ($\pi \times r^2$). Doubling the radius of a coil increases the area by a factor of four.



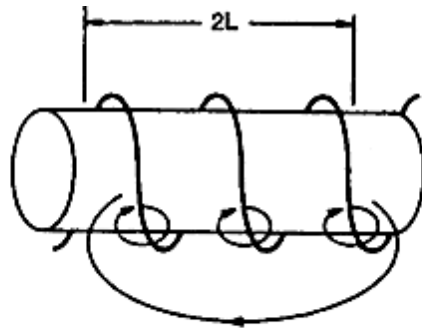
(A)



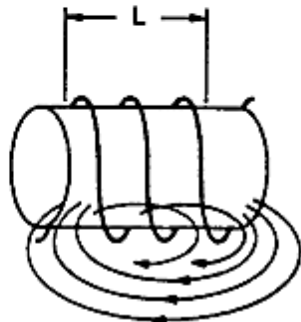
(B)

Inductance factor (diameter)

The third factor that affects the inductance of a coil is the length of the coil. The figure below shows two examples of coil spacings. Coil A has three turns, rather widely spaced, making a relatively long coil. A coil of this type has fewer flux linkages due to the greater distance between each turn. Therefore, coil A has a relatively low inductance. Coil B has closely spaced turns, making a relatively short coil. This close spacing increases the flux linkage, increasing the inductance of the coil. Doubling the length of a coil while keeping the number of turns of a coil the same halves the inductance.



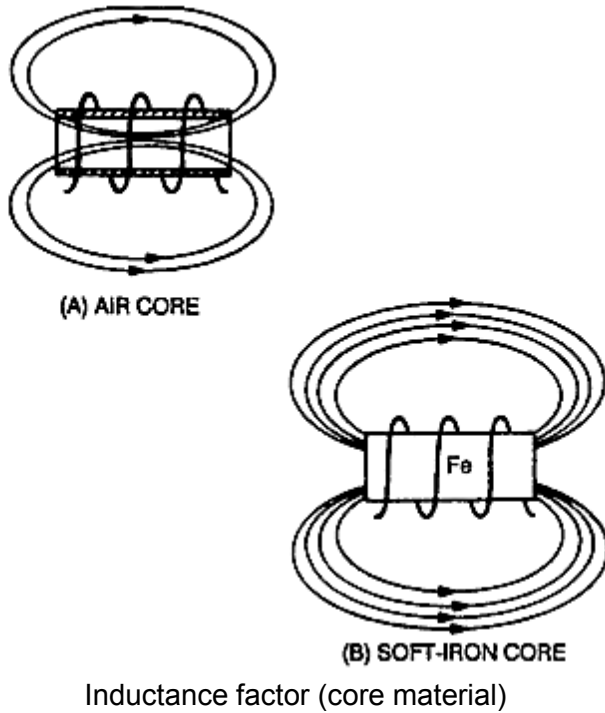
(A) WIDELY SPACED



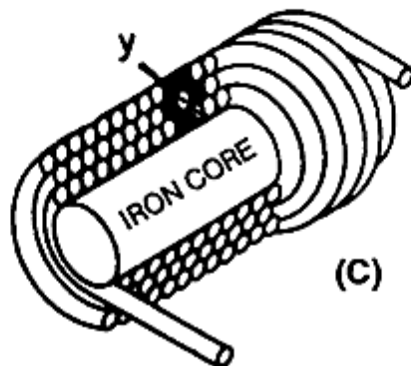
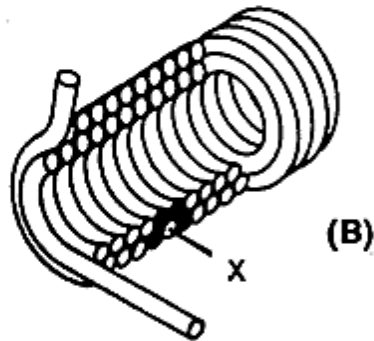
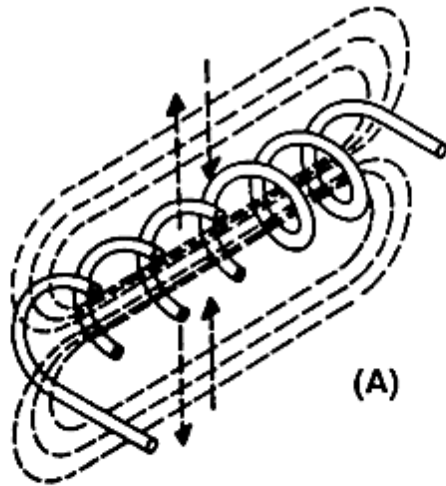
(B) CLOSELY WOUND

Inductance factor (coil length)

The fourth factor is the type of core material used with the coil. The figure below shows two coils: coil A with an air core and coil B with a soft-iron core. The magnetic core of coil B is a better path for magnetic lines of force than the nonmagnetic core of coil A. The soft-iron magnetic core's high permeability has less reluctance to the magnetic flux, resulting in more magnetic lines of force. This increase in the magnetic lines of force increases the number of lines of force cutting each loop of the coil, thus increasing the inductance of the coil. The inductance of a coil increases directly as the permeability of the core material increases.



The fifth factor is the number of layers of windings in the coil. Inductance is increased by winding the coil in layers. The figure below shows three cores with different amounts of layering. Coil A is a poor inductor compared to the others in this figure because its turns are widely spaced with no layering. The flux movement, indicated by the dashed arrows, does not link effectively because there is only one layer of turns. Coil B is a more inductive coil. The turns are closely spaced, and the wire has been wound in two layers. The two layers link each other with greater number of flux loops during all flux movements. Note that nearly all the turns, such as X, are next to four other turns (shaded). This causes the flux linkage to be increased.



Coils of various inductances

A coil can be made still more inductive by winding it in three layers (coil C). The increased number of layers (cross-sectional area) improves flux linkage even more. Some turns, such as Y, lie directly next to six other turns (shaded). In actual practice, layering can continue on through many more layers. The inductance of a coil increases with each layer added.

The factors that affect the inductance of a coil vary. Many differently constructed coils can have the same inductance. Inductance depends on the degree of linkage between the wire conductors and the electromagnetic field. In a straight

length of conductor, there is very little flux linkage between one part of the conductor and another. Therefore, its inductance is extremely small. Conductors become much more inductive when they are wound into coils. This is true because there is maximum flux linkage between the conductor turns, which lie side by side in the coil.

UNIT OF INDUCTANCE

As stated before, the basic unit of inductance (L) is the henry (H). An inductor has an inductance of 1 henry if an EMF of 1 volt is induced in the inductor when the current through the inductor is changing at the rate of 1 ampere per second.

POWER LOSS IN AN INDUCTOR

Since an inductor (coil) consists of a number of turns of wire and since all wire has some resistance, every inductor has a certain amount of resistance. Normally, this resistance is small. It is usually neglected in solving various types of AC circuit problems because the reactance of the inductor (the opposition to alternating current) is so much greater than the resistance that the resistance has a negligible effect on current.

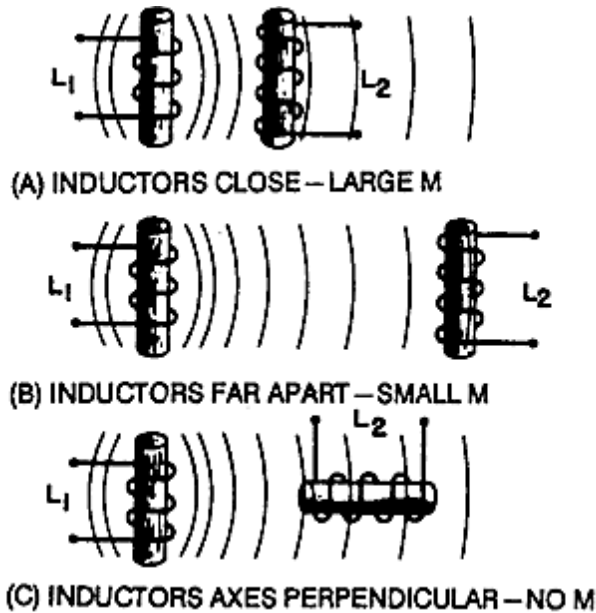
However, since some inductors are designed to carry relatively large amounts of current, considerable power can be dissipated in the inductor even though the amount of resistance in the inductor is small. This is wasted power called copper loss. The copper loss of an inductor can be calculated by multiplying the square of current in the inductor by the resistance of the winding (I^2R).

In addition to copper loss, an iron-core coil (inductor) has two iron losses. These are hysteresis loss and eddy-current loss. Hysteresis loss is due to power that is consumed in reversing the magnetic field of the inductor core each time the direction of current in the inductor changes. Eddy-current loss is due to currents that are induced in the iron core by the magnetic field around the turns of the coil. These currents are called eddy currents and flow back and forth in the iron core.

All these losses dissipate power in the form of heat. Since this power cannot be productively consumed in the electrical circuit, it is lost power.

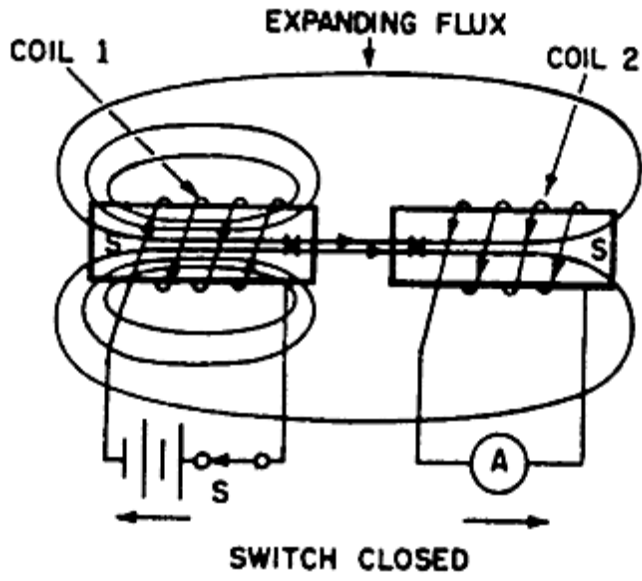
MUTUAL INDUCTANCE

Whenever two coils are located so that the flux from one coil links with the turns of another coil, a change of flux in one causes an EMF to be induced into the other coil. This allows the energy from one coil to be transferred or coupled to the other coil. The two coils are coupled or linked by the property of mutual inductance. The amount of mutual inductance depends on the relative positions of the two coils seen below. If the coils are separated a considerable distance, the amount of flux common to both coils is small, and the mutual inductance is low. Conversely, if the coils are close together so that nearly all the flux of one coil links the turns of the other, the mutual inductance is high.

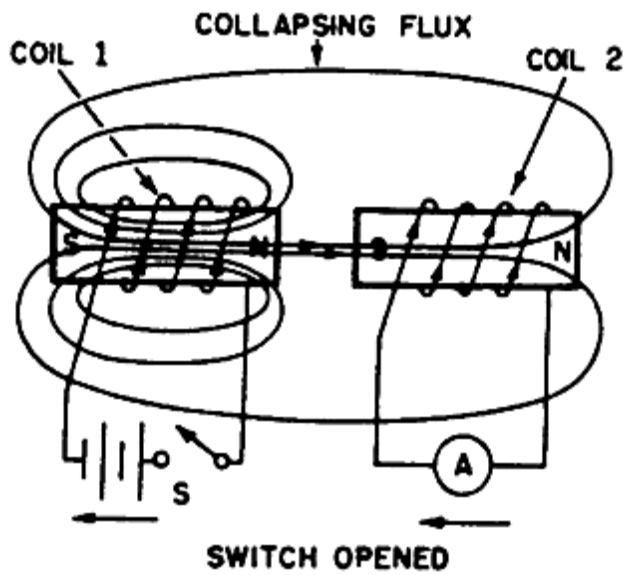


The effects of position of coils on mutual inductance

The mutual inductance can be increased greatly by mounting the coils on a common core, see figure below. Two coils are placed close together. Coil 1 is connected to a battery through switch S, and coil 2 is connected to an ammeter (A). When switch S is closed (view A), the current that flows in coil 1 sets up a magnetic field that links with coil 2, causing an induced voltage in coil 2 and a momentary deflection of the ammeter. When the current in coil 1 reaches a steady value, the ammeter returns to zero. If switch S is now opened (view B), the ammeter (A) deflects momentarily in the opposite direction, indicating a momentary flow of current in the opposite direction of coil 2. This current in coil 2 is produced by the collapsing magnetic field of coil 1.



(A)



(B)

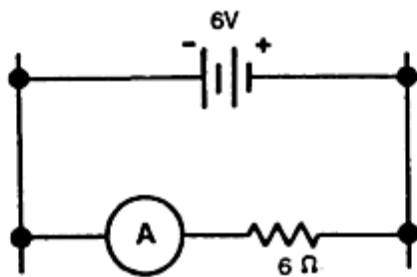
Mutual inductance

INTRODUCTION

This chapter explains the basics of circuit measurement. It covers devices used to measure voltage, current, resistance, power, and frequency. This chapter does not cover all the available testing instruments. Instead, it describes those instruments most commonly found on drilling equipment.

Because of the high cost of repair and replacement parts, the service technician must correctly diagnose and repair defects in electrical equipment. With the correct choice of meters, it is possible to determine any circuit values needed to troubleshoot the electrical system.

This chapter uses schematic symbols and schematic diagrams to explain terms. Many of these schematic diagrams represent a meter in the circuit, as shown in below.



Simple circuit representation

The current in a DC circuit with 6 volts across a 6-ohm resistor is 1 ampere. The circled A above is the symbol of the ammeter. An ammeter is a meter used to measure current in amperes. Thus, it is an ampere meter, or ammeter. The ammeter is measuring a current of 1 ampere with the voltage and resistance values given.

The quantities in an electrical circuit (voltage, current, and resistance) are important. By measuring the electrical quantities in a circuit, it is easier to understand what is happening in that circuit. This is especially true when troubleshooting defective circuits. By measuring the voltage, current, and resistance, the reason the circuit is not doing what it is supposed to do can be determined.

IN-CIRCUIT METERS

Some electrical devices have meters built into them. These are in-circuit meters, which monitor the operation of the circuit in which they are installed. Some examples of in-circuit meters are the generator or alternator meter on some automobiles; the voltage, current, and frequency meters on ship switchboards; and the electrical power meter that records the amount of power consumed in a building.

It is not practical to install an in-circuit meter in every circuit. However, it is possible to install an in-circuit meter in each critical or representative circuit to monitor the operation of a piece of equipment. A mere glance at an in-circuit meter on a control board is often sufficient to tell if the equipment is working properly. It is important to become familiar with in-circuit meter values during all facets of the system operation. Only after observing familiar "normal" readings can an engineer readily identify abnormal system operation.

An in-circuit meter will indicate when an electrical device is not functioning properly. The cause of the malfunction is determined by troubleshooting, the process of locating and repairing faults in equipment after they have occurred.

OUT-OF-CIRCUIT METERS

In troubleshooting, it is usually necessary to use an out-of-circuit meter that can be connected to the electrical equipment at various testing points. Out-of-circuit meters may be moved from one piece of equipment to another. They are generally portable and self-contained.

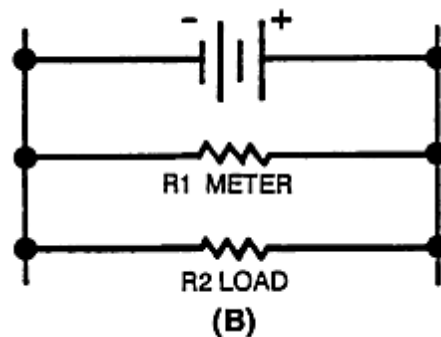
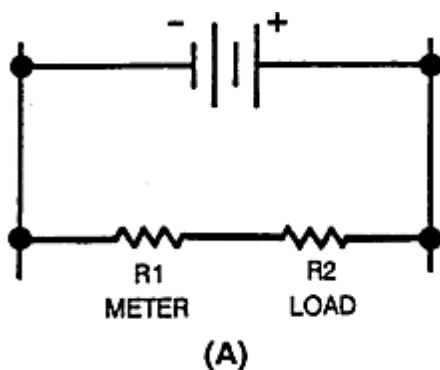
AMMETERS

An ammeter is a device that measures current. Since all meter movements have some resistance, a resistor will be used to represent a meter in the following explanations. DC circuits will be used for simplicity of explanation.

Multimeter Ammeters Connected in Series

In view A below, R1 and R2 are in series. The total circuit current flows through both resistors. The total circuit resistance R_t is --

$$R_t = R_1 + R_2$$



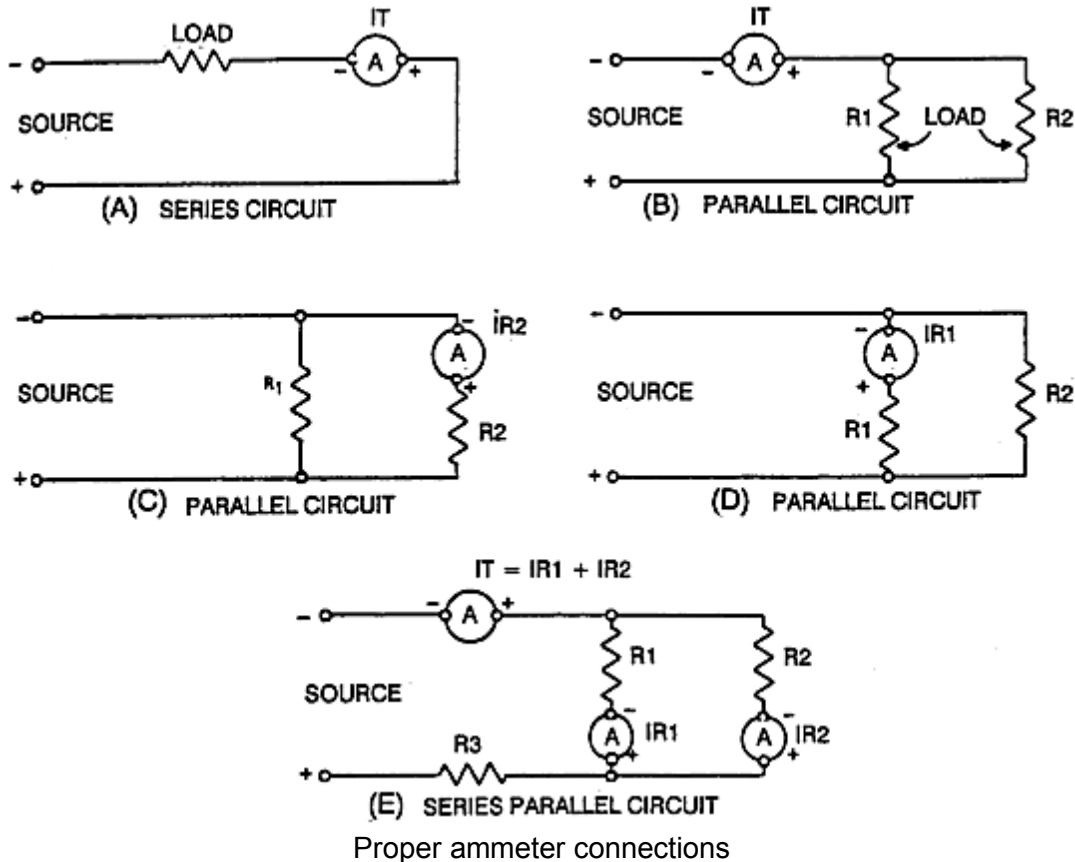
A series and a parallel circuit

In view B, R1 and R2 are in parallel. The total circuit current does not flow through either circuit. The total circuit resistance R_t is --

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

If R1 represents an ammeter, the only way in which total current will flow through the meter (and thus be measured) is to have the meter (R1) in series with the circuit load (R2), as shown in view A.

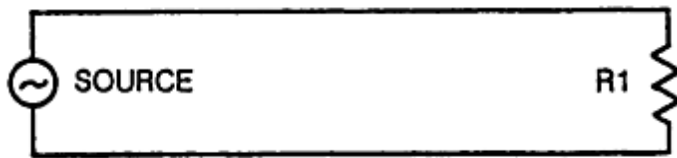
In complex electrical circuits, you are not always interested in the total circuit current. You may be interested in the current through a particular component. In any case, an ammeter is always connected in series with the circuit that will be tested. Below shows various circuit arrangements with ammeters properly connected for measuring current in various portions of the circuit.



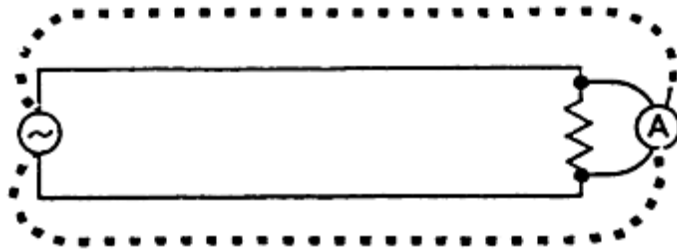
Connecting a multimeter ammeter in parallel with one of many electrical loads would give an incorrect reading. In this situation, current would be divided between the resistance in the loads and the very low resistance in the ammeter. It would not give the true total current moving through that section of the circuit.

Should the multimeter ammeter be connected across a constant potential source, such as the generator terminals, the minimal resistance in the ammeter would not be sufficient to restrict the majority of the generator's total current. This would be the equivalent of a shorted circuit. The excessive current draw through the meter movement would damage the meter. It may not be apparent at first, but if the ammeter is connected in parallel, across a higher resistance electrical load, a shorting situation results. Below shows a simple circuit and what happens when

a meter is connected across the high-resistance load. Even though current is proportionally divided between the meter and the load in a parallel circuit, the extreme difference in resistance will put most of the generator's available current through the meter. The total resistance (R_t) in a parallel circuit is always less than the smallest resistor. With less resistance in the circuit, an increased current will be delivered. Note the change in total current (I_t) from the initial circuit in to the total current with the addition of the improperly placed meter.



Initial circuit



Improperly placed ammeter in the circuit

$$E_t = 450 \text{ volts} \quad R_t = ? \quad I_t = ?$$

$$E_1 = 450 \text{ volts} \quad R_1 = 500 \text{ ohms} \quad I_1 = ?$$

(R_1 represents the electrical system loads. There is no meter connected in the circuit above.)

$$R_t = R_1 = 500 \text{ ohms}$$

$$I_t = \frac{E_t = 450 \text{ volts}}{R_t \quad 500 \text{ ohms}}$$

$$I_t = .9 \text{ amps}$$

The high circuit resistance keeps current from the generator down. Above shows the ammeter placed improperly in the circuit.

$$E_t = 450 \text{ volts} \quad R_t = ? \quad I_t = ?$$

$$E_1 = 450 \text{ volts} \quad R_1 = 500 \text{ ohms} \quad I_1 = ?$$

$$E_a = 450 \text{ volts} \quad R_a = 4 \text{ ohms} \quad I_a = ?$$

Above shows the meter incorrectly connected across a constant potential source. To say that the meter is connected only in parallel with the load can be misleading. For all electrical purposes, the meter is connected directly to the generator terminals (dotted lines). Current takes the path of least resistance. In this situation, the generator current flow will respond to the minimal resistance of the meter and increase its current output.

The new total resistance (R_t) of the circuit is found as follows:

$$R_t = \frac{R_1 \times R_a}{R_1 + R_a}$$

$$R_t = \frac{500 \text{ ohms} \times 4 \text{ ohms}}{500 \text{ ohms} + 4 \text{ ohms}}$$

$$R_t = 3.97 \text{ ohms}$$

The total resistance of this circuit has changed from 500 ohms to 3.97 ohms. With this drastic change in circuit resistance, generator current flow will increase accordingly:

$$I_t = \frac{E_t}{R_t}$$

$$I_t = \frac{450 \text{ volts}}{3.97 \text{ ohms}}$$

$$I_t = 113.4 \text{ amps}$$

Use the circuit rules and Ohm's Law to determine how this new current is divided between the load and the meter:

The load:

$$I_1 = \frac{E_1}{R_1}$$

$$I_1 = \frac{450 \text{ volts}}{500 \text{ ohms}}$$

$$I_1 = .9 \text{ amps}$$

The current through the load has not changed.

The ammeter:

$$I_a = \frac{E_a}{R_a}$$

$$I_a = \frac{450 \text{ volts}}{4 \text{ ohms}}$$

$$I_a = 112.5 \text{ amps}$$

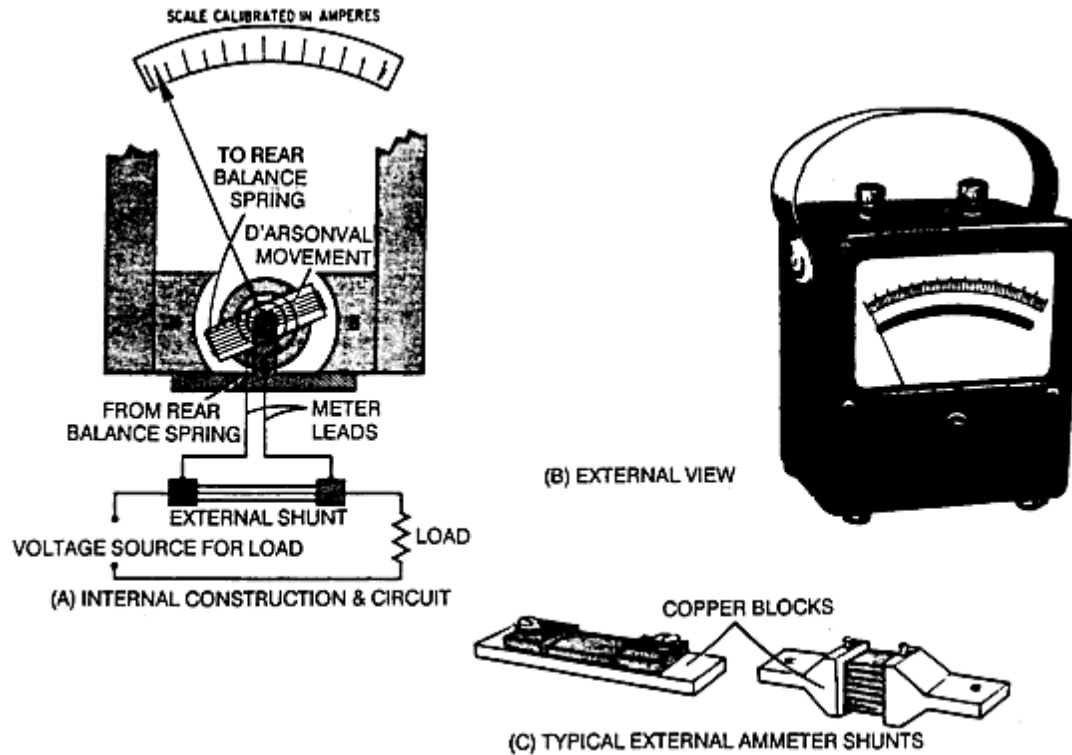
There is an excessive current flow through the meter.

Whenever you connect the ammeter portion of the multimeter, always break the circuit and connect your meter in series with the load. The small resistance of the meter is now added to the total electrical system loads (R_t) and will only serve to slightly decrease the total generator current output.

In-Circuit Ammeters Connected in Parallel

This section explains how in-circuit meters are connected in parallel for correct meter readings. This is another example of real-life applications of electrical circuit rules.

The ammeter in the instrument panel of some drills are not designed to interrupt the electrical system they are monitoring. A device known as a shunt or parallel path is used. Physically small meters, monitoring hundreds of amperes, could not withstand that amount of current without burning up their meter movements. The shunt is a calibrated parallel path that allows the majority of current to bypass the meter. A shunt is a relatively heavy-gauge copper bar, see figure below, readily able to conduct a great amount of current flow. The meter and the shunt are calibrated to each other so that the meter reacts to changes in current accurately. The shunt is always of a lesser resistance than the meter. The figure below shows how the shunt and ammeter are connected in the circuit.



An ammeter using an external shunt

If either the meter or the shunt are replaced separately, a component with the exact characteristics and ohm value must be ensured. If an ammeter or shunt of a differing value is installed, the meter reading would not be accurate. It would change the relationship between the meter and its parallel path. Otherwise, the meter may actually show a system charging properly when, in actuality, the system is deficient.

Ammeters are also connected to current transformers so that the current through the meter may be reduced accordingly. The same rules apply for replacing these current transformers and their meters that apply to the ammeter and its shunt.

Effects on Circuit Being Measured

The ammeter affects the operating characteristics of the circuit. When the meter is installed, the generator's total current (I_t) changes accordingly.

The current and voltage potential produced in the vessel's ship service generators are of such a large and deadly amplitude that a meter normally has minimal overall effects on the distribution system. However, like all components, devices, or conductors in the system, accumulative effects can be achieved. Conductor length, improper or corroded connections, and the introduction of meters (all otherwise insignificant loads) can contribute to an increased circuit resistance overall. For this reason, meter connections, as well as all device connections, must be made correctly to ensure conclusive troubleshooting

practices. Under normal circumstances, the introduction of meters into a circuit is only a concern when printed circuitry is addressed.

Ammeter Sensitivity

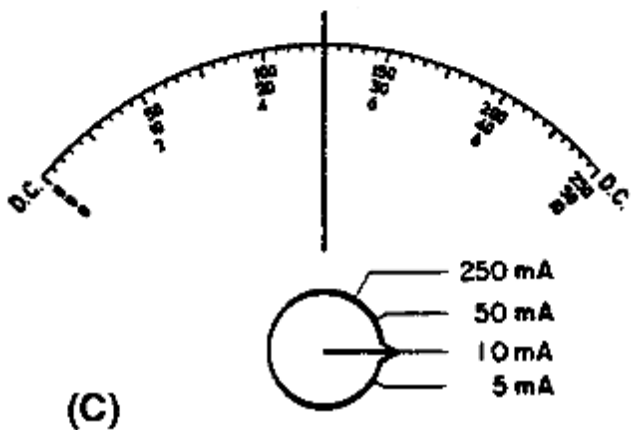
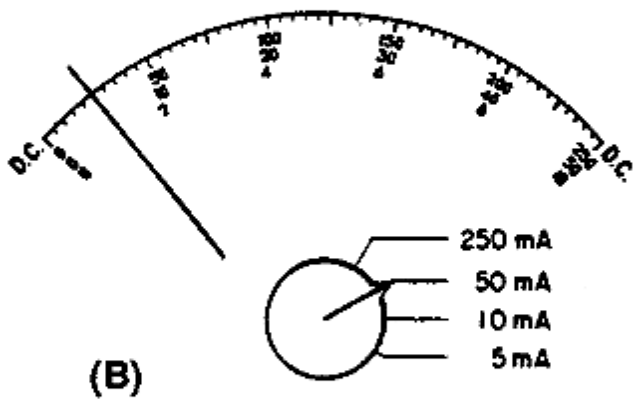
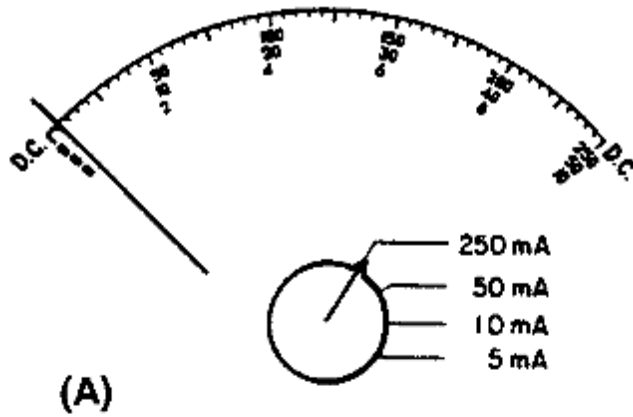
Ammeter sensitivity is the amount of current necessary to cause full-scale deflection (maximum reading) of the ammeter. The smaller the amount of current, the more sensitive the ammeter. For example, an ammeter with a maximum current reading of 1 milli-ampere would have a sensitivity of 1 milli-ampere. It would be more sensitive than an ammeter with a maximum reading of 1 ampere and a sensitivity of 1 ampere. Sensitivity ears be given for a meter movement, but ammeter sensitivity usually refers to the entire ammeter and not just the meter movement.

Range Selection

Today's meters are extremely sensitive to the ranges and types of currents tested. Before any range selection is ever made, determine whether the circuits are alternating or direct current circuits. If the incorrect type of current is chosen, the meter will become damaged, or its fuse will open (blow). In either case, the meter will be rendered ineffective.

The range switch is another very important part of the meter. To use the meter correctly, the range must be properly selected. If the current to be measured is larger than the meter scale selected, the meter movement will have excessive current and may become damaged. Therefore, it is important to always start with the highest range when using any meter.

If current can be measured on several ranges, use the range that results in a reading near the middle of the scale, see below. This is important enough for digital meters to use bar graphs to indicate what percentage of the meter scale is in use.

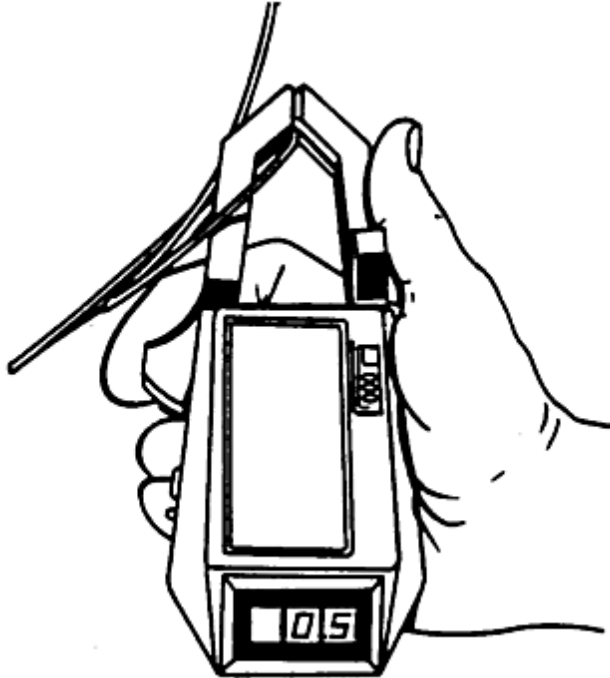


Reading an ammeter at various ranges

Clamp-on Ammeter

The clamp-on ammeter, shown below, may be of the digital or the analog (movable needle) type. This meter is restricted to AC circuits. At the top of the meter is a set of jaws used to surround the wire being tested. The beneficial part

of this meter is its ability to operate by detecting the magnetic field generated by the current moving in the conductor. This ability prevents the circuit from being opened and having to physically insert the meter. Current readings can also be taken from easily accessible locations in the circuit.



Clamp-on or induction ammeter

The clamp-on ammeter operates on the same principle that the transformer uses. The jaws of the ammeter are clamped around the conductor. The current-carrying conductor of the circuit being tested represents the primary winding. The jaws of the ammeter are the secondary winding. The current moving through the circuit generates its own magnetic field that surrounds the conductor. This AC magnetic field can induce a voltage and resulting current flow in the jaws of the ammeter.

The greater the current through the circuit conductor, the greater the magnetic field surrounding that conductor. Increased induction between the conductor and the ammeter means a greater current reading on the ammeter.

The conductor does not need to have the insulation stripped back. The only requirements for clamp-on ammeters are --

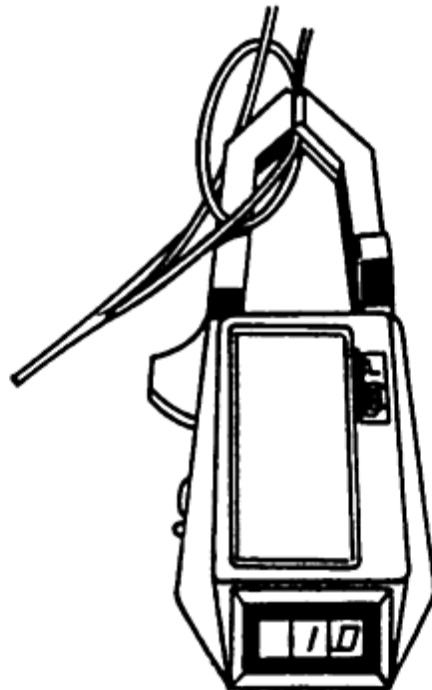
- The induction ammeter may only be used on AC systems. The DC electrical system does not have a constantly changing field. Therefore, without relative motion between the magnetic field of the conductor and

the jaws of the induction ammeter, it is impossible to induce an EMF in the meter movement.

- The ammeter must measure one conductor at a time. If the ammeter jaws are encircling both wires of a two-wire electrical system, there will be no reading. The current traveling from the power source to the load sets up a magnetic field in one direction. The same current returning to the power supply from the load creates a magnetic field in the opposite direction. These two magnetic fields cancel each other out.

Digital clamp-on ammeters, or induction ammeters, are provided with a peak hold setting. This lets the user have the highest transient current reading displayed and maintained for a period of time. This becomes very important in electrical systems because of the fluctuating currents when motors are started.

When checking a circuit where the value of current is far below the lowest reading on the meter scale, the wire can be looped around the jaws of the ammeter. Doubling the conductor passes through the meter jaws doubles the magnetic field strength. Since only one wire is used, the current is traveling in the same direction and the magnetic field is doubled. Divide the meter reading by two. This also applies when looping the conductor any number of times through the jaws of the ammeter. Simply divide the current reading by the number of loops for the actual conductor current.



Ammeter induction effects increased by number of wire loops

Ammeter Safety Precautions

When using an ammeter, certain precautions must be observed to prevent injury to yourself and others and to prevent damage to the ammeter or the equipment being serviced. The following list contains the minimum safety precautions for using an ammeter:

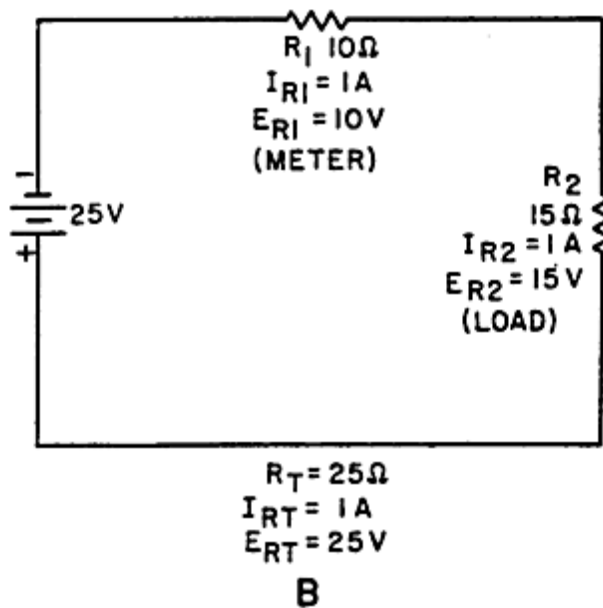
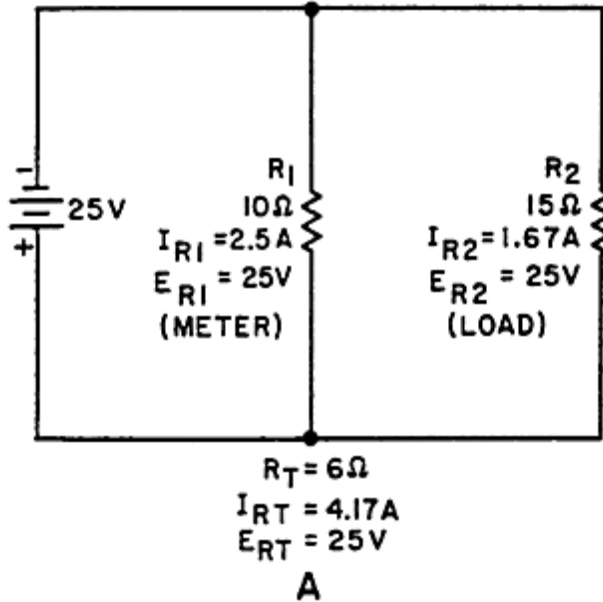
- Always connect multimeter ammeters in series with the circuit under test.
- Always start with the highest range on an ammeter (or any meter).
- De-energize and discharge the circuit completely before connecting or disconnecting the ammeter.
- In DC ammeters, observe the proper circuit polarity to prevent the meter from being damaged.
- Never use a DC ammeter to measure AC.
- Observe the general safety precautions of electricity.
- Ground all metal case meters to the hull of the ship. Many old metal case meters provide a grounding jack for this purpose.

VOLTMETERS

The voltmeter measures the voltage in a circuit or any EMF-producing component. The meter more accurately measures any difference in potential between any two places to which the meter leads are connected.

Voltmeters Connected in Parallel

Ammeters or their shunts are always connected in series with the electrical load. Voltmeters are always connected in parallel. The following figures use resistors to represent the voltmeter movement. Since a meter movement can be considered as a resistor, the concepts shown are true for voltmeters and resistors. For simplicity, DC circuits are shown, but the principles apply to both AC and DC voltmeters.



Current and voltage in series and parallel circuits

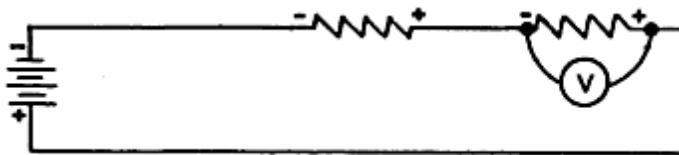
When a voltmeter is connected across or parallel to a load, the measurement value indicates how much of the voltage was used up pushing current through the electrical load. Voltage is easily referred to as difference in potential here. Connecting the voltmeter across the terminals of a generator measures the difference in potential or the difference between the area where negative electrons are, as opposed to the area where they are not (the area of positive ions). If the same combination of negative electrons and positive ions were at

each terminal of the generator, then there would be no difference in potential, or zero voltage.

To have a difference in potential, there must be an electron imbalance somewhere. When a generator is operating properly, negative electrons are excited. The negative electrons leave their atoms and accumulate at one terminal of the generator. Positive ions accumulate at the other terminal. Both these electrical particles have opposite magnetic polarities. As long as the generator keeps operating, the only way these negative electrons can recombine with the positive ions is through the electrical distribution system. Voltage is a measurement of how great the difference in potential is. The greater the difference in potential, the greater the force available to push the electrons to the positive ions.

When a load is placed in the circuit, its resistance determines how many electrons will be able to leave the negative terminal during any given period of time. Since a quantity of electrons exists on each side of the load, the difference between them is the difference in potential dropped from the original generator voltage source. If there is a high resistance, such as an open condition, then there would be maximum electrons on one side of the load, and no electrons on the other side of the load. This would be a maximum voltage reading. A negligible resistance, such as a good fuse, would have the same amount of electrons on each side of the fuse element. There would then be no difference in potential and 0 voltage reading.

A good example of this is the series circuit below, which shows two loads in series with the generator. Place a voltmeter across the R2 load. Measure the difference in potential between the negative side of the R2 load and the positive side of the R2 load.



Voltage drops

$E_t = 120 \text{ volts}$	$R_t = ?$	$I_t = ?$
$R_1 = 10 \text{ ohms}$	$I_1 = ?$	$E_1 = ?$
$R_2 = 20 \text{ ohms}$	$I_2 = ?$	$E_2 = ?$

To determine the electrical values, find the total resistance of the circuit (R_t):

$$R_t = R_1 + R_2 = 10 \text{ ohms} + 20 \text{ ohms} = 30 \text{ ohms}$$

Since this is a series circuit and current is constant, find the total current (I_t) allowed to flow through the circuit in one second:

$$I_t = \frac{E_t}{R_t}$$

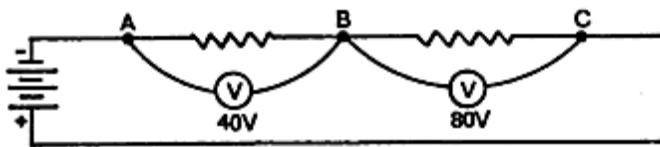
$$I_t = \frac{120 \text{ volts}}{30 \text{ ohms}}$$

Do not be concerned with the minimal influence the meter has on the circuit, but transcribe the current value to I_1 and I_2 .

Using the voltmeter, there is a reading of 80 volts across the R_2 resistance. By using Ohm's Law, verify this reading:

$$E_2 = I_2 \times R_2 = 4 \text{ amps} \times 20 \text{ ohms} = 80 \text{ volts}$$

This is the difference in potential across the R_2 resistance. When the meter is repositioned to read the voltage across R_1 , a difference in potential between the negative side and the positive side of the resistance is registered. In this case, there are 40 volts. Below figure effectively shows the differences in potential.



Differences in potential

At point A, there is full generator voltage available (120 volts). At point B, 80 volts are left. This means that the R_1 resistance was sufficient enough to use up, or drop out of the circuit, 40 volts when moving 4 coulombs of electrons through the 10-ohm resistance in one second. At point C, no voltage is left after completing all the work pushing electrons through the resistances. The voltmeter does not read the points A or B or C, but rather a difference between points A and B as well as between points B and C. Since voltage is the potential force and a difference between each side of a resistor exists, a difference in the potential (or voltage) is recorded.

Sensitivity of Voltmeters

Voltmeter sensitivity is expressed in ohms per volt (ohms/volt). It is the resistance of the voltmeter at full-scale reading in volts. Since the voltmeter's resistance does not change with the position of the pointer, the total resistance of the meter

is the sensitivity multiplied by the full-scale reading. The higher the sensitivity of a voltmeter, the higher the voltmeter's resistance. Since high-resistance voltmeters have less loading effects on circuits, a high-sensitivity meter will provide a more accurate voltage reading.

Voltmeter Safety Precautions

Just as with ammeters, voltmeters require safety precautions to prevent injury to personnel and damage to the voltmeter or equipment. The following is a list of the minimum safety precautions for using a voltmeter:

- Always connect voltmeters in parallel.
- Always start with the highest range of a voltmeter.
- In DC voltmeters, observe the proper circuit polarity to prevent damage to the meter.
- Never use a DC voltmeter to measure AC voltage.
- Observe the general safety precautions of electricity.

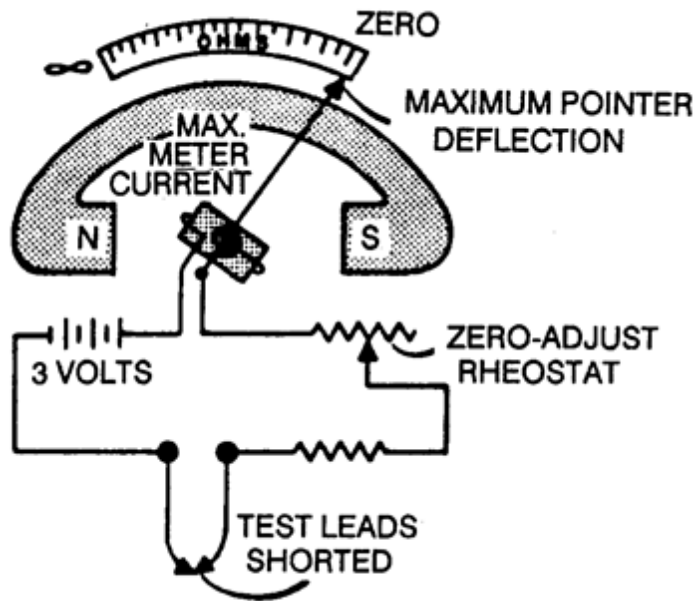
OHMMETERS

The two instruments most commonly used to measure resistance are the ohmmeter and the megohmmeter (megger).

The ohmmeter is widely used to measure resistance and check the continuity of electrical circuits and components. Using an ohmmeter to determine continuity provides the engineer with information on the circuit's ability to conduct current. The ohmmeter is inaccurate below the 3 to 5-ohm level. Its range usually extends to only a few megohms.

The megger is widely used for measuring insulation resistance, such as between a wire and another surface on the other side of the insulation. The range of a megger extends to more than 1,000 megohms.

The ohmmeter consists of a DC ammeter, with a few added features. The added features are a DC source of potential (usually a 9-volt battery) and one or more resistors (one of which is variable). Below shows a simple ohmmeter circuit.

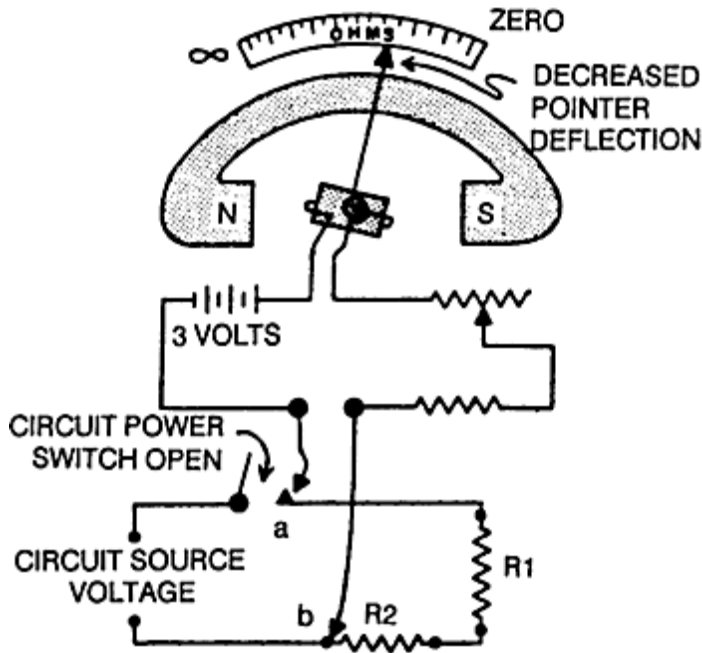


Simple ohmmeter circuit

The ohmmeter's pointer deflection is controlled by the amount of battery current passing through the moving coil. Before measuring the resistance of an unknown resistor or component, the test leads of the ohmmeter are first shorted together. With the leads shorted, the meter is calibrated for proper operation on the selected range. While the leads are shorted, meter current is maximum, and the pointer deflects a maximum amount, somewhere near the zero on the ohms scale. Consult the manufacturer's manual to zero the ohmmeter. The AN/PSM-45 and AN/PSM-45A digital multimeter calibrates automatically when the test leads are shorted together. Analog meters have a variable resistor (rheostat) that requires manual adjustment to zero (with the test leads shorted together). When the test leads are separated, the meter should indicate infinity, or the meter's maximum resistance reading. Always turn the ohmmeter off when it is not in use to prevent the leads from accidentally discharging the meter battery.

Ohmmeter Use

After the ohmmeter is adjusted for zero reading, it is ready to be connected in a circuit to measure resistance. Below shows a typical circuit and ohmmeter arrangement.



Measuring circuit resistance with an ohmmeter

The circuit must always be de-energized. This prevents the source voltage from being applied across the meter, which could damage the meter movement.

The test leads of the ohmmeter are connected in series with the circuit to be measured. This causes the current produced by the 9-volt battery of the meter to flow through the circuit being tested. Assume that the meter test leads are connected at points a and b above. The amount of current that flows through the meter coil will depend on the total resistance of resistors R1 and R2 and the resistance of the meter. Since the meter has been pre-adjusted (zeroed), the amount of coil movement now depends entirely on the resistance of R1 and R2. The inclusion of R1 and R2 raises the total series resistance, decreasing the current, and thus decreasing the pointer deflection. The pointer will now come to rest as a scale figure indicating the combined resistance of R1 and R2. If R1 and R2, or both, were replaced with resistors having a larger value, the current flow in the moving coil of the meter would be decreased further. The deflection would also be further decreased, and the scale indication would read a still higher circuit resistance. Movement of the moving coil is proportional to the amount of current flow.

When using an ohmmeter in complicated circuits, the circuit must be disconnected at the component being checked. If other parallel paths are accidentally measured with the ohmmeter, the resistance reading will be less than the smallest resistance, providing an incorrect interpretation of the test results.

Ohmmeter Ranges

The amount of circuit resistance to be measured may vary over a wide range. In some cases, it may only be a few ohms; in others, it may be as great as 1,000,000 ohms (1 megohm). To enable the meter to indicate any value being measured with the least error, scale multiplication features are used in most ohmmeters. There are various scale indicators for checking diodes and capacitors as well. The many different meters require the specific information attained from their technical manual. TM 11-6625-3199-14 is the reference for the AN/PSM-45A multimeter. This is required reading before trying to operate this multimeter.

Ohmmeter Safety Precautions

The following safety precautions and operating procedures for ohmmeters are the minimum necessary to prevent injury and damage:

- Be certain the circuit is de-energized and discharged before connecting an ohmmeter.
- Do not apply power to a circuit while measuring resistance.
- When finished using the ohmmeter, switch it to the OFF position.
- Always adjust the ohmmeter for zero after you change ranges and before making resistance measurement.

MULTIMETER

A multimeter is the most common measuring device in the Army. The name multimeter comes from multiple meter, and that is exactly what it is. It combines a DC ammeter and voltmeter, an AC ammeter and voltmeter, and an ohmmeter.

Digital Multimeters

Several models of digital multimeters have been fielded for use in the Army. Always follow instructions for use in the applicable TMs. Digital multimeters have a display screen and give their readings as numerals on the screen, usually using liquid crystal display (LCD).

Analog Multimeters

Analog multimeters are those with d'Arsonval movements using a needle and scale. Most analog multimeters have been replaced by digital multimeters, but the service technician may still be issued analog multimeters.

Analog multimeters have a mirror built into the scale to aid in reducing parallax error, see below.



Page 20 of 20

INTRODUCTION

An electrical unit is built with great care to ensure that each separate electrical circuit is fully insulated from all the others. This is done so that the current in a circuit will follow its intended path. Once the unit is placed into service, many things can happen to alter the original circuitry. Some of these changes can cause serious problems if they are not detected and corrected in time. While circuit protection devices cannot correct the abnormal current condition, they can indicate that an abnormal condition exists and protect personnel and circuits from that condition. This chapter explains circuit conditions that require protection devices and the type of protection devices used.

A circuit protection device is used to keep an undesirable current, voltage, or power surge out of a given part of an electrical circuit.

- Wiring - general reference used for the conductor that forms the link between the power source and the loads or any portion of that link.
- Bus bars - the copper bars located inside the console or boxes to electrically connect multiple devices.
- Feeder, branch, or connecting boxes - watertight boxes that permit the joining of two or more continuous electrical wires or feeders.
- Branch circuits - that portion of wiring extending beyond the final overcurrent device protecting the circuit. Branch circuits are cables that extend from the distribution panel to the loads.
- Non-motor loads - circuits that contain mostly resistive loads, such as lighting systems.

CIRCUIT CONDITIONS REQUIRING PROTECTION DEVICES

Many unwanted things can happen to the electrical circuits after they are in use. Previous chapters contained information on how to measure circuit values. Some changes in circuit values can cause conditions that are dangerous to the circuit itself or to people working near the circuits. Potentially dangerous conditions that require circuit protection are direct shorts, excessive current, and excessive heat.

Direct Shorts

One of the most serious troubles that can occur in a circuit is a direct short. Another term for this condition is a short circuit. These terms describe a situation in which full system voltage comes in direct contact with the ground or return side of the circuit bypassing the load. This establishes a path for current flow that contains only the negligible resistance present in the wires carrying the current. This is an unintentional path of current flow. In certain situations, a direct short can terminate part of the vessel's power supply.

According to Ohm's Law, if the resistance in a circuit is extremely small, the current will be extremely large. Therefore, when a direct short occurs, there will be a very large current through the wires. Suppose, for instance, that the two opposite polarity leads from a battery came in contact with each other. If the leads were uninsulated at the point of contact, there would be a direct short. Any other electrical component that could have received current from the battery is now shunted out. Shunting a component out means that there is a parallel path around the component. The minimal resistance of the direct short calls for the maximum current available from the batteries. In addition, the other high-resistance electrical loads that would have received current from the batteries now become inoperative. A direct short of this kind could result in a battery explosion.

The battery cables in this example would be very large conductors capable of carrying very high currents. Most wires used in electrical circuits are much smaller, and their current-carrying capacity is quite limited. The size of the wire used in any given circuit is determined by ambient temperature, cost, and the amount of current the wire is expected to carry under normal operating conditions. Therefore, any current flow in excess of normal would cause a rapid generation of heat in the wire.

If the excessive current flow caused by the direct short is left unchecked, the heat in the wire will continue to increase until a part of the circuit burns. Perhaps part of the wire will melt and open the circuit. In this case, only the original casualty is damaged. However, much greater damage may result. The heat in the wire can char and burn the insulation of the wire and that of other wires bundled with it. This can cause more shorts. If fuel or oil is near any of these hot wires, a disastrous fire will be started.

Excessive Current

The circuit current can increase without a direct short. If a resistor changes value, the total circuit resistance will also change in value. The resistance can come from many sources. If a resistor decreases in ohm value, the total circuit resistance (R_t) decreases. If an inductor has a partial short in its windings, inductive reactance (resistance) decreases. Any of these conditions will increase circuit current (I_t). Since the circuit wiring and components are designed to withstand normal circuit current, an increase in current could cause overheating, just as in the case of the direct short. Therefore, excessive current without a direct short will cause the same problems as a direct short.

Excessive Heat

Excessive heat destroys electrical insulation and contact surfaces and reduces component longevity. In addition to the presence of amperage and its relationship with temperature, two other problems generate the heat that causes electrical malfunctions:

- Motor cleanliness. Dirty and oily machine windings and ventilation screens prevent the transfer of heat from the current-carrying conductors. The heat accumulates and eventually deteriorates the insulating material destroying the component.
- Excessive ambient temperatures. Electrical devices and components are selected according to the environment of their placement. A component designed for 40° C applications cannot be placed in an engine room (50° C environment) without detrimental effects. Excessive ambient temperatures cause the same electrical casualty as the heat from excessive current.

CIRCUIT PROTECTION (OCP)

All of the above conditions are potentially dangerous and require the use of circuit protection devices or over-current protection (OCP). Circuit protection devices are used to stop current flow by opening the circuit. To do this, a circuit protection device must always be connected in series with the circuit it is protecting.

A circuit protection device operates by opening and interrupting current to the circuit. The opening of a protective device shows that something is wrong in the circuit and should be corrected before the power is restored. When a problem exists and the protection device opens, the device should isolate the faulty circuit from the other unaffected circuits in time to protect unaffected components in the faulty circuit. The protection device should not open during normal circuit operation.

Three types of circuit protection devices are fuses, fusible link, and circuit breakers.

A fuse is a simple circuit protection device. It derives its name from the Latin word "fusus," meaning to melt. Fuses have been employed since the invention of electricity. The earliest type of fuse was simply a bare wire between two connections. The wire was smaller than the conductor it was protecting and, therefore, would melt before the conductor it was protecting was damaged. Some copper fuse link types are still in use, but most fuses no longer use copper as the element (the part of the fuse that melts). After changing from copper to other metals, tubes or enclosures were developed to hold the melting metal. The enclosed fuse made possible the addition of filler material, which helps contain the arc that occurs when the element melts.

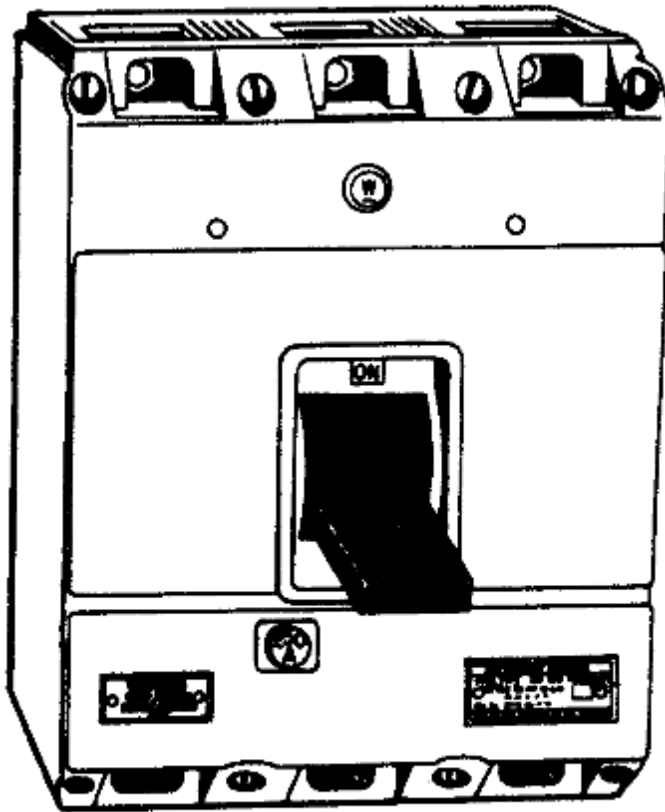
WARNING

Never take anything for granted in an electrical system. There are many possible circumstances of which you are not yet aware. Never work on a live circuit and never "tempt fate."

WARNING

When servicing electrical circuits, always remove all fuses in that circuit.

While a fuse protects a circuit, it is destroyed in the process of opening the circuit. Once the problem that caused the increased current or heat is corrected, a new fuse must be placed in the circuit. A circuit protection device that can be used more than once solves the problem of replacement fuses. Such a device is safe, reliable, and tamperproof. It is also re-settable, so it can be reused without replacing any parts. This device, shown below, is called a circuit breaker because it breaks, or opens, the circuit.

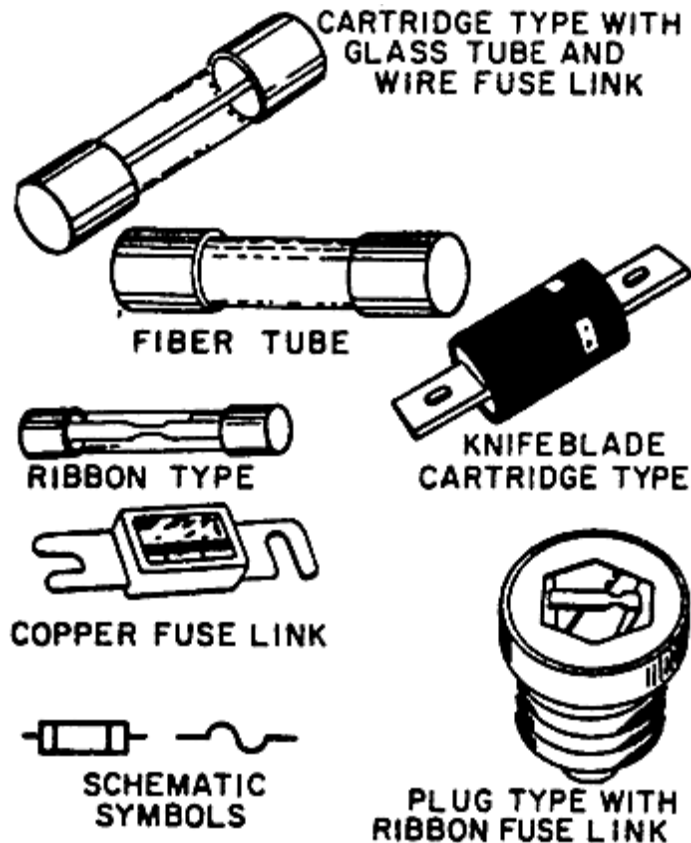


 **SCHEMATIC**  **SYMBOLS**

Commercial type 3-pole circuit breaker

FUSES

Fuses are manufactured in many shapes and sizes. In addition to the copper fuse link, the figure below shows other fuse types. Although there is a variety of fuses, there are basically only two types: plug-type fuses and cartridge fuses. Both types use either a single wire or a ribbon as the fuse element (the part of the fuse that melts). The condition (good or bad) of some fuses can be determined by visual inspection. The condition of other fuses can only be determined with a meter.

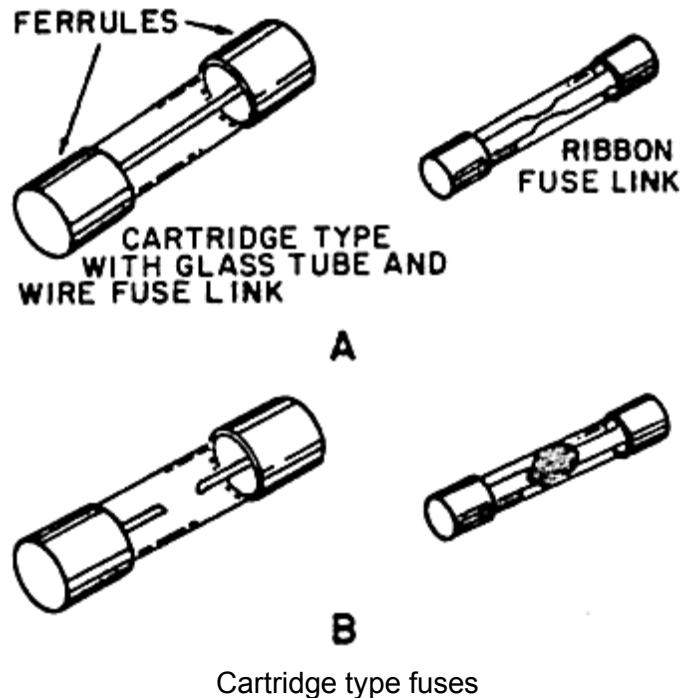


Typical fuses and schematic symbols

The threaded plug-type fuses tend to vibrate out of place, leaving the electrical circuit de-energized, and for the most part have become obsolete.

In the cartridge fuse, the fuse link is enclosed in a tube of insulating material with metal ferrules at each end (for contact with the fuse holder). Some common insulating materials are glass, bakelite, or a fiber tube filled with insulating powder.

The figure below shows a glass tube fuse. View A shows the fuse link and the metal ferrules. View B shows a glass tube fuse that is open. The open fuse link could appear either of the ways shown in view B.



Cartridge fuses are available in a variety of physical sizes. They are used in many different circuit applications. They can be rated at voltages up to 10,000 volts and have a current rating from .002 ampere to more than 10,000 amperes. Cartridge fuses may also be used to protect against excessive heat and open at temperatures from 165 to 410 F.

All circuits protected by fuses must have a fuse for each current-carrying conductor. Even though one break in the electrical circuit is sufficient to stop all current flow to the equipment, a difference in potential exists between the wire connected to the power supply and the drill chassis. Although the chassis is not an intentional current carrier, the potential from the generator will complete a path to a natural ground.

Rating Fuses

The physical size and type of a fuse can be determined by looking at it. However, to select the proper fuse, other conditions must be known. Fuses are rated by current, voltage, and time-delay characteristics.

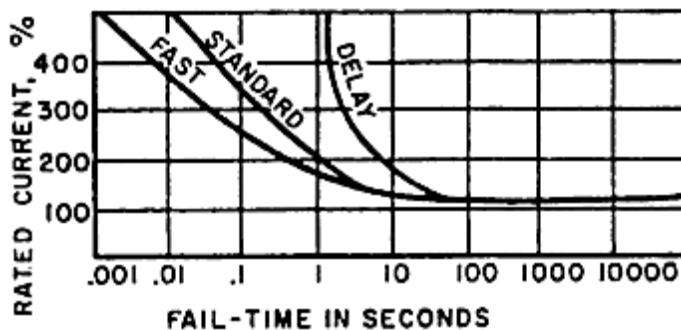
To select the proper fuse, consult the applicable technical, regulatory, or manufacturer's manuals. Do not take for granted that the fuse being removed is in fact the type of fuse that should be reinstalled.

Current Rating. The current rating of a fuse is a value expressed in amperes. It represents the current that the fuse will carry without opening. The current rating of a fuse is always indicated on the fuse ferrules.

Voltage Rating. The voltage rating of a fuse is not an indication of the voltage the fuse is designed to withstand while carrying current. The voltage rating indicates the ability of the fuse to quickly extinguish the arc after the fuse element melts and the maximum voltage the open fuse will block. In other words, once a fuse has opened, any voltage less than the voltage rating of the fuse will not be able to jump the gap of the open fuse. Because of the way the voltage rating is used, it is a maximum voltage value. Always select a fuse with a voltage rating equal to or greater than the voltage in the circuit to be protected.

Time-Delay Rating. Many types of electrical circuits and components require customized protection. Some components are very current-sensitive and require fast-acting protection. In other instances, it is unnecessary and impractical to provide a close tolerance overcurrent protection when the circuit normally experiences momentary current increases without a time delay. A time delay prevents nuisance fuse openings and protects the circuit after the specified time limit has elapsed. The three time-delay ratings are delay, standard, and fast.

The figure below shows the differences between delay, standard, and fast fuses. It shows that if a 1-ampere rated fuse has 2 amperes of current through it (200 percent of the rated value), a fast fuse would open in about 0.7 second. A standard fuse would open in about 1.5 seconds, and a delay fuse would open in about 10 seconds. In each of the fuses, the time required to open the fuse decreases as the rated current increases.



Time requirement for fuse to open, I^2t

A delay, or slow blowing, fuse has a built-in delay that is activated when the current through the fuse is greater than the current rating of the fuse. This fuse will allow temporary increases in current (surge) without opening. Some delay fuses have two elements, which allow a very long time delay. If the overcurrent condition continues, a delay fuse will open, but it will take longer to open than the

standard or fast fuse. Delay fuses are used for circuits with high surge or starting currents such as AC motors and transformers.

Standard fuses have no built-in time delay. Also, they are not designed to be very fast acting. Standard fuses are sometimes used to protect against direct shorts only. They may be wired in series with a delay fuse to provide faster direct short protection. For example, in a circuit with a 1-ampere delay fuse, a 5-ampere standard fuse may be used in addition to the delay fuse to provide faster protection against a direct short.

A standard fuse can be used in any circuit where surge currents are not expected, and a very fast opening of the fuse is not needed. A standard fuse opens faster than a delay fuse, but slower than a fast rated fuse. Standard fuses can be used for automobiles, lighting circuits, and some electrical power circuits.

Fast fuses open very quickly when current through the fuse exceeds the current rating of the fuse. Fast fuses protect components that are sensitive to increased current. A fast fuse will open faster than a delay or standard fuse. Fast fuses are used to protect delicate equipment and solid state devices.

Checking and Replacing Fuses

A fuse, if properly selected, should not open unless something is wrong in the circuit the fuse is protecting. When a fuse is found open, the reason the fuse is open must be determined. Replacing the fuse is not enough.

Before looking for the cause of an open fuse, determine if the fuse is open. There are several ways of checking for an open fuse. Some fuses and fuse holders have indicators built in. Also, a multimeter can be used to check fuses.

Using a Meter. The only sure method of determining if a fuse is open is to use a meter. An ohmmeter can be used to check for an open fuse by removing the fuse from the circuit and checking for continuity (0 ohm) through the fuse. If the fuse is not removed from the circuit and the fuse is open, the ohmmeter may measure the circuit resistance. A low resistance might lead you to think the fuse is good.

A voltmeter can also be used to check for an open fuse. The measurement is taken between each end of the fuse and the power supply end of another fuse. If voltage is present on both sides of the fuse (from the voltage source and to the load), the fuse is not open. Another method commonly used is to measure across the fuse with the voltmeter. If no voltage is indicated on the meter, the fuse is good (not open). There is no voltage drop unless there is a resistance. An open fuse has a great deal of resistance.

To check for voltage on a clip-type fuse holder, check each of the clips. The advantage of using a voltmeter to check for an open fuse is that the circuit does not have to be de-energized, and the fuse does not have to be removed.

Observing Safety Precautions. Since a fuse has current through it, be very careful when checking for an open fuse to avoid being shocked or damaging the circuit. The following safety precautions and prudent maintenance practices will protect you and the equipment you are using:

- Turn power off and discharge the circuit before removing the fuse.
- Use a fuse puller, shown below, when removing a large fuse from a fuse holder.
- When checking a fuse with a voltmeter, be careful to avoid shocks and short circuits.



Fuse puller

Replacing Open Fuses

After an open fuse is found and the trouble that caused the fuse to open has been corrected, the fuse must be replaced. Before replacing the fuse, be certain that the replacement fuse is the proper type and that it fits correctly.

To be certain a fuse is the proper type, consult the technical manual for the equipment. The parts list gives the proper fuse identification for a replacement fuse. Obtain and use the exact fuse specified.

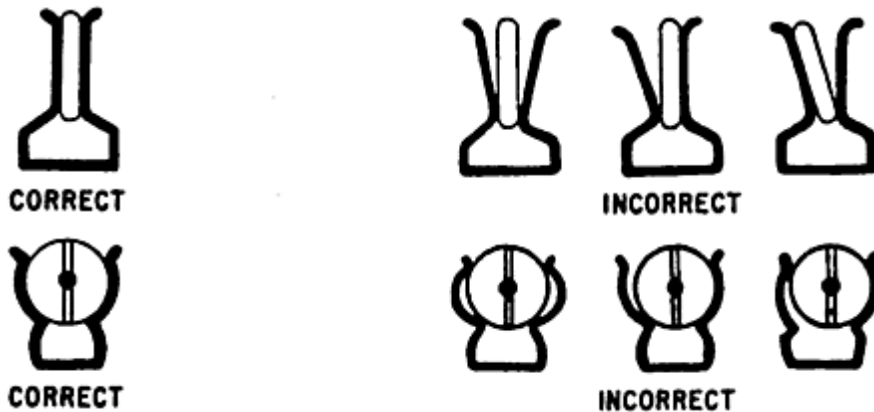
If a direct replacement cannot be obtained, use the following guidelines:

- Never use a fuse with a higher current rating, a lower voltage rating, or a slower time-delay rating than the specified fuse.
- Use the best substitution for a fuse with the same current and time-delay ratings and a higher voltage rating. (If a lower current rating or a faster time-delay rating is used, the fuse may open under normal circuit conditions.)
- Use substitute fuses that have the same style (physical dimensions) as the specified fuse.
- Regularly inspect the circuit and substitute fuse during operation.
- Return the circuit to a like-new condition when arriving in the next port.

When a proper replacement fuse has been found, make certain it will fit correctly in the fuse holder. If the fuse holder is corroded, the fuse will not conduct current

properly and will increase resistance or heating. Clean corroded terminals with fine sand paper so that all corrosion is removed. Do not lubricate the terminals. If the terminals are badly pitted, replace the fuse holder.

If the fuse clips do not make complete contact with the fuse, try bending the clips back into shape. If bending cannot repair the clips, replace the fuse holder or clip clamps. See examples below.



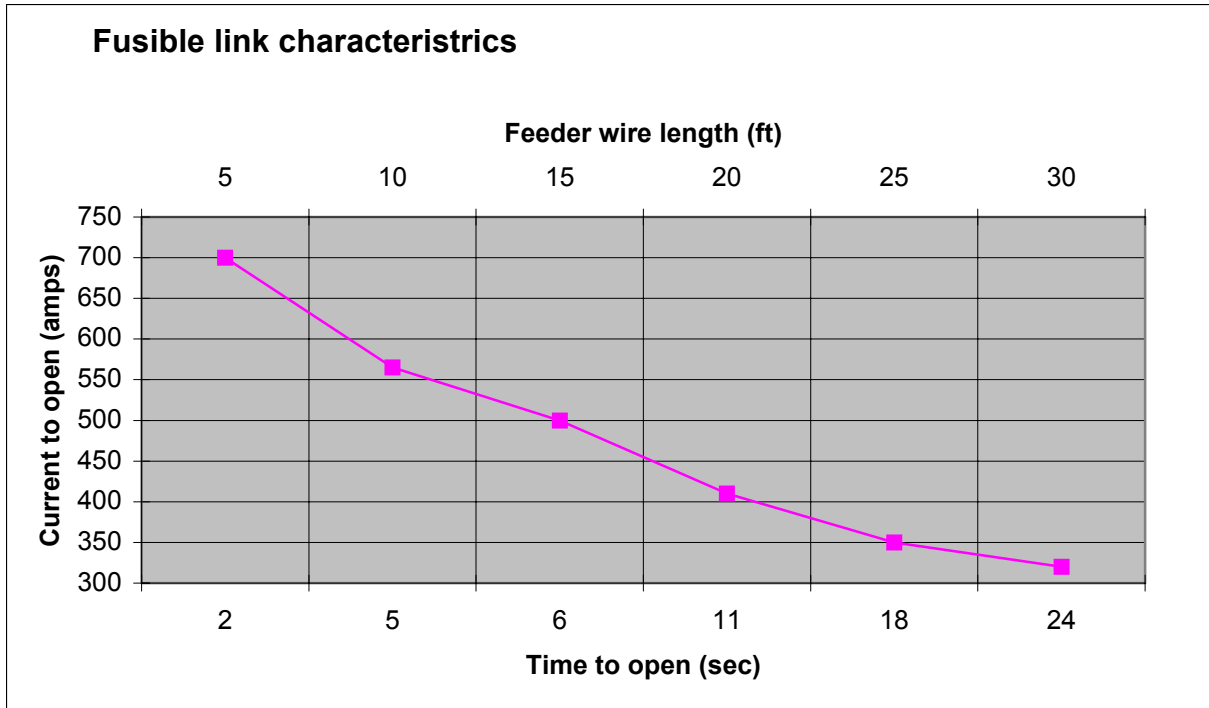
Contact between clips and fuses

FUSIBLE LINK (56999360)

Fusible links have been used on rotary drill products since 1983 to provide electrical systems wire harness protection against electrical short circuit conditions not protected by circuit breakers and/or fuses. Once the fuse links were implemented across the product line, wire harness failures became non existent.

The fusible link used on rotary drill products DC voltage systems is a tinned, stranded conductor, nine inches long, insulated with a thermosetting material. The link is designed so there is no burning of insulation in the first five seconds of fault current application and no secondary arcing after the conductor has separated. For maximum protection, the link is connected to the DC voltage source (battery and alternator) as close as is practical.

A number 12-AWG (American Wire Gauge) link is used with the wiring harness systems on rotary drill DC voltage system products to protect the 8-AWG feeder wire. Because of this size, the resistance per unit length will be larger in the fusible link and heat dissipated along the link will be greater than in other sections of the voltage source cable. The heat generated starts to melt the core at a location in the link. The copper core becomes fused and molten. Capillary action draws the copper away from the hot spot, which causes the area to neck. This action continues until the core is completely separated, at this point no current will flow. See chart below for typical fusible link characteristics.



CIRCUIT BREAKERS

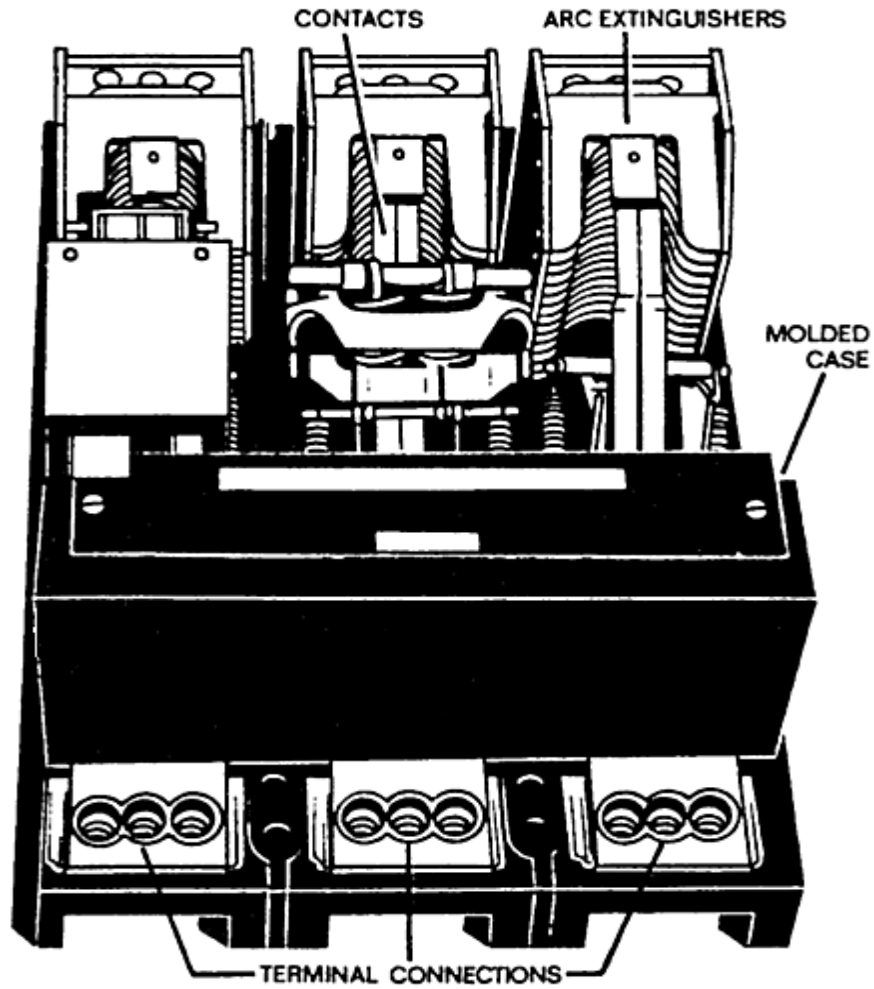
A circuit breaker is a circuit protection device that, like the fuse, will stop current in the circuit if there is a direct short, excessive current, or excessive heat. Unlike a fuse, a circuit breaker is reusable. The circuit breaker does not have to be replaced after it has opened and broken the circuit. Instead of replacing the circuit breaker, it is reset.

Circuit breakers can also be used as circuit control devices. By manually opening and closing the contacts of a circuit breaker, the power can be selectively switched on and off. This is of practical use when trying to isolate a circuit ground.

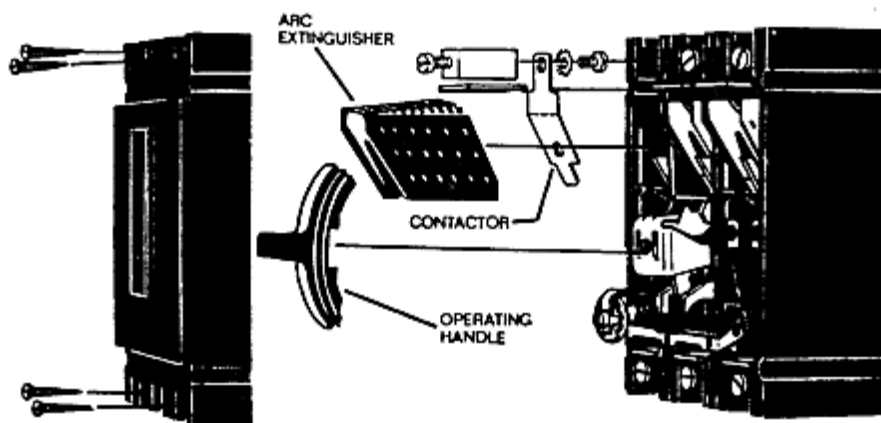
Circuit breakers are available in a great variety of sizes and types. The circuit breaker rating should be the value of current the breaker will carry continuously without exceeding the specific temperature rise.

CIRCUIT BREAKER COMPONENTS

Circuit breakers have five main components, as shown below. The components are the frame, the operating mechanism, the arc extinguishers, the terminal connectors, and the trip elements.



Circuit breaker components

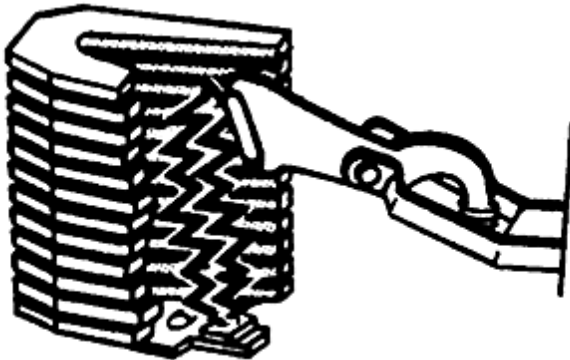


Circuit breaker construction

The Frame. The frame provides an insulated housing and is used to mount the circuit breaker components. The frame determines the physical size of the circuit breaker and the maximum allowable voltage and current.

The Operating Mechanism. The operating mechanism provides a means of opening and closing the breaker contacts (turning the circuit on and off). The toggle mechanism is the quick-make, quick-break type, which means the contacts snap open or closed quickly, regardless of how fast the handle is moved. In addition to indicating whether the breaker is on or off, the operating mechanism handle indicates when the breaker has opened automatically (tripped) by moving to a position between on and off. To reset the circuit breaker, first move the handle to the OFF position, then to the ON position.

Arc Extinguishers. The arc extinguisher confines, divides, and extinguishes the arc drawn between the contacts each time the circuit breaker interrupts current. The arc extinguisher is actually a series of contacts that open gradually, dividing the arc and making it easier to confine and extinguish. This is shown in below. Arc extinguishers are generally used in circuit breakers that control a large amount of power, such as those found in distribution switchboards. Small power circuit breakers, such as those found in lighting panels, may not have arc extinguishers.

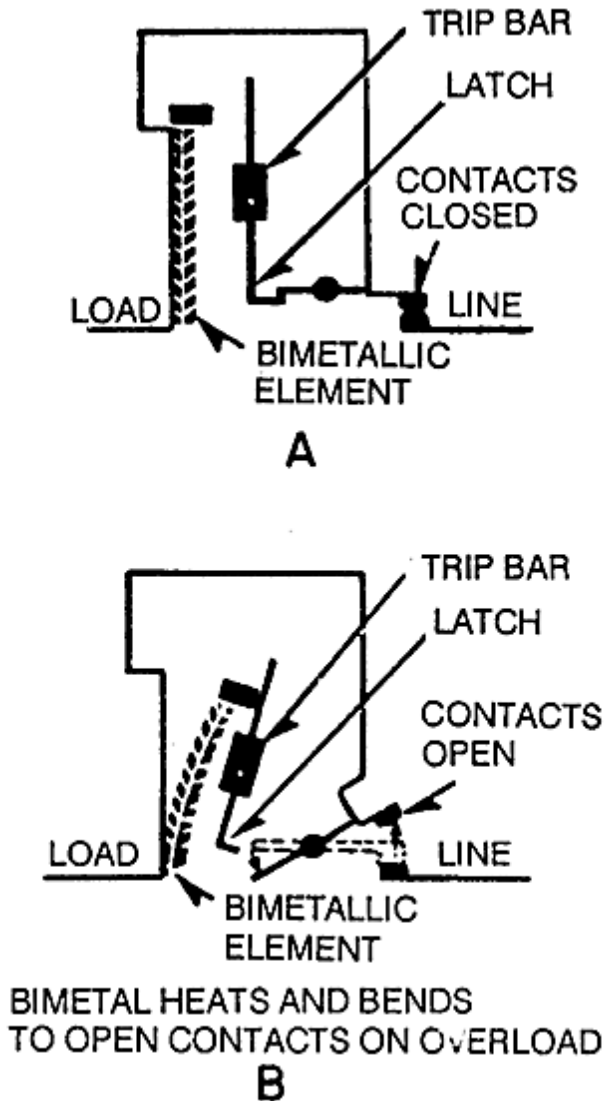


Arc extinguisher action

Terminal Connectors. Terminal connectors are used to connect the circuit breaker to the power source and the load. They are electrically connected to the contacts of the circuit breaker and provide the means of connecting the circuit breaker to the circuit.

Trip Element. The trip element is the part of the circuit breaker that senses the overload condition and causes the circuit breaker to trip or break the circuit. Thermal, magnetic, and thermal magnetic trip units are used by most circuit breakers. Some circuit breakers use solid state trip units with current transformers and solid state circuitry.

Thermal trip element. A thermal trip element circuit breaker uses a bimetallic element that is heated by the load current. The bimetallic element is made from strips of two different metals bonded together. The metals expand at different rates as they are heated. This causes the bimetallic element to bend as it is heated. Below shows how this can be used to trip a circuit breaker.

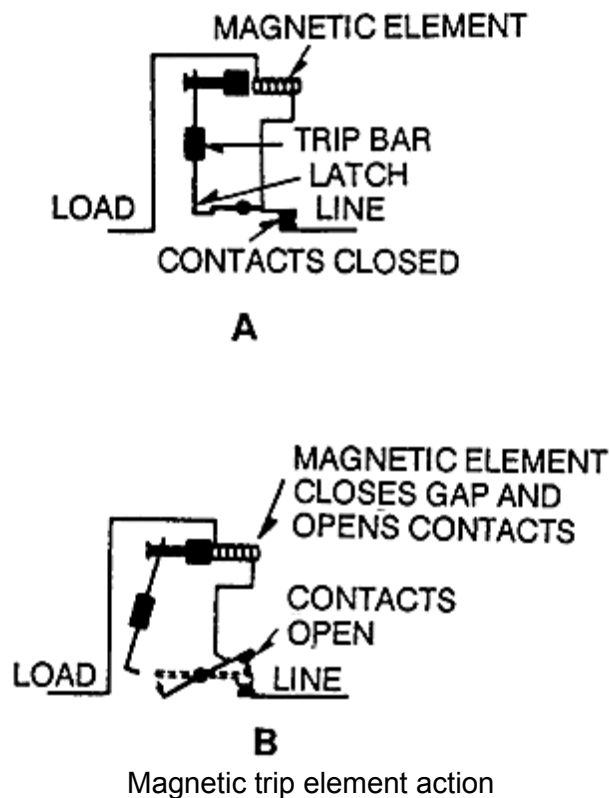


Thermal trip element action

View A, shows the trip element with normal current. The bimetallic element is not heated excessively and does not bend. If the current increases (or the ambient temperature around the circuit breaker increases), the bimetallic element bends, pushes against the trip bar, and releases the latch. Then the contacts open, view B.

The amount of time it takes for the bimetallic element to bend and trip the circuit breaker depends on the amount the element is heated. A large overload will heat the element quickly. A small overload will require a longer time to trip the circuit breaker.

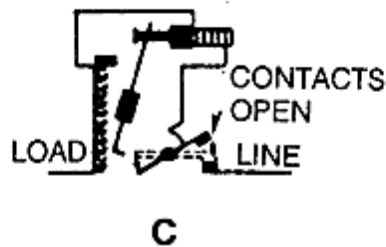
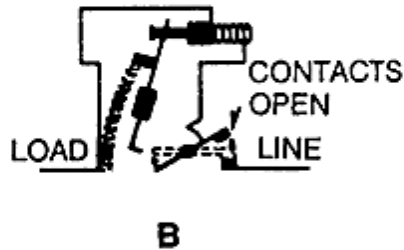
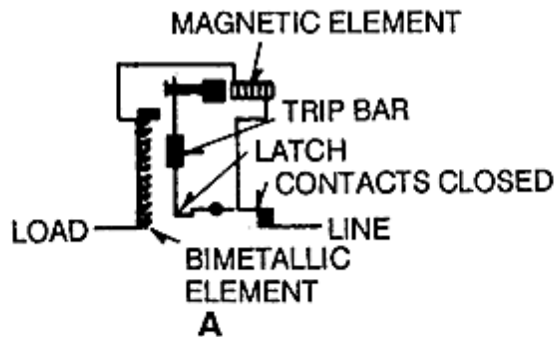
Magnetic trip element. A magnetic trip element circuit breaker uses an electromagnet in series with the circuit load. With normal current, the electromagnet will not have enough magnetic force on the trip bar to move it, and the contacts will remain closed (view A). The strength of the magnetic field of the electromagnet increases as current through the coil increases. As soon as the current in the circuit becomes large enough, the trip bar is pulled toward the magnetic element (electromagnet). The contacts are opened, and the current stops (view B).



The amount of current needed to trip the circuit breaker depends on the size of the gap between the trip bar and the magnetic element. On some circuit breakers, this gap (and therefore the trip current) is adjustable.

Thermal-magnetic trip element. The thermal-magnetic trip element circuit breaker, like a delay fuse, will protect a circuit against a small overload for a long period of time. The larger the overload, the faster the circuit breaker will trip. The thermal element portion will protect the circuit against ambient temperature rises. The magnetic element portion will trip instantly when the preset current is

present. In some applications, both types of protection are desired. Rather than using two separate circuit breakers, a single trip element combining thermal and magnetic trip elements is used. Below shows a thermal-magnetic trip element.



Thermal-magnetic trip element action

In the thermal-magnetic trip element circuit breaker, a magnetic element (electromagnet) is connected in series with the circuit load, and a bimetallic element is heated by the load current. With normal circuit current, the bimetallic element does not bend, and the magnetic element does not attract the trip bar (view A).

If the temperature or current increases over a sustained period of time, the bimetallic element will bend, push the trip bar, and release the latch. The circuit breaker will trip as shown in view B.

If the current suddenly or rapidly increases enough, the magnetic element will attract the trip bar, release the latch, and trip the circuit breaker (view C). (This

circuit breaker has tripped even though the thermal element has not had time to react to the increased current.)

CIRCUIT BREAKER CLASSIFICATIONS

Circuit breakers are classified as being trip-free or non-trip-free. A trip-free circuit breaker will trip (open) even if the operating mechanism (on-off switch) is held in the ON position. A non-trip-free circuit breaker can be reset and/or held on even if an overload or excessive heat condition is present. In other words, a non-trip-free circuit breaker will remain closed by holding the operating mechanism on.

Trip-free circuit breakers are used on circuits that cannot tolerate overloads and on non-emergency circuits. Examples of trip-free applications include precision or current-sensitive circuits, non-emergency lighting circuits, and nonessential equipment circuits.

INTRODUCTION

Circuit control, in its simplest form, is the application and removal of power. It can also be expressed as turning a circuit on and off or closing and opening a circuit.

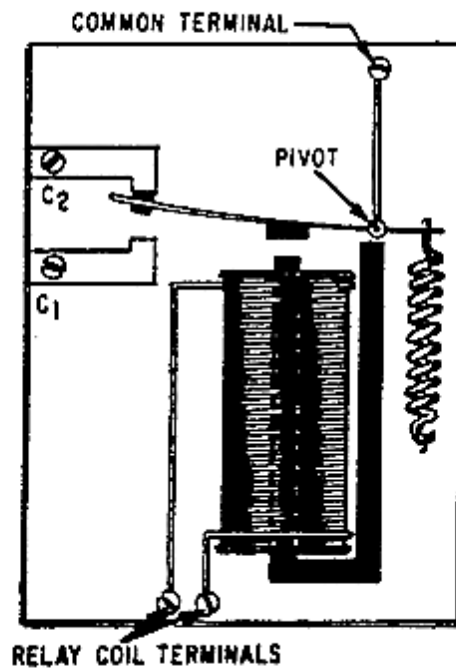
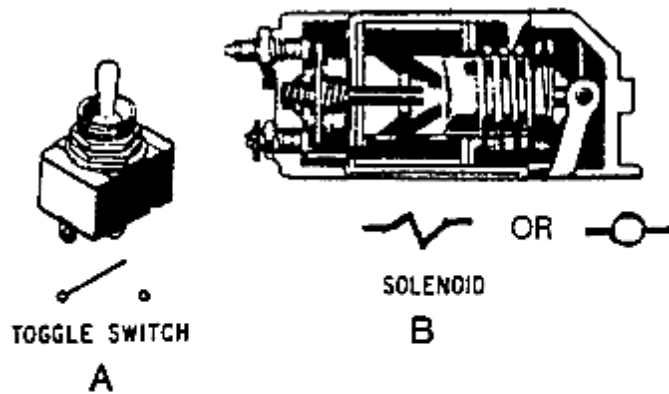
If a circuit develops problems that could damage equipment or endanger personnel, it must be possible to remove the power from the circuit. The circuit protection devices discussed in the previous chapter will remove power automatically if current or temperature increases sufficiently. Even with this protection, a manual means of control is needed so the operator can start and stop electrical equipment as he chooses.

When working on a circuit, it is often necessary to de-energize the circuit to install test equipment or replace components. When power is removed from a circuit for servicing, be sure to tag out that circuit breaker that supplies power to those components. When work has been completed, restore power to the circuit. Check the circuit for proper operation before placing it back in service. After the circuit has been checked for proper operation, remove the tag and log the work.

Many electrical devices are used only part of the time. These controlling devices can allow a programmed sequence of events to take place or to repeat cycles of specific operations. The air conditioner is a good example. The compressor motor cycles on and off automatically, controlled by the thermostat switch. As the temperature increases, the thermostat switch closes the circuit, and the air conditioner starts. When the temperature drops to the predetermined level, the thermostat opens the circuit and shuts the compressor off.

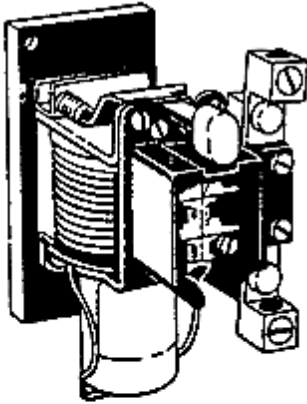
TYPES OF CIRCUIT CONTROL DEVICES

Circuit control devices have many different shapes and sizes, see below. There are three basic groups of circuit control devices: manual, magnetic, and electronic.

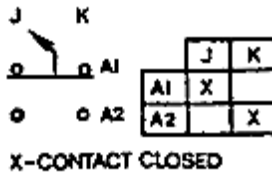


C

Typical circuit control devices



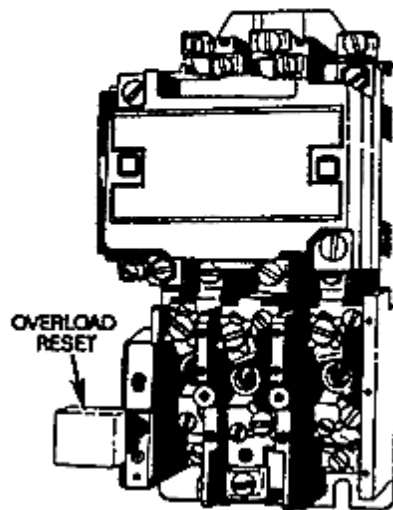
MAGNETIC OVERLOAD RELAY



SWITCH



SWITCH



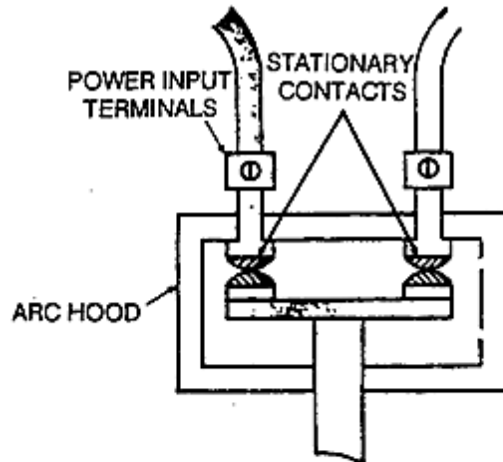
MOTOR STARTER, THERMAL

Types of circuit controls

There are many ways of physically positioning electrical control devices. The toggle switch and push button comprise the largest concentration of manual controls. Other manually activated controls are those operated by an outside physical force, such as pressure operating a pressure switch or a water level operating a float switch. Even with the varied number of switching devices, all have one thing in common. They all have contacts.

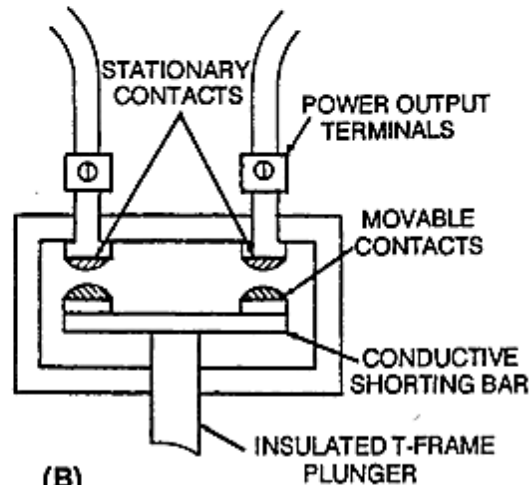
CONTACTS

Copper and silver alloy are the two most common types of contact materials. A contact is usually a circular or rectangular surface designed to carry and interrupt the flow of current. The figures below shows contacts both normally closed ([view A](#)) and normally open ([view B](#)). Contacts are found in pairs. One contact is permanently fixed in position. The other contact is affixed to a movable arm or plunger. When the switch is closed, both contacts come together and complete the circuit. When the switch is opened, the contacts are separated, and the circuit is broken. The contacts and their terminal connections are insulated from the switch housing and actuator handle. The contacts are always in series with the components they control.



(A)

NORMALLY CLOSED CONTACTS



(B)

NORMALLY OPEN CONTACTS

(REPRINTED WITH PERMISSION FROM THE
AMERICAN TECHNICAL PUBLISHERS, INC.)

Contacts

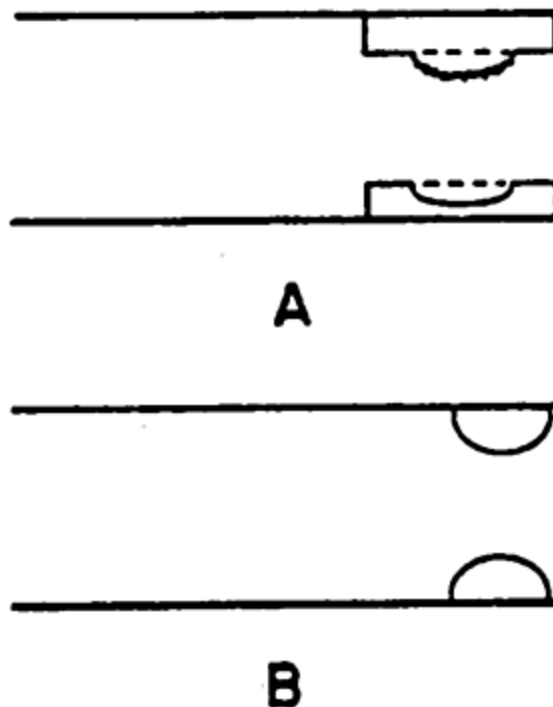
Inspect and clean copper contact surfaces of any black-oxide film. This copper oxide film is a partial insulator. Large copper contacts are designed to open and close with a wiping action. That helps eliminate the copper black-oxide that prevents good continuity (contact) between the contact surfaces.

Newer contacts are composed of silver alloy materials. During normal circuit operation, arcing causes a blackened condition on the silver alloy contact faces as well. However, this silver oxide has been found to improve contact operation. It minimizes the tendency of one contact to weld to another. The silver oxide also

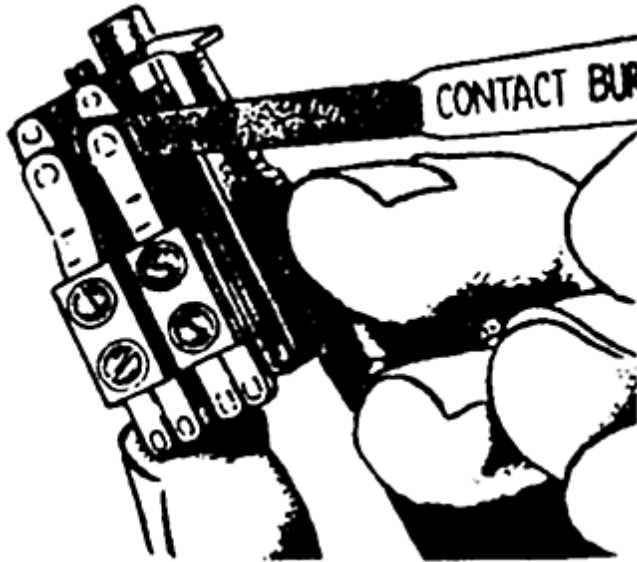
inhibits the transfer of material from one contact face to the other contact face. It is not recommended to remove this film from silver alloy contacts.

Any buildup of film on the contact surface is a cause for concern. Normal oxidation will form a film on the contacts because of the action of the atmosphere and other surrounding gases. This cannot be avoided. The film caused by grease is particularly detrimental to good contact operation. Normal arcing causes grease and other petroleum products to burn. Carbon rings form on the contact surfaces, and eventually the contacts are prevented from operating properly. Grease contamination is often caused by service technicians who ignore the need for cleanliness. Cleanliness must be second nature to all engineers.

When current flows in only one direction through a set of contacts, a problem known as cone and crater may develop. The crater is formed by the transfer of metal from one contact to the other contact. View A below shows this condition. If this condition is present, replace the contacts.



Some contacts are formed in a ball shape. In many applications, this type of contact is superior to a flat surface. View B shows a set of ball-shaped contacts. Dust or other substances are not easily deposited on a ball-shaped surface. Also, a ball-shaped contact penetrates film more easily than a flat contact. When cleaning or servicing ball-shaped contacts, be careful to avoid flattening or otherwise altering the rounded surfaces. The contacts can be damaged by using sandpaper or emery cloth. Only a burnishing tool should be used for this purpose, see below. Do not touch the surfaces of the burnishing tool. After the burnishing tool is used, it should be cleaned with alcohol.

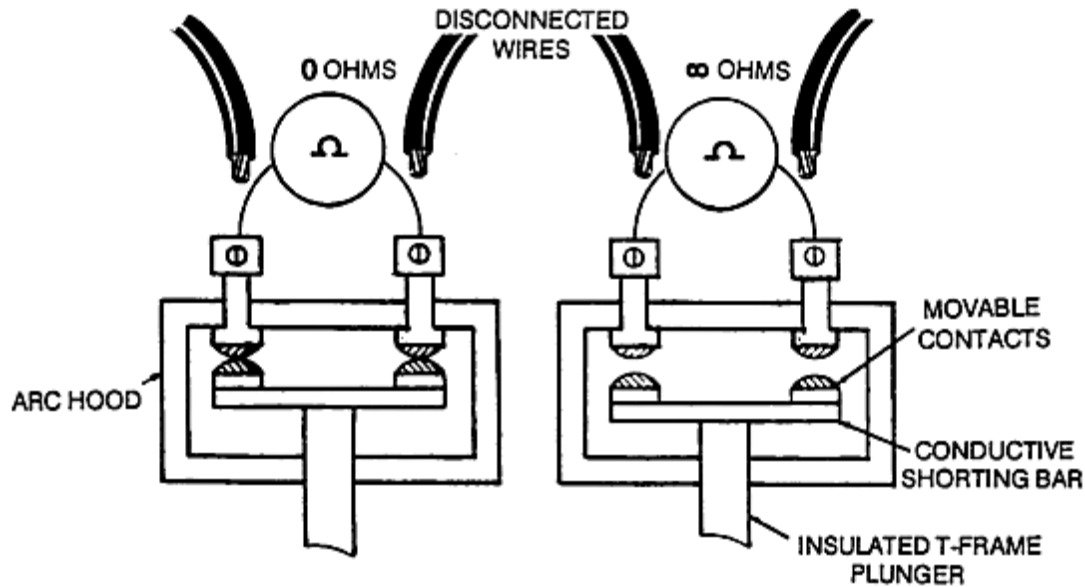


Burnishing tool

Never use finishing papers that are conductive. Conductive particles fall from the paper during servicing and can short across parts of the circuit. When these particles are dropped into the equipment, an engineer's first response is to blow the equipment out with compressed air. Never blow particles deeper into an electrical device. Always use a vacuum cleaner to pull the particles back out the way they went in, rather than trying to drive them through the component.

Cleanliness is important when servicing semi-sealed relays. When these relays are installed in a compartment where there is a possibility of contact with explosive fumes, take extra care with the cover gasket. The gaskets must be free of grease and defects. The housing gasket surfaces must be free of burrs. Any damage to or incorrect seating of the gasket increases the possibility of igniting the vapors.

After servicing the contacts, verify their operation with an ohmmeter. Ensure the circuit is de-energized. Disconnect at least one of the leads to the contact surfaces. This is necessary to ensure that other parallel circuits are not read by the ohmmeter. Connect one lead of the ohmmeter to one side of the contacts. Connect the other ohmmeter lead to the other contact, see below. Physically open and close the contacts and observe the ohmmeter readings. The ohmmeter should read zero resistance when the contacts are closed and an infinite resistance when the contacts are open.



Checking contacts with an ohmmeter

SWITCH RATING

The previous chapter discussed how the contacts open the electrical circuit during overcurrent conditions. Circuit breakers, circuit control devices, and switches have contacts of either copper or silver alloy materials. The National Electrical Manufacturers Association (NEMA) rates contractors according to the size and type of load. How contacts are rated and what they are made of depend on their physical size, current, voltage capacities, and particular application.

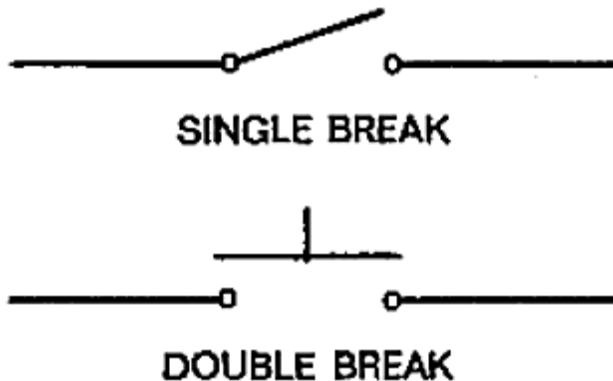
The table below lists some common ratings for AC contractors.

Common size and rating of AC contactors

Size	Three-Phase 230/460V	Single-Phase 115V
00	2 HP	1/3 HP
0	5 HP	1 HP
1	10 HP	2 HP
2	25 HP	3 HP
3	50 HP	

The overall size of a single-break contact device can be reduced by making it a double-break contact. The figure below shows a single- and double-break switch.

A double-break contact can carry a much higher current in a smaller space because it interrupts the circuit in two places at the same time. It can further be reduced by making it out of silver alloy. Silver alloy is an excellent conductor with better mechanical strength. Contacts made of silver alloy will allow many more operations than a contact of copper construction. Copper is a good choice for large contacts because it is a good conductor and is relatively inexpensive.



Single and double-break contacts

The current rating of the switch refers to the maximum current the switch is designed to carry. The current rating of a switch should never be exceeded. Excessive currents will weld the contacts together making it impossible to open the circuit.

The voltage rating of a switch refers to the maximum voltage allowable in the circuit in which the switch is used. The voltage rating will be given as AC, DC, or both. If the voltage rating of the switch is exceeded, the voltage may jump the open contacts of the switch, energizing the circuit.

Application is very important because both AC and DC are found on Army watercraft. Direct current sends electrons in one direction constantly. As long as the circuit is complete, the current will be sustained at the maximum source level. For this, larger, heavier contacts are needed. Alternating current, by its nature, sends current through the circuit in two directions alternately. For 60 hertz, the AC shuts itself off 120 times a second. This characteristic allows AC to be interrupted without as great an arcing as a DC produces.

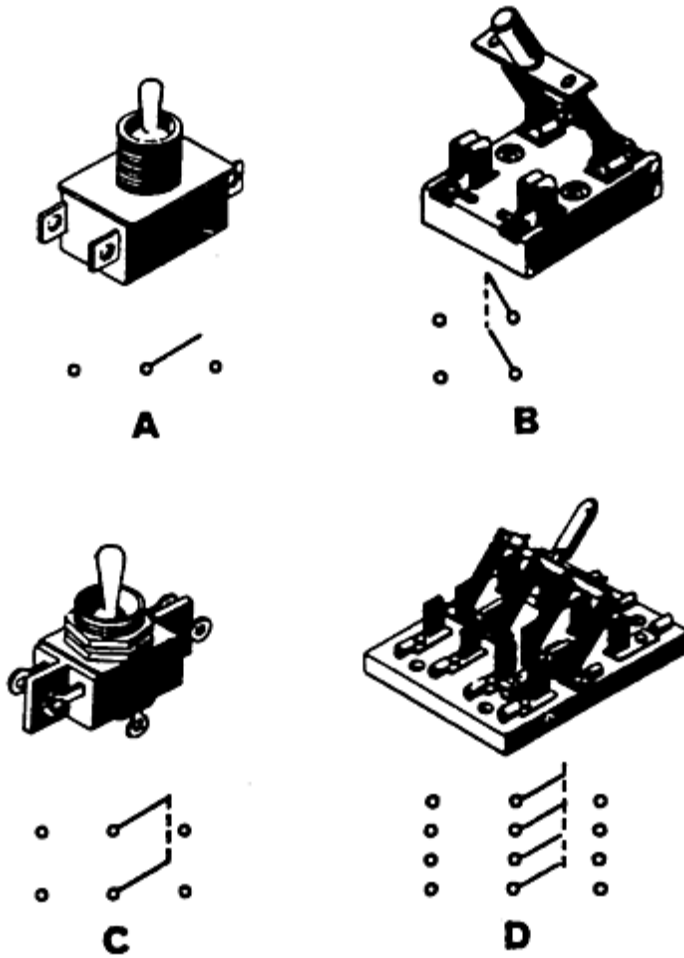
The following rules apply to switch and contact symbols:

- The position that the switch is in when placed in an electrical diagram is its normal position. This means that unless acted on by an outside force, such as a finger or a mechanical pressure, this switch will remain in that position. The switch can be either normally open (NO) or normally closed (NC).

- Relays and contractors follow the same rules as switches. These devices have electromagnets (coils) that control the position of their contacts. When the coil is not energized, the contacts will be in the same position as shown by their symbol on the diagram. This is their normal position, either NO or NC. When the coil is energized, the contacts change their position. Normally open contacts close, and normally closed contacts open.
- Pole refers to the number of terminals at which current can enter the switch. The single-pole switch has only one terminal for current to enter. The three-pole switch has three terminals in which current can enter.
- Throw refers to the number of additional circuits that can be controlled by physically repositioning the pole or poles. The double-throw switch provides a choice of two possible circuits.

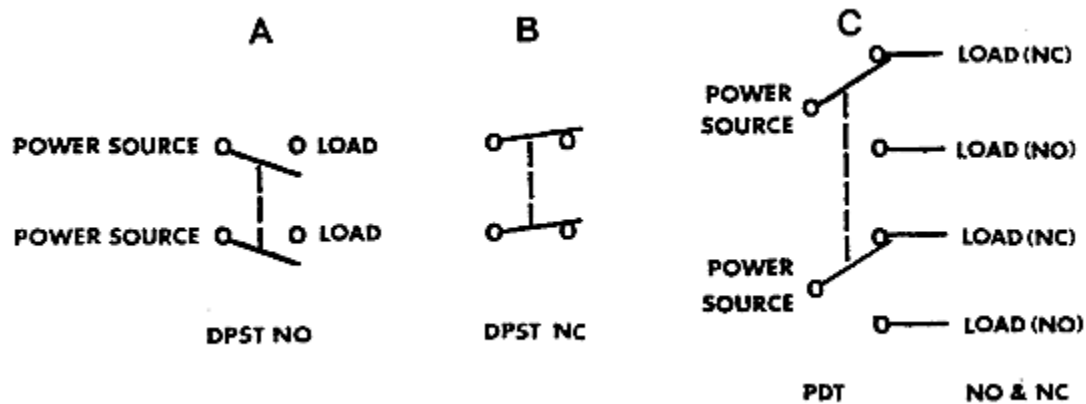
The number of poles can be determined by counting the number of points where current enters the switch (from the schematic symbol or the switch itself). By counting the number of different points each pole can connect with, the number of throws can be determined.

For example, the figure below shows some of the symbols for a toggle switch. View B shows a double-pole, single-throw (DPST) switch. This means that when the toggle switch is moved, two paths for current to flow will be completed. The dotted lines connecting the two poles indicates that they are mechanically connected. They are both activated with a single motion. This is known as mechanical interlocking.



Multi-contact switches

The figure below, View A, shows a DPST normally open switch. View B shows the same configuration except that the switch is normally closed. View C shows a symbol for the double-pole, double-throw (DPDT) switch. In this situation, there is a possibility of four paths for current to flow. This type of switch has contacts that are normally opened and normally closed. At any given time, at least two circuits will have power available.

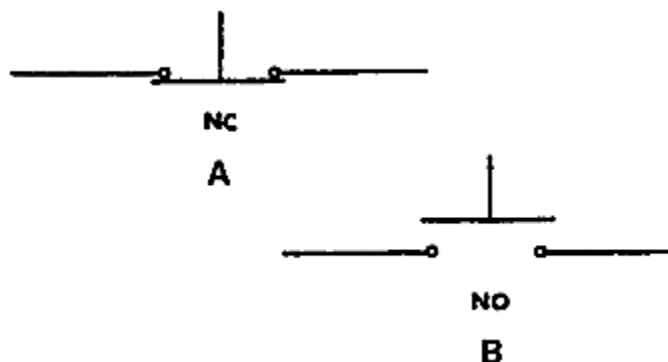


TYPES OF SWITCHES

Push Button

A common manual switch is the push button shown below. The push button, like all the schematic symbols, has a standard that governs its drawn position on diagrams:

- The position it is drawn on the diagram represents the position it maintains until acted on by an outside force. It is maintained in the normal position by spring pressure.
- The position will always be structurally natural. That is, if you could physically touch the diagramed switch and make it move, it will move only as the picture will let it move.



View B shows the symbol for the normally open, double-break push button. This switch, normally used for a start push button, can be physically depressed to touch the contacts or circles. When the finger is removed, the push button is spring-loaded and returns to its NO position.

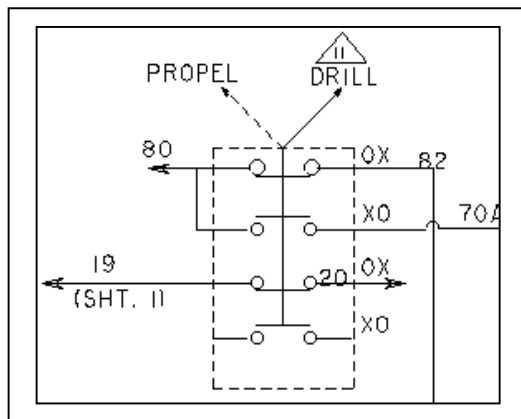
View A shows the normally closed push button in contact below the contacts. This normally closed switch is generally used for a stop push button. When

pressure is applied to the button, the pole moves away from the contacts. This push button is also spring-loaded and will return to its normally closed position.

If the stop push button's pole was placed above the contacts (circles), it would be impossible to imagine pushing the electrical diagram out of the way to open the circuit. This is a very important concept when dealing with more complex symbols. The way the switch is illustrated represents the manner in which the switch is constructed.

Selector Switches

A selector switch is rotated by the operator to a desired position to energize a specific circuit. The next figure shows a two-position selector switch positioned in a diagram. The X and O symbolize closed and open contact position, respectively. The left most symbol is associated with the left most switch position. The top line has a contact that is closed when the selector operator is in the right (drill) position. The arrow or pointer of the selector is solid indicating the current position and the dotted line represents the other possible positions.

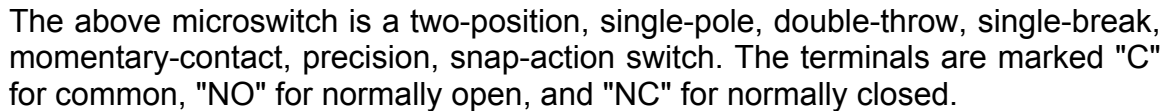


Snap-Action Switches

A snap-action switch keeps the movement of the contacts independent from the physical activation of the switch. In a toggle switch, for example, no matter how fast or how slow the toggle is moved, the actual switching of the circuit takes place at a fixed speed. The snap-action switch is constructed by making the switch mechanism a leaf spring so that it snaps between positions. Increasing the contact closing speed decreases the time arcing can take place. A snap-action switch cannot be between positions.

Microswitch

A microswitch is a precision snap-action switch in which the operating point is preset and very accurately determined, see figure below. The operating point is the point at which the plunger causes the switch to switch.

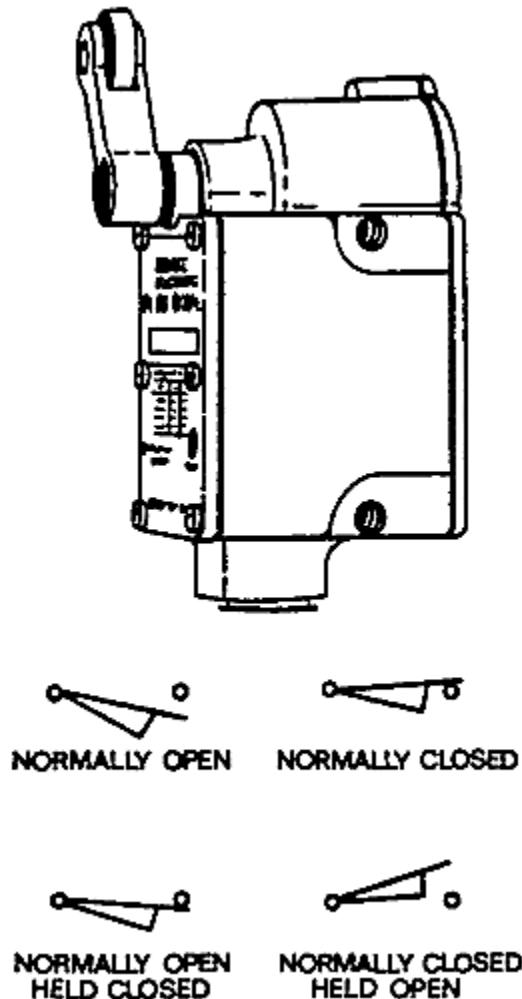


The diagram illustrates the internal mechanism of a relay switch. Key components labeled include the COVER, PLUNGER, SPRING, and CONTACTS. The contacts are divided into COMMON, NORMALLY CLOSED, and NORMALLY OPEN. The electrical circuit shows POWER IN entering a COMMON terminal, which connects to either a NORMALLY CLOSED contact (leading to terminal A) or a NORMALLY OPEN contact (leading to terminal B) depending on the plunger position. The output is labeled POWER OUT.

There are hundreds of switches that require some type of activation by other than human interaction. The following are a sampling to serve as a guide in understanding the operation of circuit control devices and their symbol relationships.

Limit Switch: The switch is made up of two parts. The lever, or the actuator, is physically moved by an outside source (or the cable as mentioned above). The lever physically changes the position of the contacts from NO to NC or NC to NO.

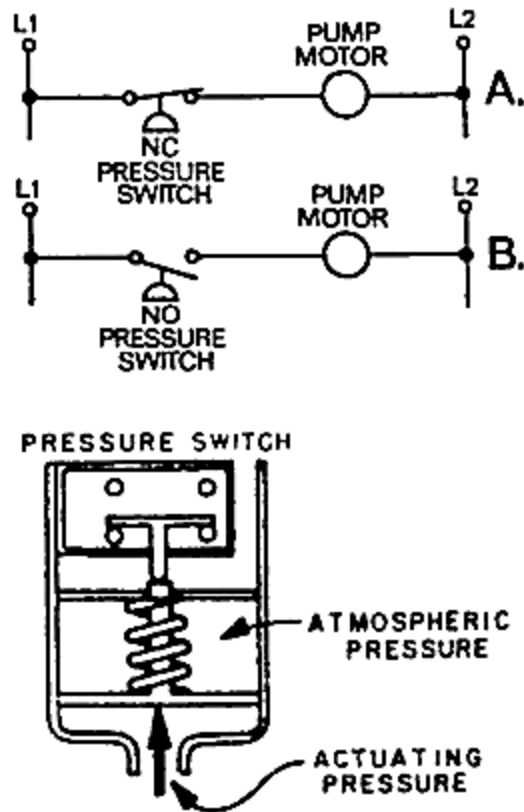
This switch can be used in four ways: normally open, normally open held closed, normally closed, or normally closed held open. The figure below shows the four limit switch positions. By arranging them according to the circuit and the response wanted from the circuit, this two-position switch will provide a wide range of safety options.



NOTE: Manufacturers require strict compliance in observing polarity when installing limit switches in DC circuits. If the limit switch is connected incorrectly, metal transfer between the switch contacts will occur. Possible welding of the contacts can take place. Follow polarity indication on the device.

Pressure Switch: Pressure switches are control devices that react to pressure changes in water, oils, gases, and so forth. The figure below shows a cutaway portion of the pressure switch. A normally closed pressure switch is used to maintain the correct water pressure in a potable water system ([view A](#)). As the

pressure from the pump increases, the pressure switch contacts will open and disconnect the pump motor from the circuit. As the water is used and the pressure drops, the switch closes, and the pump starts to replenish the reservoir.

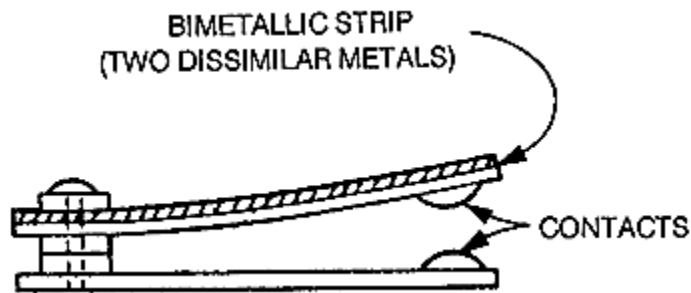


The normally open switch in view B cannot be used in this situation. With water pressure at below acceptable standards, the pump would continue to remain idle because there was no outside force acting on it to close the contacts. If the contacts could be held closed until they stayed closed under pressure, then the pump would not shut off. The NO pressure switch is used to maintain inches of mercury (vacuum) in the sewage systems. When the vacuum is lost, the pressure increases (toward atmospheric pressure of 14.7 psia). This increase in pressure (or loss of vacuum) closes the switch. The vacuum pumps then pull out the air to maintain the correct pressure in inches of mercury.

A NO pressure switch needs an outside force to close its contacts. A NC pressure switch needs an outside force to open the contacts.

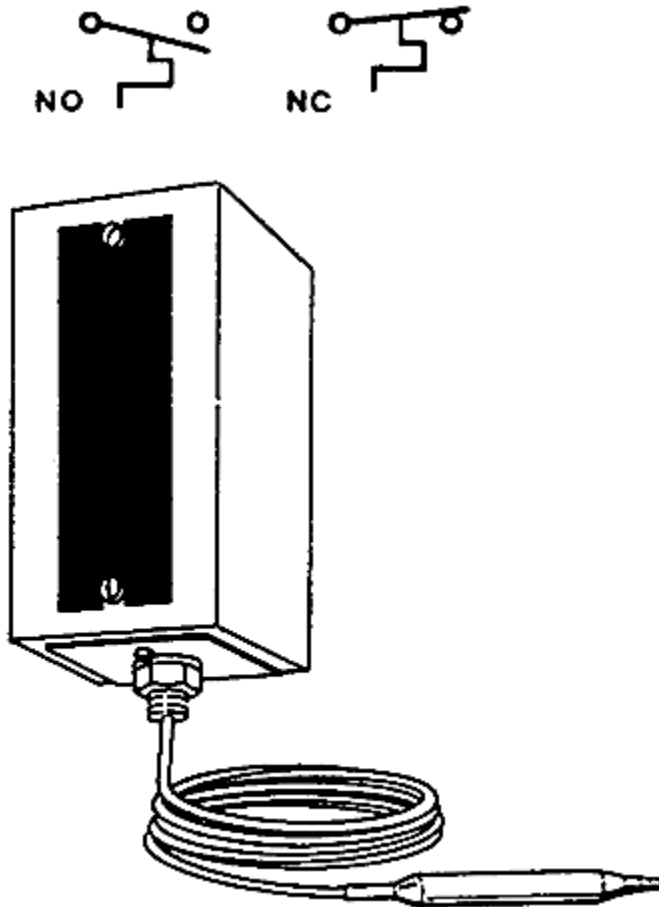
Temperature Switch: A bimetallic control device responds to changes in temperature. Two dissimilar metal stripes are attached together. The fusion of two dissimilar metals, one material on top of the other material, is called a bimetallic strip. The bimetallic strip has a contact surface at one end. As long as the bimetallic strip remains cool, the contacts remain together, completing a circuit. As the temperature increases, each of these two metal strips expand at a different rate. The faster expanding metal curves toward the slower expanding

material. When the bimetallic strip distorts sufficiently, it curves away from the other contact, opening the circuit, see below.



This type of bimetallic device is affected by heat. Heat can be from the ambient temperature around the switch or from the current flowing through the strip. When current is used to create the heat that can distort the bimetallic strip, it can be used in an overload protection device.

The figure below illustrates a capillary tube control device. The temperature switch is far removed from the bulb sensor, separated by a long capillary tube. The temperature switch can be placed in a convenient location, while the sensing bulb is positioned for the most effective temperature measurement. A volatile liquid or gas within the bulb and capillary tube reacts proportionally to temperature changes. As the ambient temperature surrounding the bulb rises, the bulb's internal volatile gas expands with a resulting increase in pressure. The pressure within the bulb is transmitted through the capillary tube acting on the remotely located switch. As the temperature surrounding the bulb is reduced, so is the internal pressure of the volatile gas.



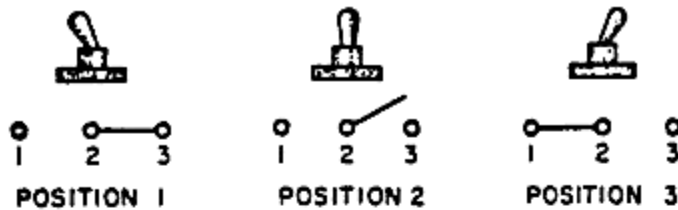
MAINTENANCE AND REPLACEMENT OF SWITCHES

Switches are usually very reliable electrical devices. Most switches are designed to operate 100,000 times or more without failure if the voltage and current ratings are not exceeded. Even so, switches do fail. The following information will help you in troubleshooting switches.

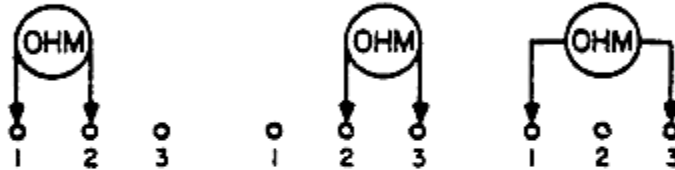
Checking Switches

Two meters can be used to check a switch: an ohmmeter or a voltmeter. The method employing these meters is explained below using a single-pole, double-throw, single-break, three-position, snap-acting toggle switch.

The figure below shows the method of using an ohmmeter to check a switch. View A shows the toggle switch positions and schematic diagrams for the three-switch positions. View B shows the ohmmeter connections used to check the switch while the toggle switch is in position 1. View C is a table showing the switch position, ohmmeter connection, and correct ohmmeter reading for those conditions.



A. SWITCH POSITION



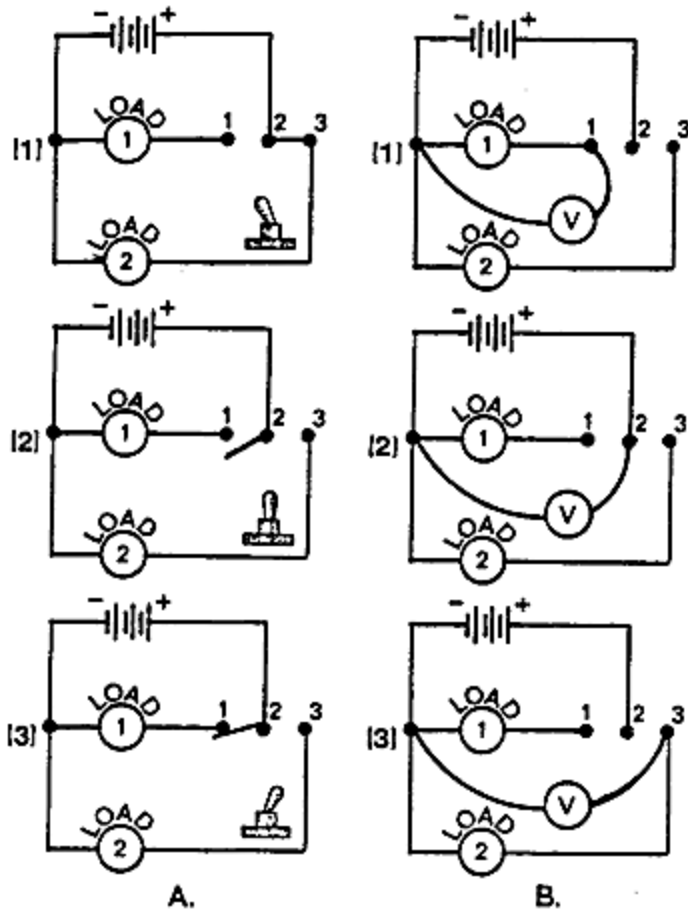
B. OHMMETER CONNECTION

SWITCH POSITION	OHMMETER CONNECTION	CORRECT READING
1	1-2	∞
1	2-3	0
1	1-3	∞
2	1-2	∞
2	2-3	∞
2	1-3	∞
3	1-2	0
3	2-3	∞
3	1-3	∞

C. TABLE OF CORRECT READINGS

Before the ohmmeter is used, remove power from the circuit and isolate the suspected switch from the circuit. The best way to isolate it from the circuit is to remove it from the circuit entirely. This is not always practical, and it is sometimes necessary to check a switch while there is power applied to it. In these cases, an ohmmeter cannot be used to check the switch, but a voltmeter can.

The figure below shows the method of using a voltmeter to check a switch. View A shows a switch connected between a power source (battery) and two loads. View B shows a voltmeter connected between the battery terminal negative node and each of the three-switch terminals while the switch is in position 1. View C is a table showing the switch position, voltmeter connection, and the correct voltmeter reading.



SWITCH POSITION	VOLTMETER CONNECTION	CORRECT READING
1	1	0V
1	2	VOLTAGE
1	3	VOLTAGE
2	1	0V
2	2	VOLTAGE
2	3	0V
3	1	VOLTAGE
3	2	VOLTAGE
3	3	0V

TABLE OF CORRECT READINGS

C.

With the switch in position 1 and the voltmeter connected between the battery terminal negative node and terminal 1, the voltmeter should indicate no voltage (0V). When the voltmeter is connected to terminal 2, the voltmeter should indicate the source voltage. With the voltmeter connected to terminal 3, the source voltage should also be indicated. The table in [view C](#) shows the correct readings with the switch in position 2 or 3.

Replacing Switches

When a switch is faulty, it must be replaced. The technical manual for the equipment will specify the exact replacement switch. If it is necessary to use a substitute switch, it must have all of the following characteristics:

- At least the same number of poles.
- At least the same number of throws.
- At least the same number of breaks.
- At least the same number of positions.
- The same configuration in regard to momentary or locked positions.
- A voltage rating equal to or higher than the original switch.
- A current rating equal to or higher than the original switch.
- A physical size compatible with the mounting.

The number of poles and throws of a switch can be determined from markings on the switch itself. The switch case will be marked with a schematic diagram of the switch or letters, such as SPST for single pole, single throw. The voltage and current ratings will also be marked on the switch. The number of breaks can be determined from the schematic marked on the switch or by counting the terminals after the number of poles and throws have been determined. The type of actuator and the number of positions of the switch can be determined by looking at the switch and switching it between positions.

Whenever component substitutions are made, the correct replacement must be installed as soon as possible. Vessel configuration must be maintained, and unauthorized modifications are prohibited.

Performing Preventive Maintenance of Switches

Switches do not fail very often. However, there is still a need for switch preventive maintenance. Switches should be checked periodically for corrosion at the terminals, smooth and correct operation, and physical damage. Any problems found need to be corrected immediately.

Most switches can be inspected visually for corrosion and damage. The operation of the switch may be checked by moving the actuator. When the actuator is moved, you can feel whether the switch operation is smooth or seems to have a great deal of friction. To check the actual switching, observe the operation of the equipment or check the switch with a meter.

INTRODUCTION

A generator is a machine that converts mechanical energy into electrical energy using the principle of magnetic induction. This principle is based on the fact that whenever a conductor is moved within a magnetic field so that the conductor cuts across magnetic lines of force, voltage is generated in the conductor.

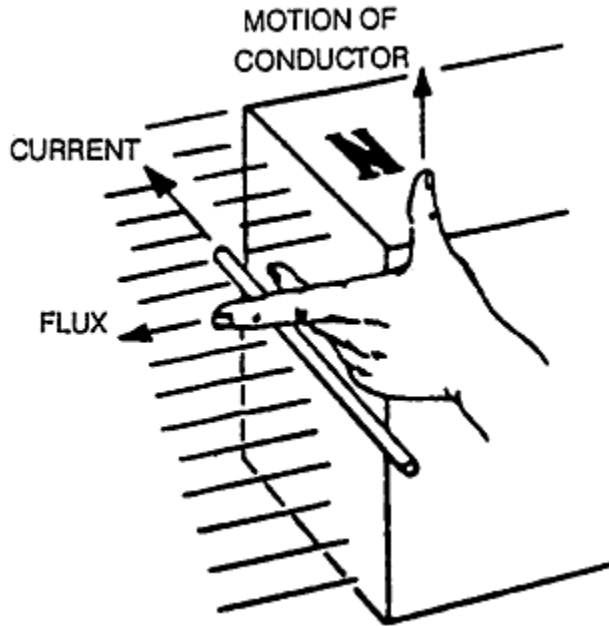
The three requirements to produce an electromotive force or EMF are a conductor, a magnetic field, and a relative motion between the conductor and the magnetic field.

The amount of voltage generated depends on --

- The strength of the magnetic field.
- The speed at which the conductor is moved.
- The length of the conductor in the magnetic field.

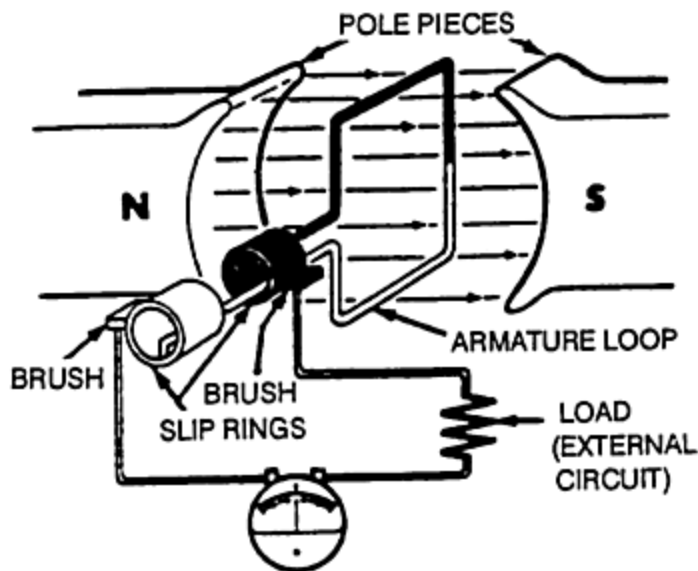
The polarity of the voltage depends on the direction of the magnetic field (or flux) and the direction of the movement of the conductor. To determine the direction of current movement in the conductor, the left-hand rule for generators was developed. The rule is explained as follows:

- Extend the thumb, forefinger, and middle finger of your left hand at right angles to one another, see figure below.
- Point your thumb in the direction the conductor is going to be moved.
- Position your forefinger in the direction of the magnetic flux (from north to south, knuckle to nail). Your middle finger will then point in the direction of current flow when an external circuit is connected. At the end of your fingernail is the area where the electrons are gathering. This is the negative terminal at this instant in time.



THE ELEMENTARY GENERATOR

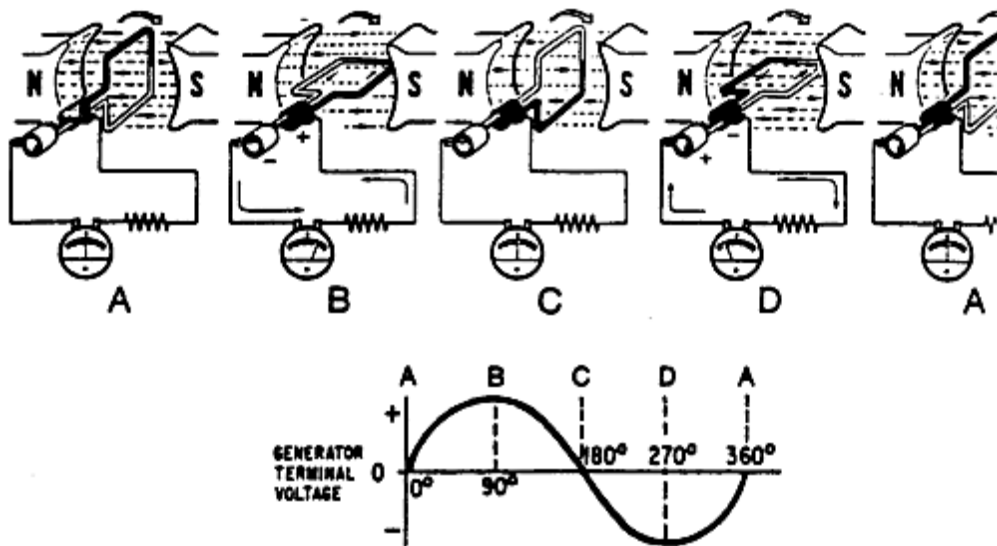
An elementary revolving armature AC generator, shown below, consists of a wire loop that can be rotated in a stationary magnetic field. This will produce an induced EMF in the loop. Sliding contacts (brushes and slip rings) connect the loop to an external circuit.



The pole pieces (marked N and S) provide the magnetic field. They are shaped and positioned to concentrate the magnetic field as close as possible to the wire loop. The loop of wire that rotates through the field is called the rotor. The ends of the rotor are connected to slip rings, which rotate with the rotor. The stationary

brushes, usually made of carbon, maintain contact with the revolving slip rings. The brushes are connected to the external circuit.

The elementary generator produces a voltage in the following manner, see below. The rotor (or armature in this example) is rotated in a clockwise direction. Position A shows its initial or starting position. (This will be considered the 0-degree position.) At 0 degrees, the armature loop is perpendicular to the magnetic field. The black and white conductors of the loop are moving parallel to the field. At the instant the conductors are moving parallel to the magnetic field, they do not cut any lines of force. There is no relative motion between the magnetic lines of force and the conductor when both the conductor and the magnetic lines of force move in the same direction. Therefore, no EMF is induced in the conductors, and the meter in position A indicates 0.



Output voltage of a single-phase elementary generator during one revolution.

As the armature loop rotates from position A to B, the conductors cut through more and more lines of flux at a continually increasing angle. At 90 degrees (B), they are cutting through a maximum number of magnetic lines of flux and at a maximum angle. The result is that between 0 and 90 degrees, the induced EMF in the conductors builds up from 0 to a maximum value. Observe that from 0 to 90 degrees, the black conductor cuts down through the magnetic field (or flux). At the same time, the white conductor cuts up through the magnetic field. The induced EMF in the conductors is series-aiding. This means the resultant voltage across the brushes (the terminal voltage) is the sum of the two induced voltages. The meter at position B reads maximum value.

As the armature loop continues rotating from position B (90 degrees) to position C (180 degrees), the conductors that were cutting through a maximum number of lines of flux at position B now cut through fewer lines of flux. At C, they are again moving parallel to the magnetic field. They no longer cut through any lines of flux. As the armature rotates from 90 to 180 degrees, the induced voltage will

decrease to 0 in the same reamer as it increased from 0 to 90 degrees. The meter again reads 0. From 0 to 180 degrees, the conductors of the rotor armature loop have been moving in the same direction through the magnetic field. Therefore, the polarity of the induced voltage has remained the same. This is shown by A through C on the graph. As the loop starts rotating beyond 180 degrees, from C through D to A, the direction of the cutting action of the conductors (of the loop) through the magnetic field reverses. Now the black conductor cuts up through the field. The white conductor cuts down through the field. As a result, the polarity of the inducted voltage reverses. Following the sequence shown in C through D and back to A, the voltage will be in the direction opposite to that shown from positions A, B, and C. The terminal voltage will be the same as it was from A to C except for its reversed polarity, as shown by meter deflection in D. The graph in Figure 13-3 shows the voltage output wave form for the complete revolution of the loop.

ROTOR AND STATOR

An alternator has two separate coils (or windings) of wire. One coil will carry DC and produce a magnetic field for use inside the generator. This coil of wire is wrapped around an iron core pole piece to concentrate its magnetic effects. This coil is always called the field. The other coil, usually called the stator, will have an EMF induced into it from the rotor's field and produce an AC flow for use by the electrical system. This is the conductor used in cutting the magnetic field. This coil is always called the armature.

Two of the three requirements for producing an EMF in an alternator have now been identified. Some form of relative motion between the magnetic field and the conductor is still necessary. By rotating one of these coils, an EMF can be developed. The item that moves a generator coil is called a prime mover. The prime mover can be a diesel engine or turbine.

The coil of wire that is rotating can be called the rotor. The coil of wire that is permanently fixed to the alternator housing can be called the stator. This text will not use these terms. The reasons will become apparent as multistator and multirotor machines are discussed.

ARMATURE AND FIELD

In an AC generator, the conductor coil does not always have to rotate. Often it is the field (the coil with the DC applied magnetic field) that rotates. As long as relative motion exists between the magnetic field and the conductor, an EMF will be produced. Since either the rotor or the stator can be the conductor or the field, it is necessary to further distinguish between the two fields. The coil connected to the electrical system to supply the system's voltage and current requirements is the armature. The armature is the stationary winding found on Army watercraft belt-driven alternators.

By definition, the armature is the conductor that has an EMF induced into it. The coil of wire that provides the magnetic field for the generator to develop an EMF is called the field. This field must always be supplied with DC.

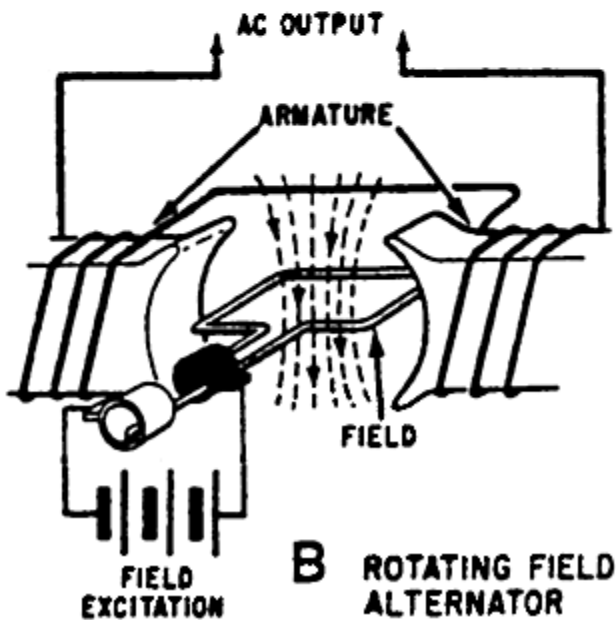
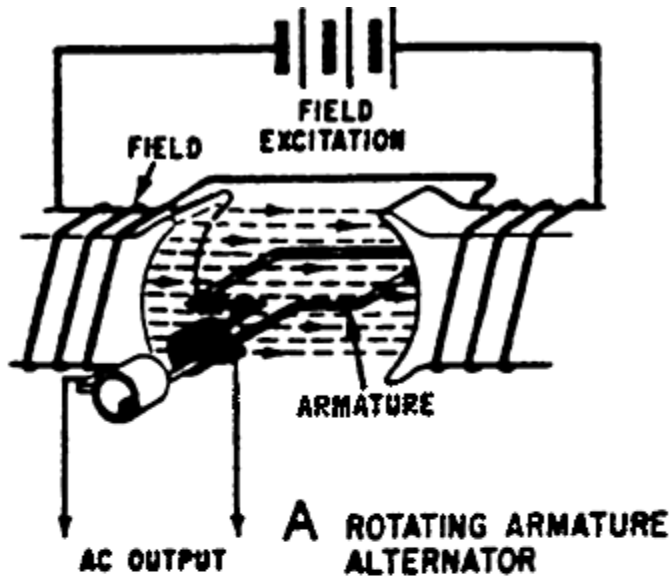
The explanation in *The Elementary Generator* describes the rotating armature type. This is not common to small generators. The electromagnetic flux (or magnetism) produced in the field coil requires a very small current to sustain it. On the other hand, the current produced in the armature, for use by the electrical system, can be enormous. It is not in the best interests of the electrical system to have a high current connection that is not fixed.

ROTATING ARMATURE ALTERNATORS

A rotating armature alternator requires slip rings and brushes to connect the high output voltage and current from the armature to the load. The armature, brushes, and slip rings are difficult to insulate. Arc-over and short circuits can result at high voltages. For this reason, high-voltage alternators are usually of the rotating field type. Army applications of this type alternator are extremely limited.

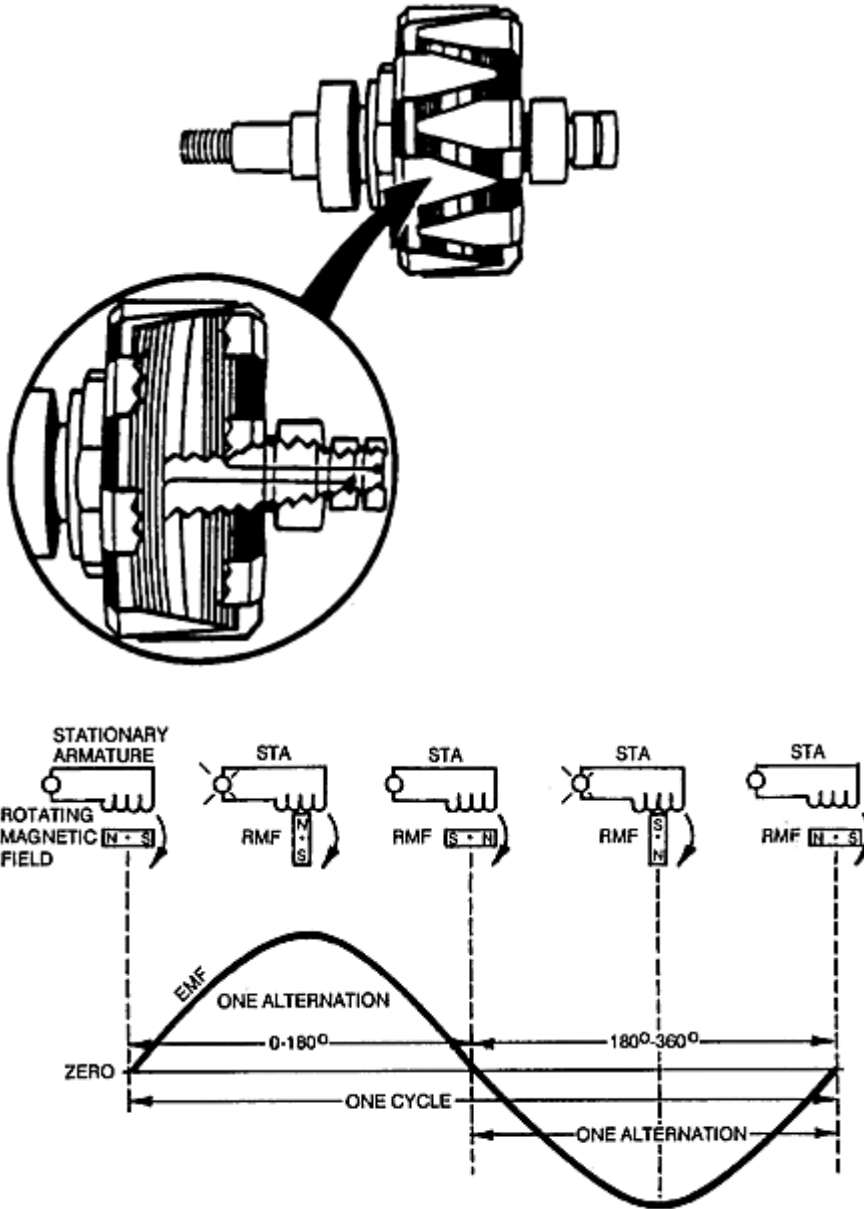
ROTATING FIELD ALTERNATORS

The rotating field alternator has a stationary armature winding and a rotating field winding, see figure below view B. This is the most common type of small generator in use today. The advantage of having a stationary armature is that the generated current can be connected directly and permanently to the load. There are no sliding connections (slip rings and brushes) to carry the heavy output current.



Field

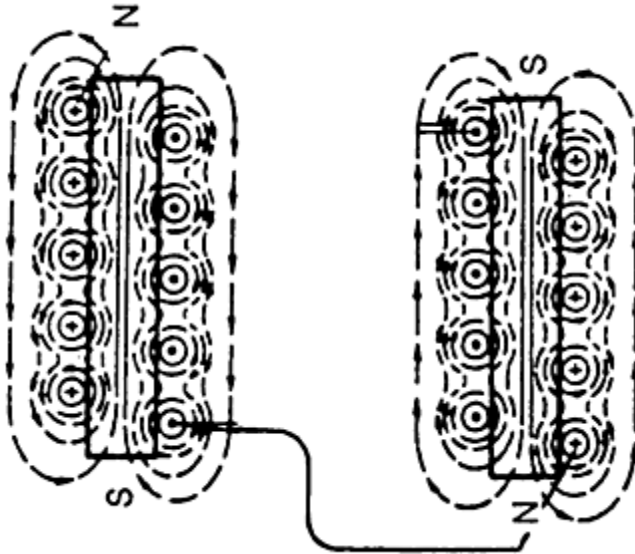
The figure below shows the motorola field. The rotating field consists of one fine wire wrapped a multitude of times around its core. This wire terminates at two slip rings where DC is applied through brushes. Direct current is necessary to produce AC because of the need to maintain a magnetic field much the same way that a revolving bar magnet would if it were rotated by its center. The figure below, shows how the direction of current flow is reversed when the magnetic field changes. The small DC needed for the magnetic field can be supplied by the battery or the alternator's own rectified output.



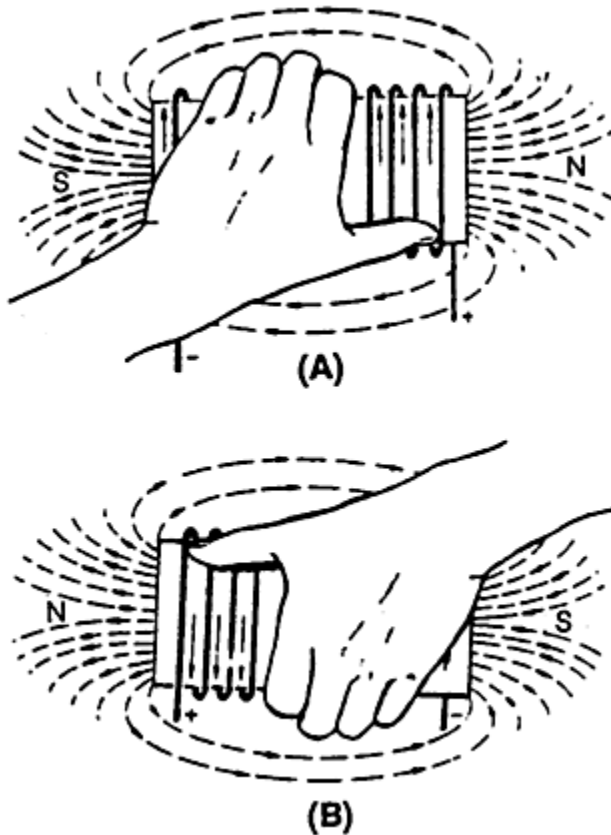
Multiple Magnetic Polarities in the Field

Alternate north and south field polarities are necessary to produce the AC desired from AC generators. By increasing the number of magnetic north and south poles, the efficiency of the alternator can be increased. As these alternate polarities sweep past the armature conductors, the current is forced to change directions.

Many AC and DC machines require the use of multiple north and south poles. How the field develops many north and south poles from only one wire is very simple. When the single field wire is wrapped around an iron core (clockwise, for example), it produces a given magnetic polarity. If the same wire is then wrapped around another iron core in a different direction (counterclockwise), the poles of this iron core are opposite to those in the clockwise-wrapped iron core. The figure below shows one wire wrapped around two iron cores in different directions. The north polarity of the left coil is up, and the south polarity of the right coil is up.

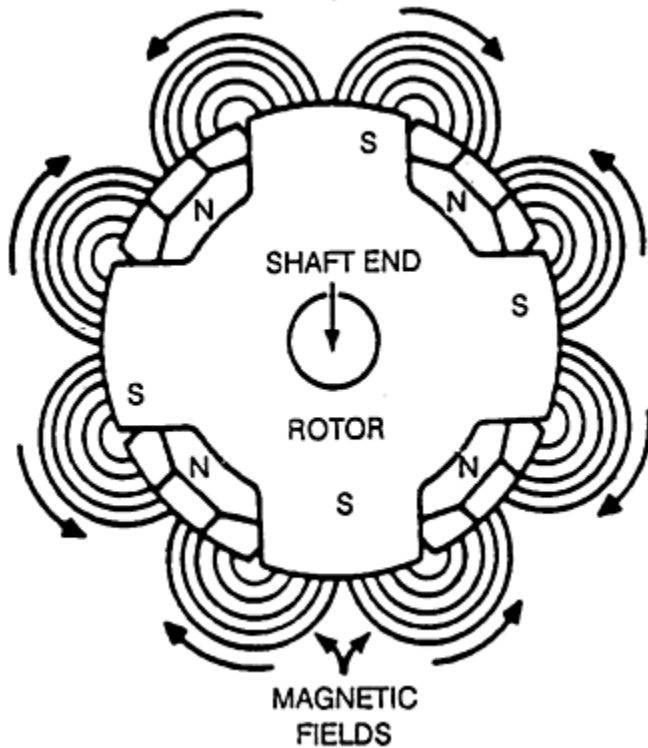


This is determined by the left-hand rule for coil polarity, see below.



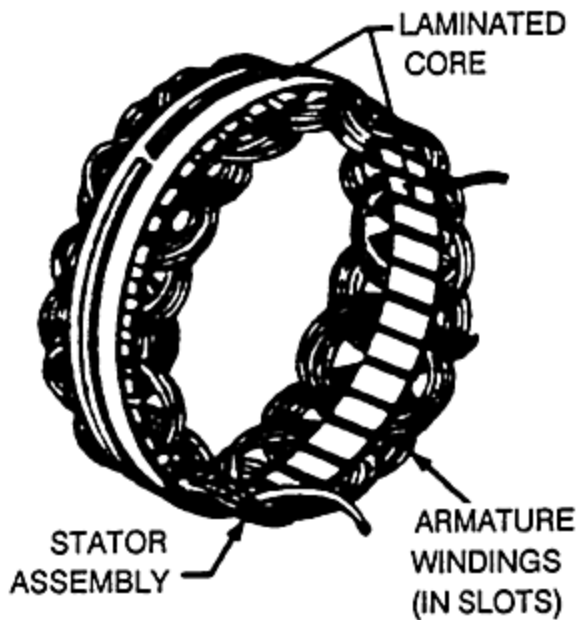
Multiple Alternator Fields

The alternator field uses only a single wire on a solid core. When direct current goes through the conductor, a fixed polarity is established in the core. The ends of the core branch out into fingers. These pointed fingers direct and concentrate the magnetic field from the core. All the fingers at the north polarity end maintain a north polarity. The same is true for the south polarity end. The figure below clearly shows the positioning of the north and south fingers alternately positioned around the outside of the magnetic core. It also shows the end view of the south pole field. Notice the alternate north and south polarities available at the circumference of the rotor. Notice also how the magnetic lines of flux are extended outward toward the armature windings.

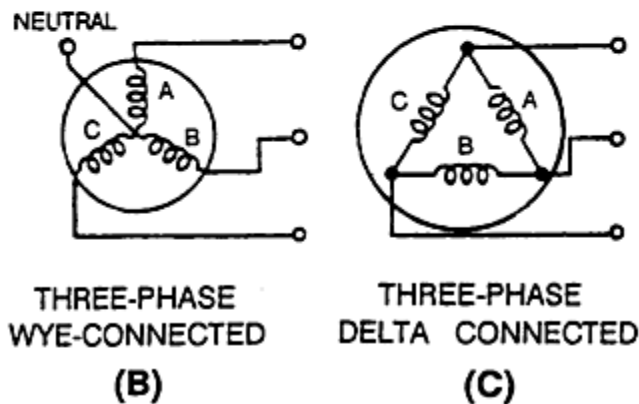
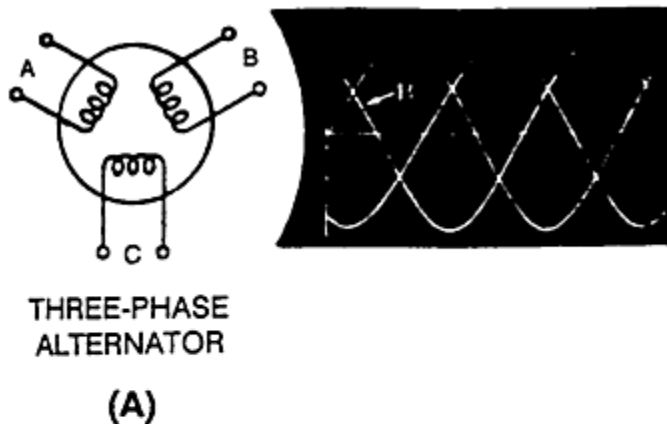


Armature

The rotating field alternator is the most common type found in the Army. The armatures of all rotating field alternators appear the same. The armature consists of a laminated iron core with the armature windings embedded in this core, see figure below. The core is secured to the generator housing.



The armature in the figure above has the stationary conductors that are cut by the revolving magnetic field. There are three conductors (or windings) connected together in the armature. This allows three separate circuits that are overlapped and spaced apart 120 electrical and mechanical degrees from one another. These three windings, positioned accordingly, act as three separate single-phase armatures. The three independent windings act together to provide three-phase AC. View A of the figure below shows the three windings and their combined sine waves.



Numerous coils are used for each of the three armature windings. This provides an effective use of conductors by placing them in close proximity to all the rotor field poles. The armature coils are not wrapped in opposite directions. They are merely placed strategically around the circumference of the alternator housing to be in close proximity to the field's magnetic field. The closer the conductor is to the magnetic field's origin, the greater the induced EMF in the armature windings.

Rather than have six individual leads coming out of the three-phase generator, two internal wiring configurations are available. One end of each winding may be connected together to form a wye connection, view B. If every end of an armature winding is connected to another armature winding, the resulting configuration is a delta-connected armature, view C. The voltage and current

generated in the armature, as a result of induction, are the AC voltage and current that are applied to the loads.

The three-wire armature can be easily distinguished from the two-wire DC field by merely counting the wire ends and observing the overlapping of the armature coils.

RECTIFIED ALTERNATING CURRENT GENERATORS

Induction has made AC the power of today. Alternating current can be transmitted at high voltages and changed to a low voltage through the use of transformers. Alternating current also saves money in the construction of large motors. The efficiency of AC generators has all but eliminated the DC generator. This is not to say that it is possible to eliminate all DC systems. The automobile electrical system is an example. The starting, control, and lighting systems on most mobile equipment will still be DC. To take advantage of the properties and efficiency of AC and the requirements of a DC electrical system, a compromise has been found in the rectified AC generator.

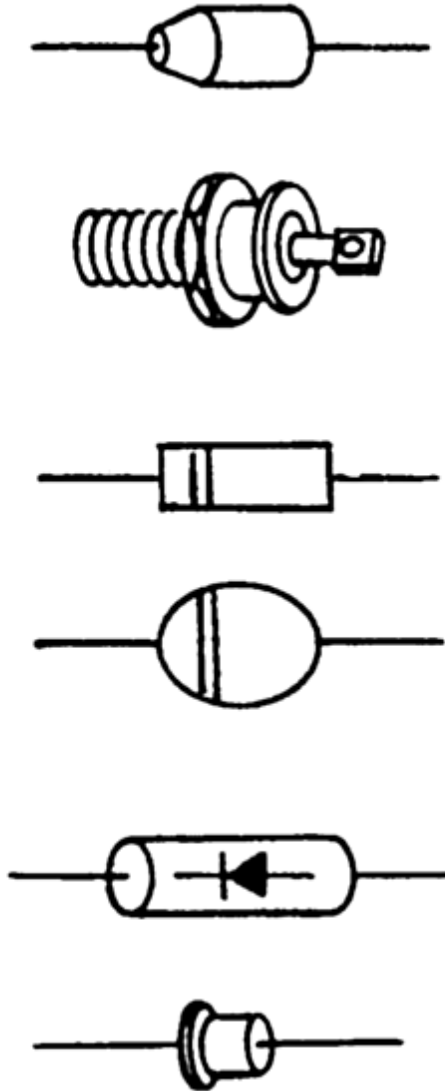
DIRECT CURRENT OUTPUT FROM ALTERNATORS

The alternators on most mobile equipment produce a DC current. Original DC generators were very inefficient. They could not meet the growing electrical needs of the mobile equipment industry.

The alternator was the obvious choice. The AC output had to be modified in some way so that a constant polarity could be established and current flow would be maintained in one direction only. The use of diodes in a full-wave bridge rectifier is used to do this. The full-wave bridge rectifier consists of six diodes: three positive and three negative.

Diodes

Semiconductor diodes are an electrical check valve, see below. Current can readily travel through a diode in one direction only. **Diodes are commonly made from silicon and germanium. By adding certain impurities to these two materials, called doping, a diode will become conductive only when a current moving in the proper direction is applied.**



Various diodes

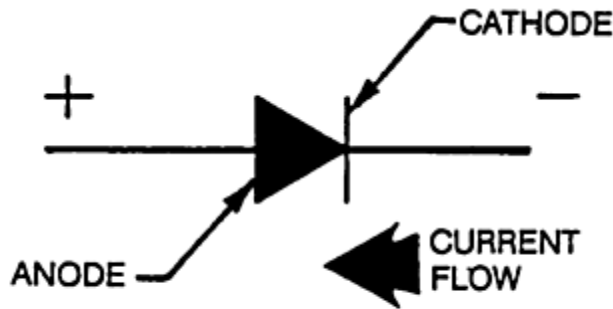
Some diodes have wires for terminals. Most of our diodes used for rectifying AC to DC have only one wire for a terminal. The other terminal is the diode housing.

Forward and Reverse Bias

Current conducts through the diode when the proper difference in potential (voltage) is applied across its terminals. When the proper difference in potential exists and current does conduct, this is called forward bias. When the wrong polarity exists and current is restricted, this is called reverse bias.

The diode has a relatively low resistance in one direction and a relatively high resistance in the other direction. This is determined through the use of a multimeter. The figure below shows the symbol of a diode. The straight line is

called the cathode. The triangle is called the anode. Current (electrons) always flows against the triangle in electron flow theory.

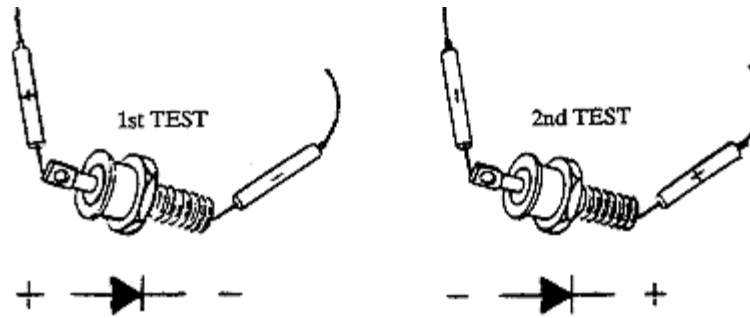


The current flow indicated here, is actually the direction of electron flow.

FORWARD BIAS

Diode Testing

The ohmmeter can be used to test a diode, see below. Since the ohmmeter has a battery and a battery has a predetermined polarity, the direction in which current will move through a diode can be established. Whether or not there is continuity can be determined by connecting the leads of the ohmmeter to each end of a diode.



CONNECT THE RED (+) AND BLACK (-) TEST LEADS ONE WAY AND CHECK THE READING. THEN REVERSE THE LEADS AND CHECK THE READING.

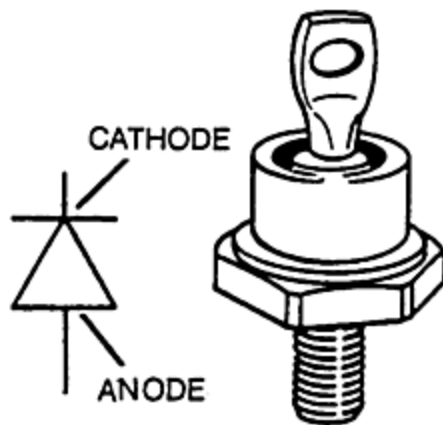
GOOD		SHORTED		OPEN	
1st TEST		1st TEST		1st TEST	
--	MAXIMUM RESISTANCE	--	MAXIMUM RESISTANCE	✓	MAXIMUM RESISTANCE
✓	MINIMUM RESISTANCE	✓	MINIMUM RESISTANCE	--	MINIMUM RESISTANCE
2nd TEST		2nd TEST		2nd TEST	
✓	MAXIMUM RESISTANCE	--	MAXIMUM RESISTANCE	✓	MAXIMUM RESISTANCE
--	MINIMUM RESISTANCE	✓	MINIMUM RESISTANCE	--	MINIMUM RESISTANCE
1st TEST	2nd TEST	1st TEST	2nd TEST	1st TEST	2nd TEST

(Reprinted with permission from the American Technical Publishers, Inc.)

When the meter is connected across a diode, it should read high resistance and low resistance. If the meter indicates a low resistance in both directions, the diode is shorted. If the meter indicates a high resistance in both directions, the diode is open. Neither condition is acceptable. Consult the manufacturer's manuals for specific information.

Diode Polarity

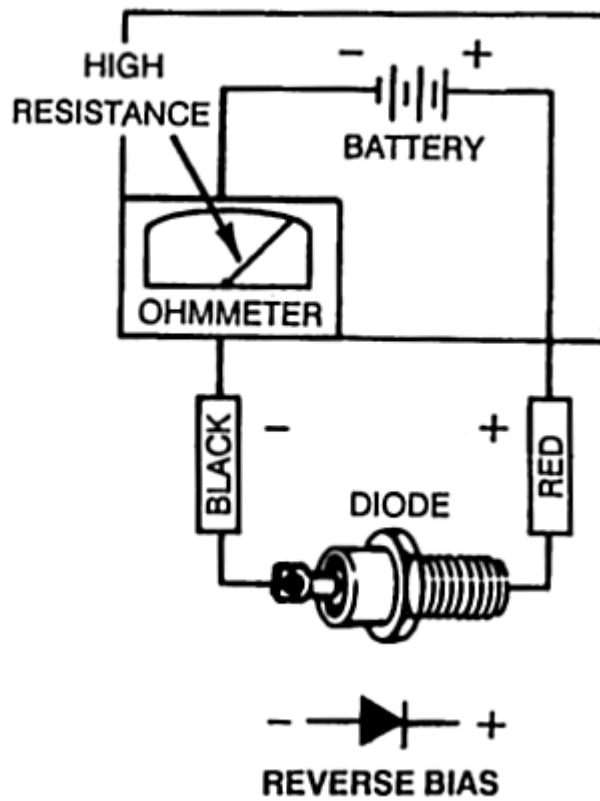
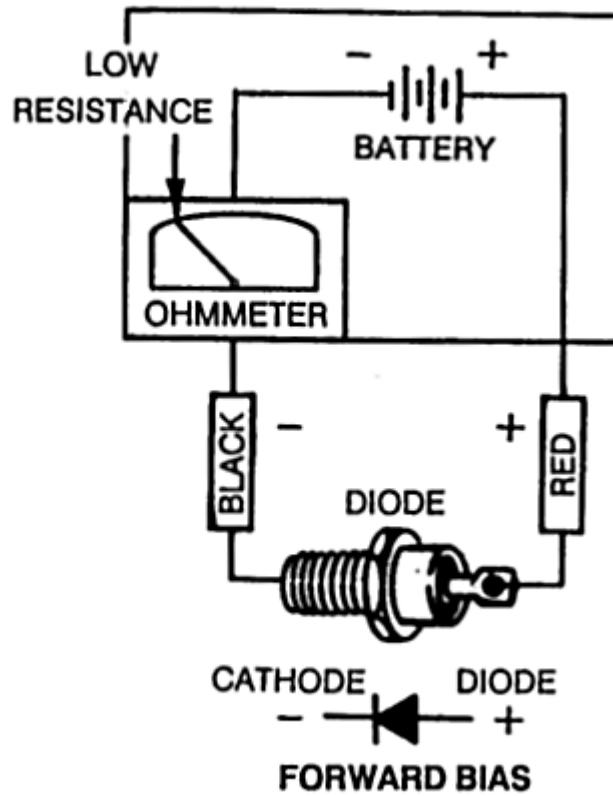
Belt-driven alternators use diodes that look exactly alike. This makes maximum use of the limited internal space. However, the diodes operate in two distinct manners. The negative diode passes current in the opposite direction that the positive diode passes current. Black coloring or writing indicates a negative diode; red coloring or writing indicates a positive diode. This can be further verified by the multimeter.



The polarity of the ohmmeter is indicated by the colored leads or jack polarity markings on the meter. Identifying the diode terminals can be done as follows:

- Connect the ohmmeter for forward bias. The ohmmeter will read a low resistance. If the ohmmeter reads a high resistance, reverse the ohmmeter leads.
- In forward bias, the negative meter lead determines the diode's cathode terminal.
- The positive meter lead now determines the anode.
- When the ohmmeter has the negative lead on the diode terminal, the positive ohmmeter lead on the diode housing, and the diode is forward bias, then the diode is considered negative.
- When the ohmmeter has the positive lead on the diode terminal, the negative ohmmeter lead on the diode housing, and the diode is forward bias, then the diode is considered positive.

In forward bias, the ohmmeter is correctly connected to the diode and indicates a low resistance, see below. The negative (black) lead is connected to the diode cathode, and the positive (red) lead is connected to the diode anode. Current is leaving the ohmmeter's battery by the negative terminal and completing a circuit through the diode, to the red lead, and back to the meter battery. In reverse bias, the ohmmeter is incorrectly connected to the diode. Current flow is restricted and the ohmmeter reads a high resistance. Remember, there are two different diodes in alternators that look physically identical.



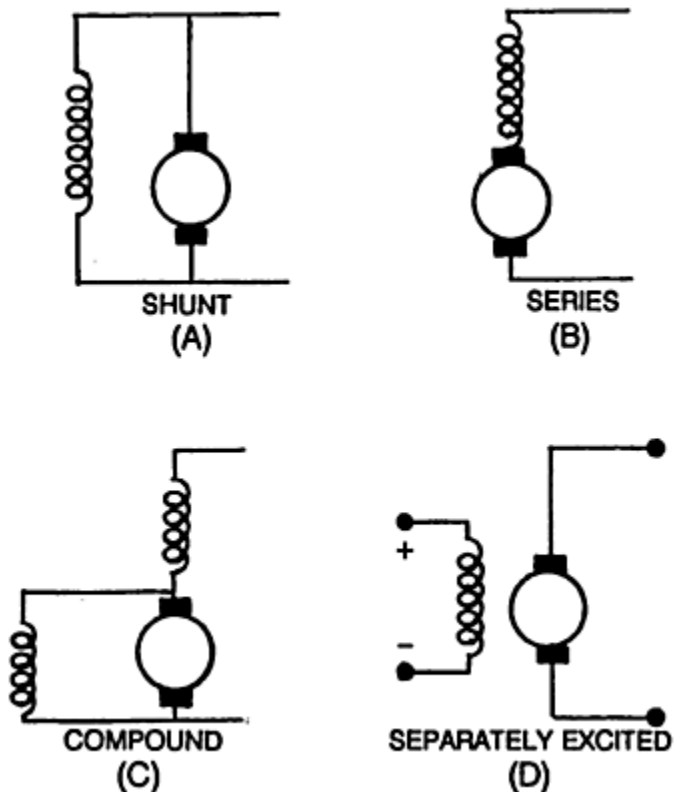
INTRODUCTION

DC motors have been extensively used on mobile equipment because they had a great advantage where precise speed control and varying loads are concerned, and DC current is available.

In all important aspects, DC motors are identical to DC generators. Many manufacturers make DC machines for use either as a DC motor or DC generator. The main differentiating factor between the motor and the generator is what the end user must electrically control. The end user must control what comes out of the generator and what goes into the motor. As with generators, the major classes of DC motors are --

- Shunt wound.
- Series wound.
- Compound wound.
- Separately excited.

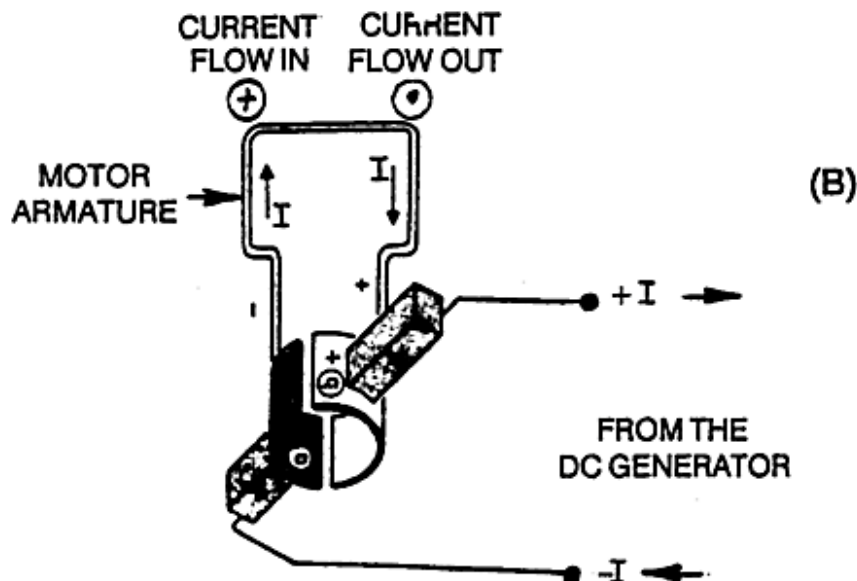
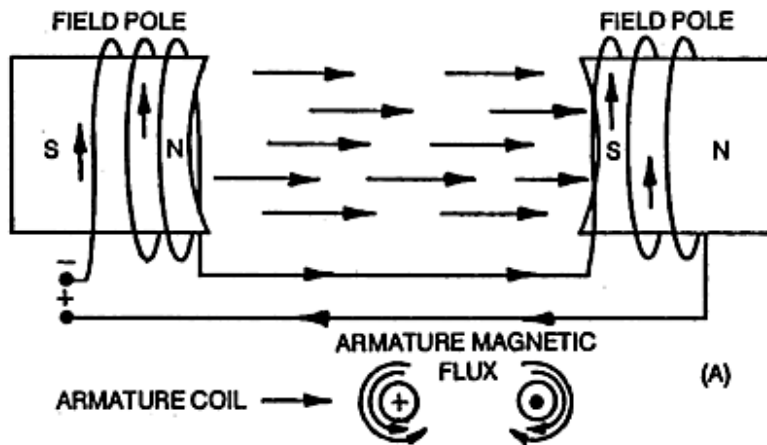
These types of motors differ only in the connection of the field circuits, see below. All four major classes of motors are widely used. This is in contrast to the generators, in which the compound wound type is used for nearly all general power applications.



PRINCIPLE OF DC MOTOR ROTATION

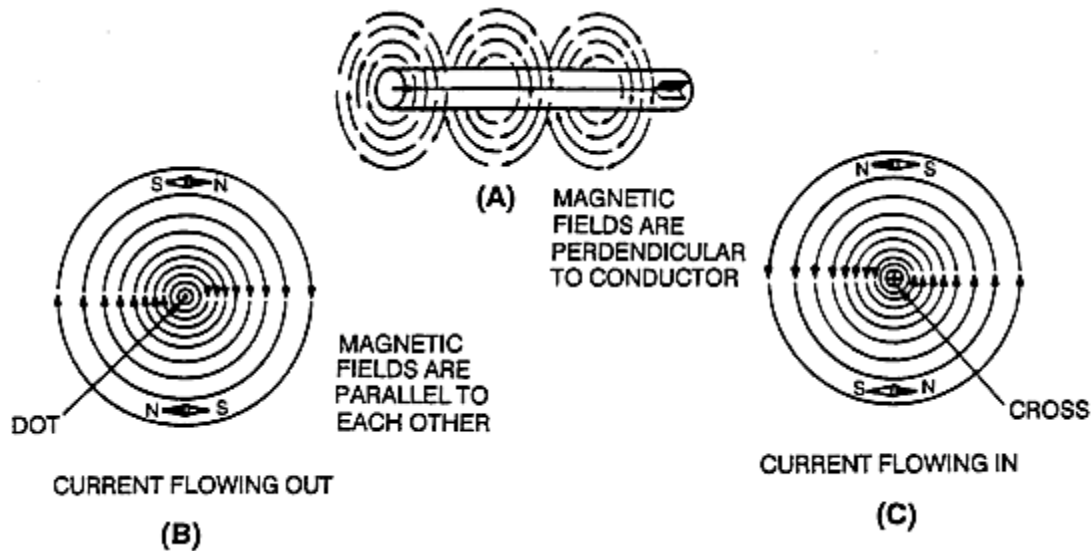
The operation of a DC motor depends on the attraction and repulsion principles of magnetism. When current is supplied to the field poles of a motor, the field poles turn into electromagnets. If a two-pole machine is used, north and south polarities are established toward the center of the machine.

View A below shows how the two field poles are wound to produce the opposite magnetic effect. The magnetic lines of force, between these two unlike magnetic poles, establish a direction of movement from the north polarity to the south polarity. By themselves, these lines of force from the field poles cannot do anything to force the motor's armature to rotate.



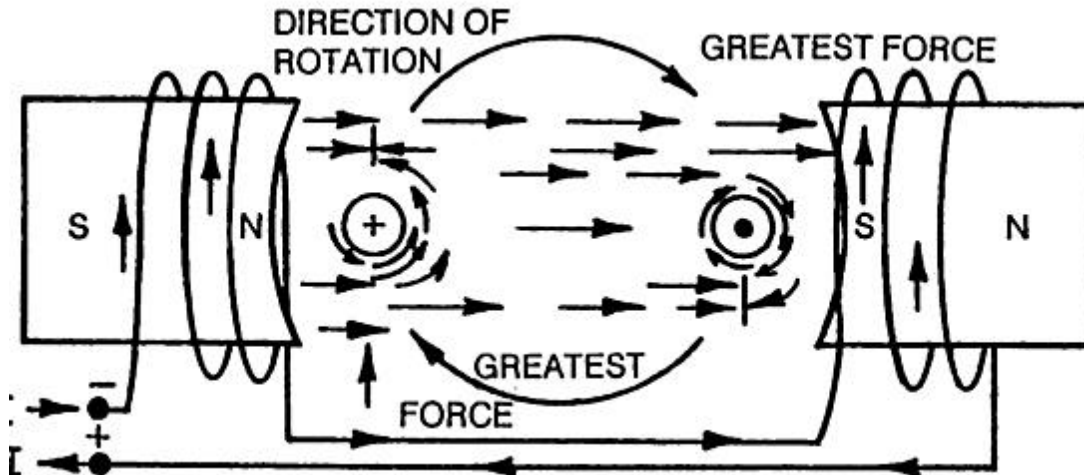
If current is supplied from the generator through the motor's brushes and commutator to the armature windings, a magnetic field results around the

armature windings (view B). DC motor torque depends on the principle that a current-carrying armature conductor has a magnetic force encircling it. These lines of force are determined by the left-hand rule for conductors. You can determine these lines of force when you know which direction the current flows through the conductor. If you visualize yourself grasping the insulated conductor in your left hand with your thumb extended in the direction of current flow, negative (-) to positive (+), your fingers will point in the direction of the magnetic lines of force. The figure below illustrates this point.



The current entering the motor armature windings and the magnetic lines of force that result around the armature windings interact with the magnetic lines of force from the field poles. Torque is produced in proportion to the current in the armature windings. The greater the armature current, the greater the motor torque. Additionally, the direction of current flow through the armature and the polarity of the field poles determine the direction that the armature will revolve.

The figure below shows the lines of force established around the armature coils. The cross signifies the current from the generator's negative terminal moving away from us into the motor armature. The dot represents the current moving toward us (and toward the positive generator terminal) in the motor armature. The left-hand rule establishes the lines of force around these armature conductors.



Combined armature and field magnetic lines of force.

The two field poles show their magnetic lines of force establishing a direction from north to south (left to right). The armature conductor magnetic lines of force are circular and are determined by the current direction. The following outline describes the combining of the current-carrying armature magnetic lines of force with the field pole magnetic lines of force:

- The circular lines of force in the cross conductor and the magnetic lines of force from the field poles effectively cancel out each other directly above the cross conductor.
- The circular lines of force below the cross conductor work with or add to each other's magnetic lines of force. In this way, the additive force below the cross conductor forces the conductor up through the canceled lines of force directly above it.
- The circular lines of force developed from the dot conductor effectively cancel the magnetic lines of force from the field poles directly below the dot conductor.
- The circular lines of force directly above the dot conductor add to the magnetic lines of force from the field poles. In this manner, the dot portion of the armature is moved down.

Since both the cross and the dot conductors are connected together and rotate at the center, the armature starts to turn. This turning force developed from the magnetic lines of force is known as torque. The amount of torque developed depends primarily on the current through the armature.

COUNTER EMF

Any time a conductor is moved in a magnetic field, an EMF is produced. When this occurs in a motor as a by-product of motor torque, the EMF is called counter EMF. This is because the EMF produced in the motor opposes the EMF of the generator. To distinguish between the two EMFs, the term "counter EMF" is applied to every component that is not a prime distribution system power-generating device. The rigs service generator, battery systems, and the emergency generator are EMF-designated devices.

Counter EMF is directly proportional to the speed of the armature and the field strength. That is, the counter EMF is increased or decreased if the speed is increased or decreased, respectively. The same is true if the field strength is increased or decreased.

Counter EMF is a form of resistance. Any resistance opposes and reduces the current. The greater the CEMF, the less current delivered to the motor armature. When the motor is first started, during that infinitesimal moment when the armature has not yet begun to turn, armature CEMF is at zero. Maximum current is available from the generator to the motor armature because the only resistance is in the motor wire.

CEMF is produced in the motor armature as it begins to turn. The faster the armature turns, the more CEMF is generated. This counter EMF reduces the current from the rigs service generator. The table below is a comparison of the armature speed, CEMF, motor armature current, and resulting motor torque for normal motor operations.

	START UP	NORMAL OPERATION	INCREASING LOAD
Motor Armature Speed (RPM)	Zero	Highest	Decreasing
CEMF	Zero	Highest	Decreasing
Armature Motor Current	Highest	Lowest	Increasing
Motor Torque	Highest	Lowest	Increasing

The CEMF restricts the current flow. When current in the motor armature is reduced so is the motor's torque. Since CEMF is proportional to the speed of a motor and current is indirectly proportional to CEMF, a motor automatically adjusts its speed to corresponding changes in load. When the motor's RPM decreases because of an increase in load, the CEMF is reduced, and current increases. The increased current produces greater torque, and the motor increases its RPM.

Most DC motors conform to Table 19-1. They will deviate only in the specific characteristics of that motor's individual design. For example, all torque is increased when the armature moves slowly. In the series motor, however, its design produces an unusually high value of motor torque. This becomes the characteristic of the series motor.

A motor is not designed to operate at the excessive current levels exhibited when it is first started. If the motor were unable to increase in speed because it was too heavily loaded, sufficient CEMF would be unavailable to reduce the generator's current. This excessive current would shortly burn out the motor. A motor must be allowed to come up to its rated speed rapidly.

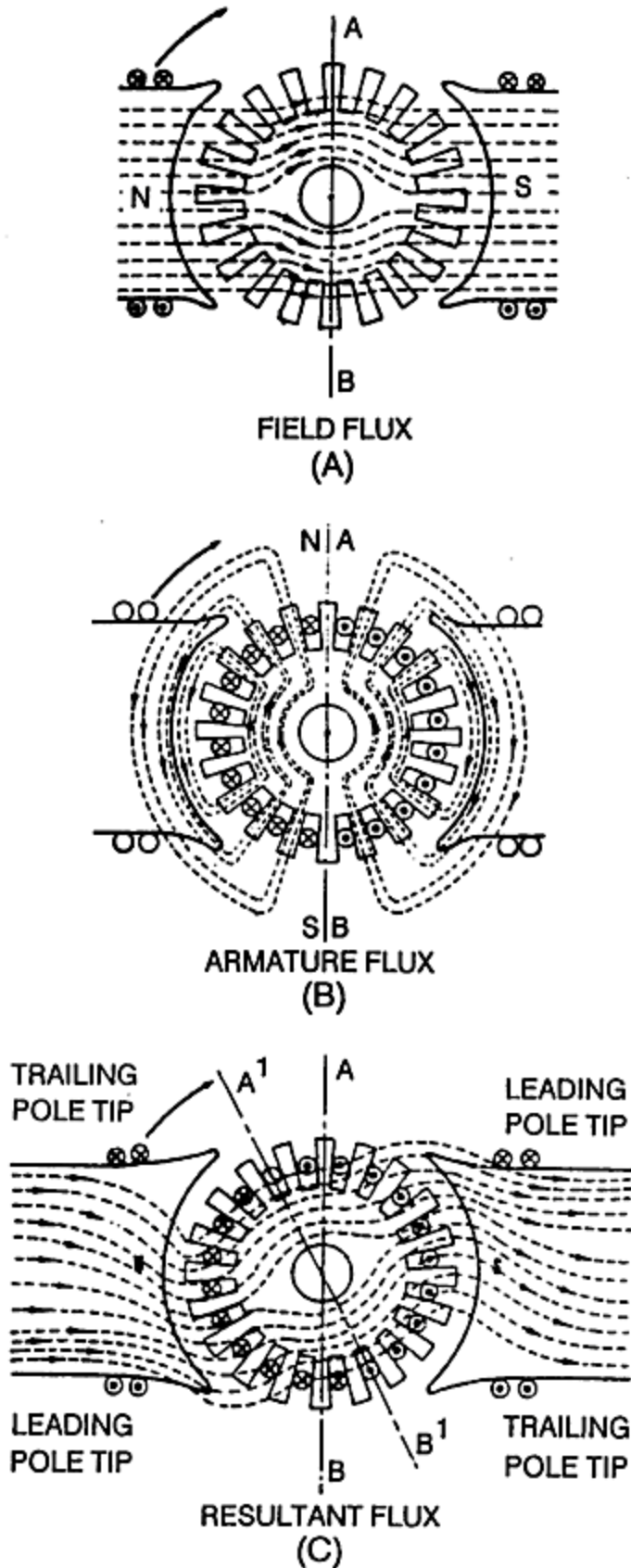
ARMATURE REACTION

There are individual magnetic lines of force from the field poles and the armature. Magnetic fields tend to combine. Additionally, the magnetic lines of force are distorted (or concentrated) by an iron core. The figure below shows the field flux (view A) and the armature flux (view B) individually. View C shows the distortion caused by the interaction of the two fields and the armature core movement. This distortion is known as armature reaction.

The armature current in a generator flows in the same direction as the generated EMF, but the armature current in a motor is forced to flow in the opposite direction to that of the CEMF. In a motor, the main field flux is always distorted in the opposite direction to armature rotation (view C); whereas in a generator, the main field flux is always distorted in the same direction as armature rotation. The resultant field in the motor (view C) is strengthened at the leading pole tips and weakened at the trailing pole tips. This action causes the neutral plane to shift to A'B'.

The armature reaction is overcome in a motor by the same methods used in the generator; that is, by the use of laminated pole tips with slotted ends, interposes, and compensating windings. In each case, the effect produced is the same as the results produced in the generator, but it is in the opposite direction.

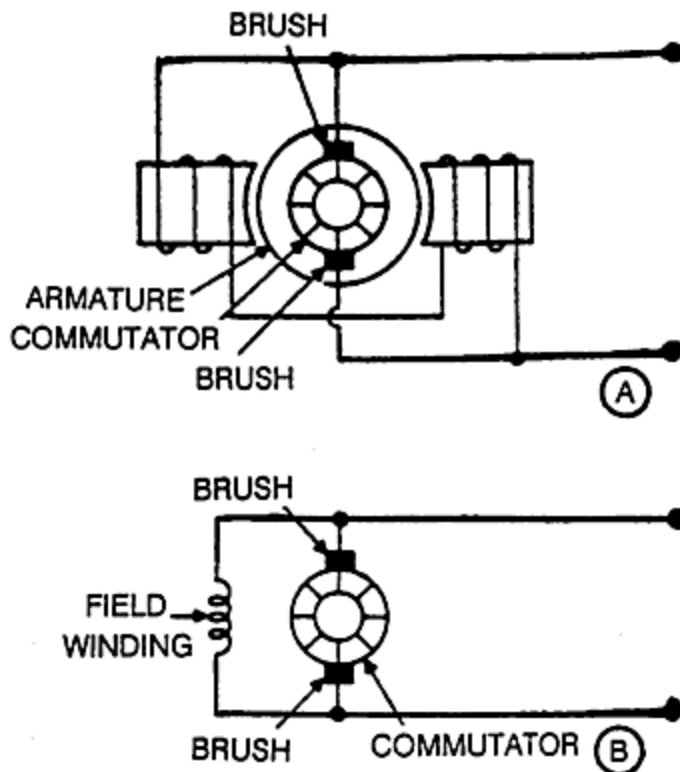
To further ensure successful commutation, small slots on the brush rigging permit a slight brush position adjustment. By placing a tachometer on the motor shaft, an indication of motor efficiency may be obtained. Adjust the brush position for the fastest armature rotation in the absence of sparking.



SHUNT WOUND MOTOR

The shunt wound motor is used where uniform speed, regardless of load, is wanted. It has reasonably good starting torque but is not suited for starting very heavy loads. It is therefore used where the starting load is not too heavy, as in blowers, or where the mechanical load is not applied until the motor has come up to speed. It is essentially a constant speed machine.

The shunt motor is electrically identical with the shunt generator diagramed below. It is considered a constant speed machine because speed does not ordinarily change more than 10 to 15 percent within the load limits.



The field pole circuit of a shunt motor is connected across the line and is thus in parallel with the motor armature. Both the motor armature and the shunt field are in parallel with the switchboard bus. If the supply voltage is constant, the current through the field pole coils and consequently the magnetic field will remain constant. The resistance in the field pole coils will change little. Hence, the current in the field poles will remain virtually constant. On the other hand, the resistance in the armature will change as the CEMF increases and decreases. This means that the current in the armature will vary inversely with the CEMF.

When there is no load on a shunt motor, the only torque necessary is that which is required to overcome friction and windage. (Windage is a mechanical loss due to the friction between the moving armature and the surrounding air.) The rotation of the armature coils through the field pole flux develops a CEMF. The

CEMF limits the armature current to the relatively small value required to maintain the necessary torque to run the motor at no load.

When an external load is applied to the shunt motor, it tends to slow down slightly. The slight decrease in speed causes a corresponding decrease in CEMF. If the armature resistance is low, the resulting increase in armature current and torque will be relatively large. Therefore, the torque is increased until it matches the resisting torque of the load. The speed of the motor will then remain constant at the new value as long as the load is constant. Conversely, if the load on the shunt motor is reduced, the motor tends to speed up slightly. The increased speed causes a corresponding increase in CEMF and a relatively large decrease in armature current and torque.

The amount of current flowing through the armature of a shunt motor depends on the load on the motor. The larger the load, the larger the current. Conversely, the smaller the load, the smaller the current. The change in speed causes a change in CEMF and armature current in each case.

No Field Condition

In order for a DC motor to turn, there must be the magnetic lines of force from the armature and the magnetic lines of force from the field poles. As shunt motors age and corrosion becomes a problem, a runaway condition may present itself. When the shunt field is opened and current is available only to the armature, the motor speed will increase dangerously.

It would seem that without the shunt field the motor would stop. However, the large metal pole shoes of the DC machine support a fairly substantial residual magnetic field. This residual magnetism is just enough to ensure that the magnetic principles that sustain the armature movement are present.

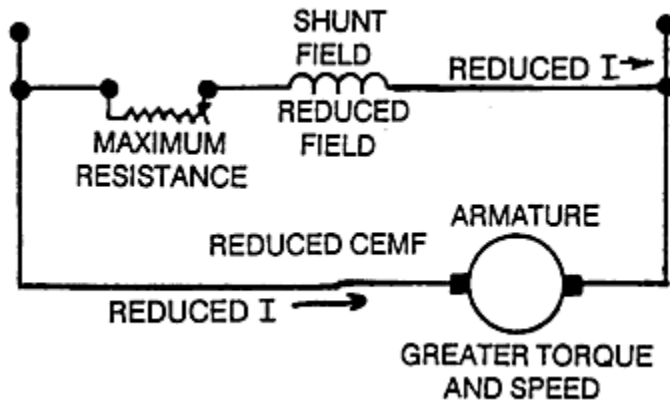
The residual magnetic field is not, however, substantial enough to develop a suitable CEMF in the armature. Without the proper proportion of CEMF, current flow to the armature increases. The more current to the armature, the greater the torque and the faster the damaged shunt motor rotates. A no field release is employed by shunt motors to prevent such a casualty. When the shunt field is de-energized, the no field release disconnects the motor from the circuit.

Speed Control

The magnetic field from the shunt motor field poles is necessary to maintain an adequate CEMF in the motor armature. As long as the CEMF is maintained, the current to the armature is restricted, and the motor operates at its rated speed.

Above Normal Speed Control. DC motors with shunt fields (both shunt and compound motors) can control the speed above a certain operating (or base) point. This is called speed control above normal speed. The figure below shows a shunt motor with full field resistance. A rheostat in series with the shunt field will determine the amount of resistance in the shunt field. The greater the

resistance in the shunt field, the less current will enter the shunt field. The reduced current in the shunt field means that the magnetic field has been reduced. With a reduction in magnetic field, there is a reduction in armature CEMF. When the CEMF is reduced, the motor armature receives more current. The more current in the armature, the greater the torque developed. Therefore, motor speed increases.



Below Normal Speed Control. To reduce the speed of the shunt or any DC motor, it is necessary to reduce the current to the armature. A rheostat in series with the armature will increase the resistance in the armature circuit or decrease the resistance in the armature circuit. As armature resistance is increased, current to the armature is decreased. The decrease in armature current decreases the torque and armature speed. Control of the armature circuit in this manner does not substantially affect the CEMF created from the rotating armature conductors within the field poles' strong magnetic field.

Use of Shunt Motors

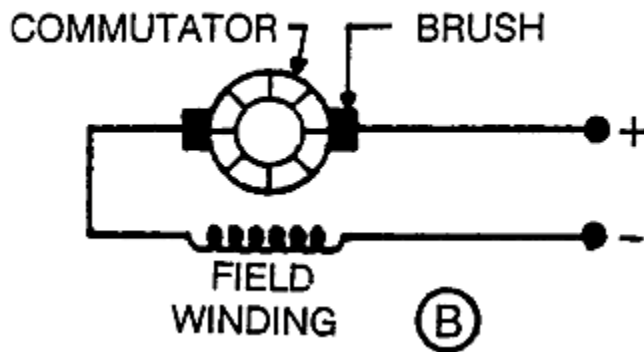
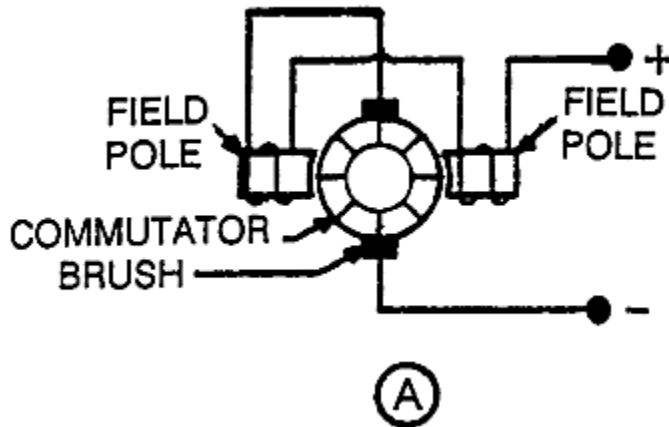
The speed of a shunt motor remains nearly constant for a given field current. The constant speed characteristic makes the use of shunt motors desirable for driving machine tools or any other device that requires a constant speed driving source.

SERIES WOUND MOTOR

Where there is a wide variation in load or where the motor must start under a heavy load, series motors have desirable features not found in shunt motors. The series wound motor is used where high starting torque and varying speed is desired. The armature and the series field are connected in series. With high armature and field currents, it has a very high starting torque and is well suited for starting heavy loads such as the diesel engines.

The figure below illustrates the series wound motor. Notice that the series field is in series with the armature windings. When the motor is first started, with the negligible effects of the CEMF, current flow through the armature is high. Since the armature and the series field are in series, the current in the armature is the same current through the series winding. TM large current develops a very

strong magnetic field and results in an extremely high torque. Conversely, if the motor is operating at rated speed, the CEMF will be very high, and the current in the series field winding and armature is reduced proportionally. This means that the series motor can develop a very high torque and respond to increases in loading (reductions in armature RPM) rapidly.



Series Motor Speed

The series motor will continue to increase in speed as long as there is more torque developed than is necessary to turn the load. This additional torque is called acceleration torque.

When a series motor is heavily loaded, it slows and produces more torque. As the load is removed, the motor increases in speed. If the load is suddenly removed from the series motor, the accelerating torque is just enough to continue to increase the motor's speed. The continuously increasing speed can destroy the motor.

No-Load Operation

With the load removed and armature speed increasing, CEMF should also increase. However, CEMF is a by-product of a conductor moving in a magnetic field. The series motor field varies with armature current, and CEMF decreases as the field decreases.

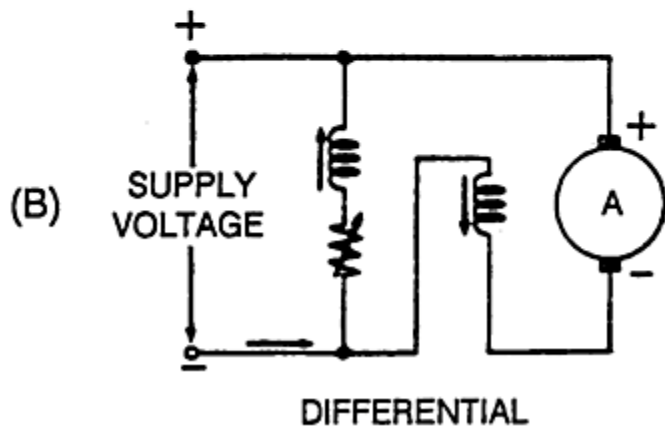
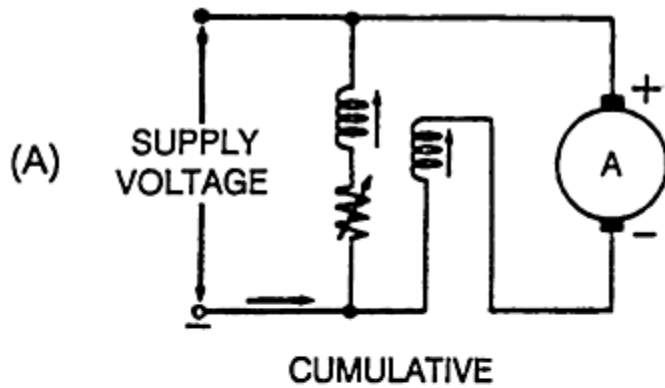
There is sufficient CEMF to reduce current to the armature, but in doing so, CEMF also limits the current to the series field pole windings. The series field still passes enough current to overcome windage and friction and develop an accelerating torque. However, at a reduced current flow, there is not enough of a magnetic field established to generate a proportional CEMF at these reduced current levels. Even though CEMF increases as speed increases, the overall reduction of current through the series field winding makes it impossible for a magnetic field to produce the CEMF necessary to eliminate the acceleration torque. Due to internal losses, the CEMF will always be overcome by the EMF in a branch circuit. After all, the EMF from the power supply was essential to the creation of the CEMF. The difference between the shunt field and the series field is that the shunt field current is not changed by the armature current.

When the load is removed from the series motor, enough current and accelerating torque is available to exceed the feeble CEMF. Armature RPM increases endlessly.

To prevent the series motor from overspeeding and destroying itself, many series motors are provided with a small shunt field to maintain adequate CEMF if the load is accidentally removed from the motor.

COMPOUND MOTORS

Compound motors, like compound generators, have both a shunt and a series field. In most cases, the series winding is connected so that its magnetic field aids that of the shunt winding magnetic field. The current entering both the series field and the shunt field is moving in the same direction. Both fields produce the same magnetic field and aid each other. Motors of this type are called cumulative compound motors. In the cumulative motor, the speed decreases (when a load is applied more rapidly than it does in a shunt motor, but less rapidly than in a series motor. The cumulative compound motor is used where reasonably uniform speed combined with good starting torque is needed.



The differential compound motor is used only for low power work. View B above shows the opposing magnetic fields of the differential compound motor. Notice that the series winding's magnetic field is connected to oppose the shunt winding's magnetic field. The differential compound motor maintains even better constant speed, within its load limit, than the shunt motor. But it has very poor starting torque and is unable to handle serious overloads.

INTRODUCTION

The distribution system is an extension of the generator. All electrical loads are connected in parallel with the generator terminals through connection points (nodes) at the switchboards and distribution panels. Through proper design, large cables (feeders) provide power to bus bars inside electrical cabinets. The use of a single feeder cable will eliminate dozens of individual parallel cables that would have otherwise been needed for the connection between the generator and each load.

The distribution system is also designed to protect the overall electrical environment from electrical component casualties. Circuit breakers and fuses are installed in switchboards and distribution panels to separate abnormally operating electrical apparatus from the rest of the system. Each circuit protective device, from the generator to the load, is set at decreasingly smaller ampacity increments. When all overcurrent and short circuit protective devices are properly selected and correctly adjusted, selective tripping can be provided. Selective tripping allows an abnormal circuit to be separated from the electrical distribution system very close to the fault.

GROUNDING

To understand the type of electrical system used, the term "grounding" must be understood. This is the most misunderstood term in electricity today. For the most part, mobile equipment has an entirely ungrounded current-carrying system.

Earth vs. chassis grounding:

- Earth or normal grounding in a stationary AC application, such as a house or building provides a return path for leakage or fault current. Normally all current flows through the insulated wires. If there is a cut or breakdown in the insulation of the system, there will be another path for current to flow back to the power source. This leakage current can flow through the bare copper "ground" wire, metallic water pipes, and in some cases through the earth.
- Chassis grounding in DC two-wire isolated system is a return path for leakage or fault current. Again, normally all current flows through the insulated wires. In a non-isolated system, where a machine's frame or chassis is used as the negative current return path. The positive insulated wire is connected to an insulated terminal or wire of a load and the negative side is connected to the load's frame.

WARNING

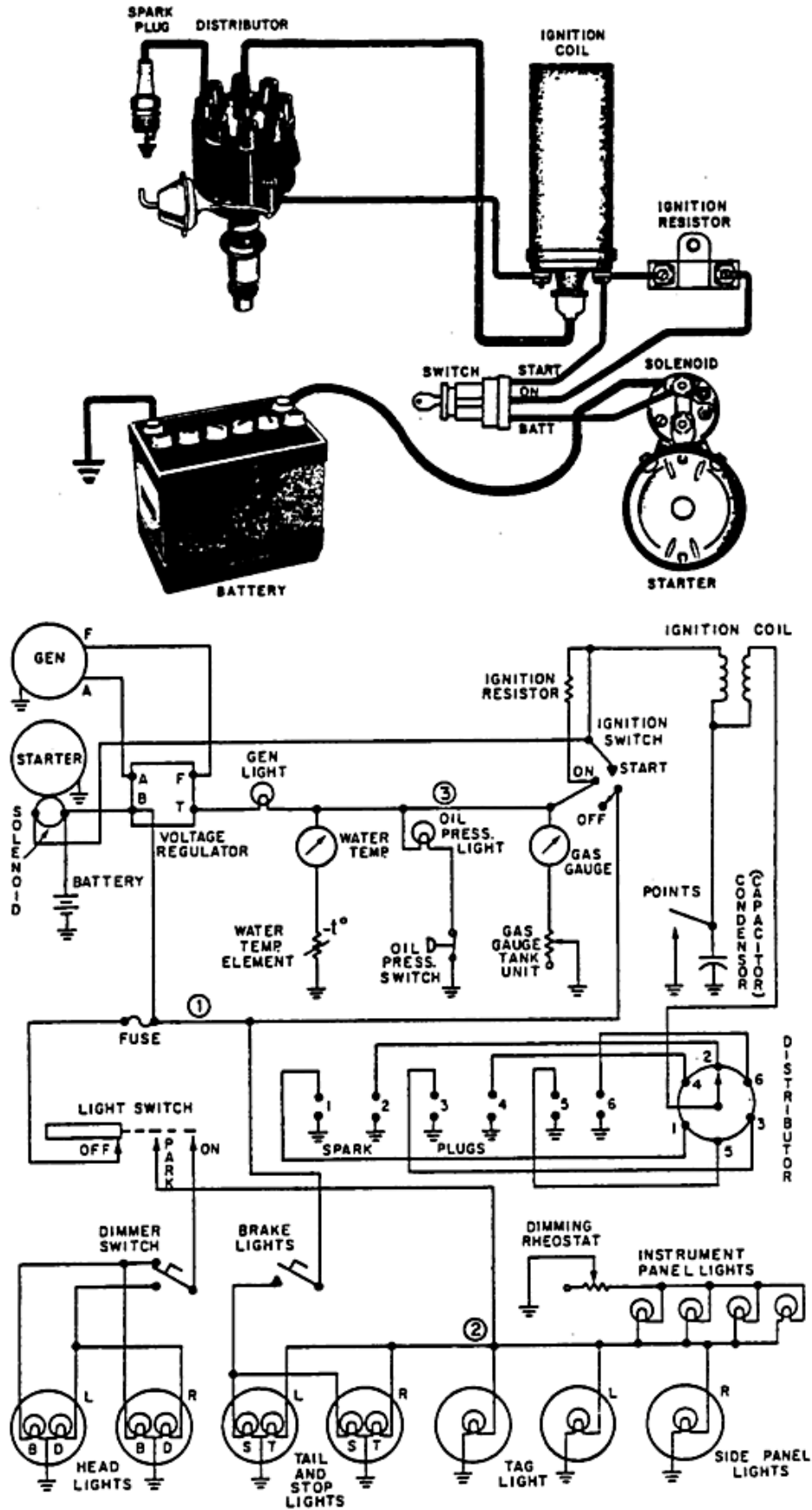
All electrical component enclosures, switchboards, motor housings, generator frames, and so forth must be grounded for safety.

The definitions of ground and grounded do not state whether or not the conductive material carries current. Engineers ground components for two reasons:

- To carry current through a structural component to complete a circuit under normal operating conditions.
- To carry current through a structural component only under abnormal electrical conditions. This is not designed to complete a circuit for normal electrical operations.

The "grounded" system of some mobile equipment has current traveling through the chassis, engine block, and all connected metal. The frame of the equipment represents the negative conductors of its electrical system. All circuits are completed from the negative battery terminal through the chassis, the electrical loads, positive wires, and back to the positive battery terminal. The ground symbol identifies the point in the electrical circuit that connects to the metallic structure. All the ground symbols in the figure below are connected like a node, as if the entire automobile frame was a giant connector.

Recently with the use of more electronics, such as microprocessors and semiconductors, in mobile equipment, there is a need to reduce the chassis / frame as a return path for current. The 2-wire method has become predominant to minimize "circulating ground current" in equipment. Electronic devices typically operate in the micro-amp (μA) or milli-amp (mA) range. These low current levels make them susceptible to unwanted signals or damage caused by circulating ground currents. In some cases the signal will effect the electronics to cause an unwanted operation or damage the circuitry enough to render the device useless.

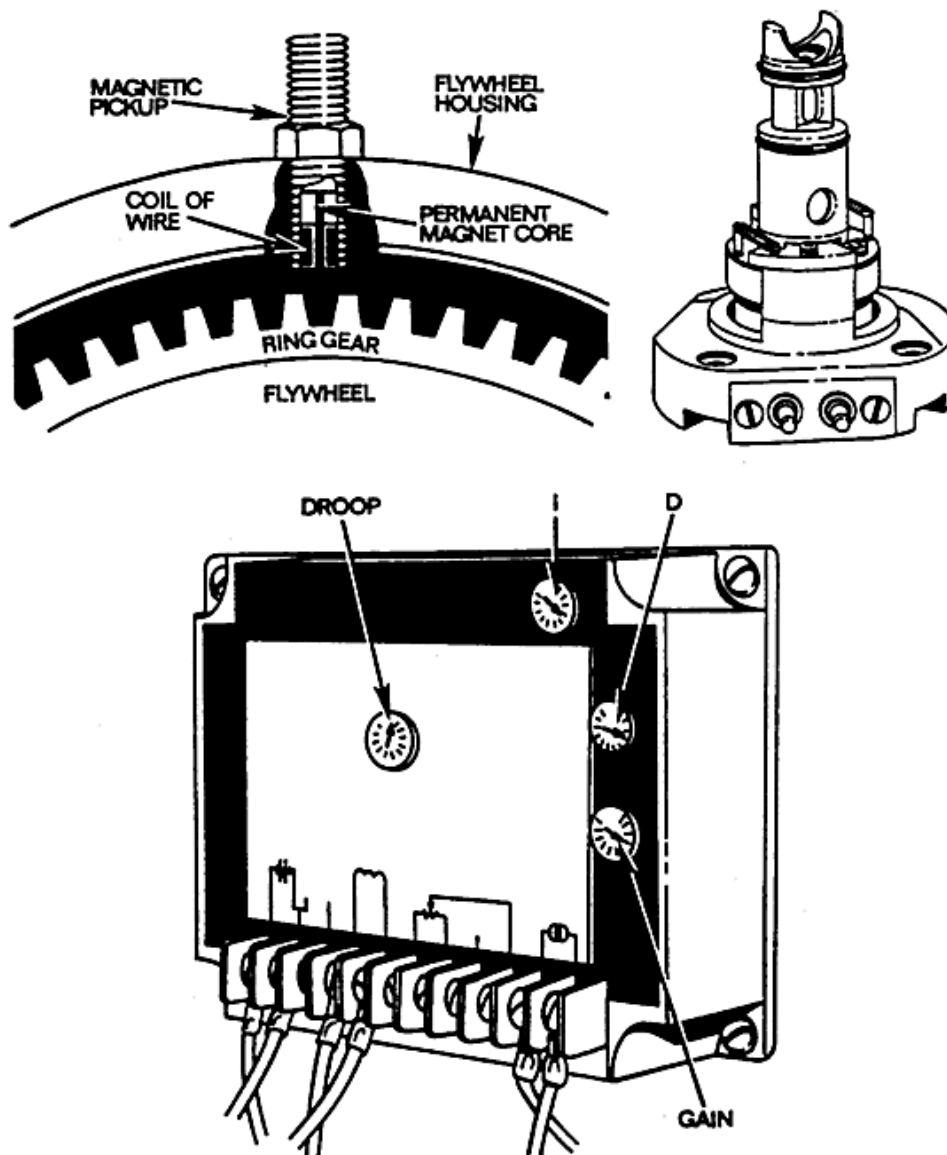


ELECTRONIC GOVERNORS

Electronic fuel control (EFC) and governing system. The following information is provided as introductory information only. Specific information is available from the equipment technical manuals and manufacturer's manuals.

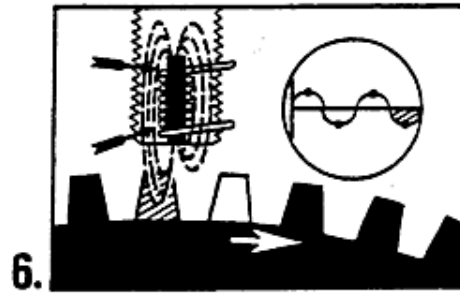
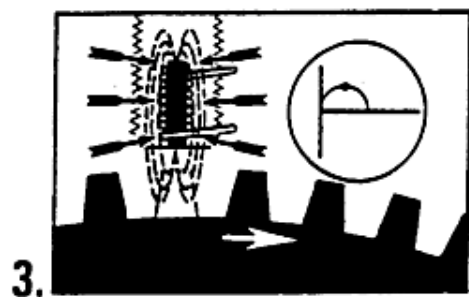
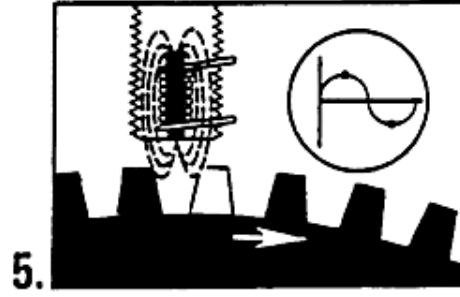
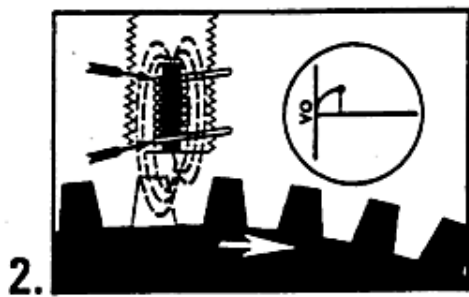
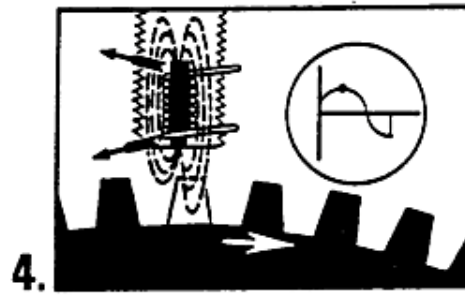
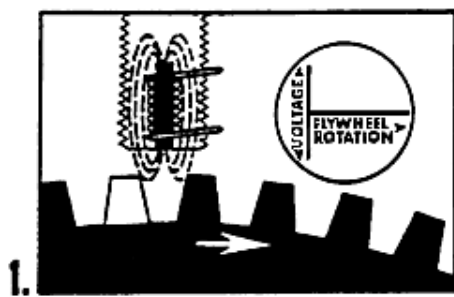
The EFC system will be made up of three basic units, shown below:

- Electronic speed sensor, magnetic pickup (MPU).
- Electronic control box, governor control.
- Electronic actuator, fuel delivery.



The elimination of most throttle controls and linkages means that the system is less maintenance-intensive than current fuel control systems.

The MPU is an electromagnetic component mounted through the flywheel housing, see figure below. The MPU is a permanent magnet with the circuit from the governor control tightly wrapped around it. The MPU comes in close proximity with the teeth of the flywheel. As the teeth from the flywheel move past the magnetic field from the MPU, the MPU's magnetic field becomes distorted. The motion of the distorted magnetic field induces an EMF into the governor control circuit wrapped around the magnet. As the flywheel teeth move further past the MPU, another portion of the MPU field becomes distorted in a like but opposite manner. This magnetic field motion in the MPU induces an EMF in the opposite direction as previous. The signal developed in the MPU is sent to the governor control. The cycles per second can be easily converted to revolutions per minute. This provides the governor with an indication of prime mover speed. The faster the flywheel turns, the faster the induced EMF frequency. In this manner, the governor control senses the changes in speed.



The governor control interprets these speed changes and, depending on the setting of the controls, provides an electrical signal to the actuator port.

The actuator is basically a solenoid valve that admits fuel to the engine in a quantity determined by the signal from the governor control. The slower the speed of the prime mover, the more the governor control electrically opens the fuel port. The faster the prime mover speed, the smaller the quantity of fuel delivered through the actuator port.

INTRODUCTION

The basic items found in the equipment's distribution have been presented. Power-consumers, such as motors and resistors, and those non-power consuming devices, such as circuit breakers and switches, have been examined. Generators, through the distribution system, provide power to the loads and switches that control or protect those loads. How these loads are controlled and protected between the last lighting or power panel will now be discussed.

WIRING SCHEMATICS

Diagrams are used to accurately portray the electrical system. Over the years, many techniques have been used to simplify the diagram for the reader. These attempts often produced more questions than they answered. Symbols were not standardized, and pictorial schematics showed the electrical system in various degrees of accuracy. Often the illustrator took for granted that his codes could be understood. In effect, there were no industry standards. Although each diagram might be electrically accurate, it was not developed for uniform individual interpretation. Today, as electrical systems become more complex, the electrical community has adopted specific standards to allow a more universal comprehension of the electrical circuits they describe. Up-to-date industry standards have been presented throughout this text. However, you will still find many variations due to physical constraints, cost, and the broad time span encompassing the industry.

BASIC DIAGRAM

The previous chapter used a wiring diagram of an automotive system in describing the power supply and its distribution to individual loads. This provided abroad overall view of the main electrical system. This is an example of one method to illustrate an electrical system.

Power Circuit

The power circuit usually consists of heavier cables used to carry the higher currents necessary to operate large components. Power circuits can be three-phase, single-phase, or direct current. In the majority of cases, the power circuit will always carry the highest current or voltage from the branch circuit.

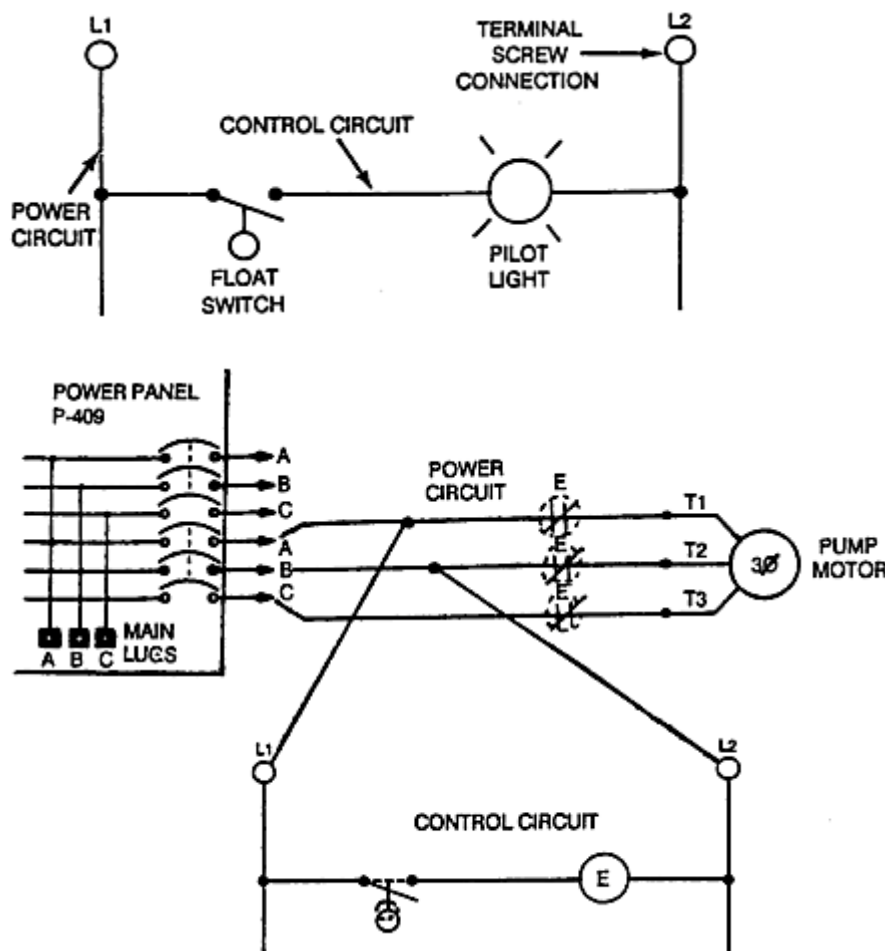
Control Circuit

The control circuit is derived directly from the power circuit. The control circuit provides power to the timers, relays, and switches necessary to control the operating contacts of the main component in the power circuit. The control circuit "controls" the normally open contacts in the power circuit that turn on or turn off the main component.

The control circuit is almost always a single-phase derivative from a three-phase power circuit. The control circuit will almost always consist of cables intended to carry less ampacity or low voltages than the power circuit.

The control circuit provides the logic behind the operation of the main component in the power circuit. The heavy vertical lines, L1 and L2, are connected to the distribution system in an immediate and convenient manner. The control circuit consists of an electrical load, the pilot light, and a control device (the float switch). Whenever the float switch rises and completes a circuit between L1 and L2, the pilot light will light.

The pilot light in the figure below could just as easily be replaced with a relay. If the relay physically operated three normally closed contacts and these contacts were placed in the power supply lines of a three-phase motor, then the motor operation would indirectly be controlled by the float switch.



As long as the float switch was in the open position (down), the E relay would not be energized. The contacts the E relay controlled would be closed, and the pump motor would run. When the float rose sufficiently to complete the control circuit, the E relay would become energized. When the relay was energized, all its contacts would change position. This means that the three E contacts would

open the power circuit to the pump motor, and the motor would stop. This three-phase circuit is controlled with a simple single-phase circuit. The coil code letter E is used to make a point E simply shows possession. All E contacts are controlled by the E coil. An E coil does not control an X contact or any other contact not labeled E.

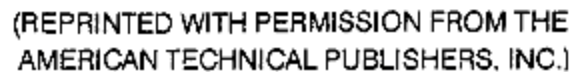
LADDER DIAGRAM OR SCHEMATIC

The line diagram, or ladder diagram, is constructed to show the basic operation of the electrical control circuit and explain the process, in a logical order, of the electrical sequence of events. This diagram does not show the actual wiring present in the system and may even eliminate actual connections not necessary for the understanding of the circuit's operation.

The line diagram shows specifically --

- The power source supply lines provided by the power circuit, represented in heavier black lines generally running vertically.
- The control circuit, containing the controlling devices and the loads, represented by thin lines, generally running horizontally.
- The relationship of the control devices to the loads they control.

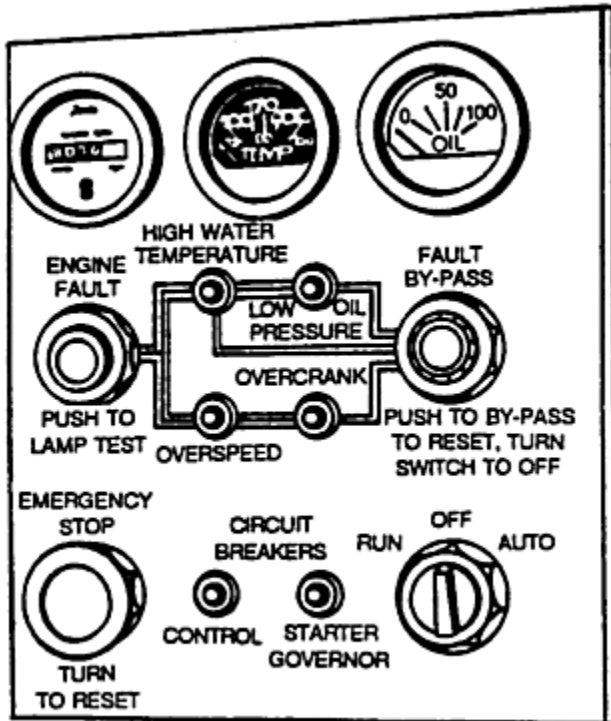
The figure below shows another line diagram. The operating coil and the pilot light represent the electrical loads in this control circuit. The stop, start, auxiliary contacts, and overload contacts represent the controlling devices.



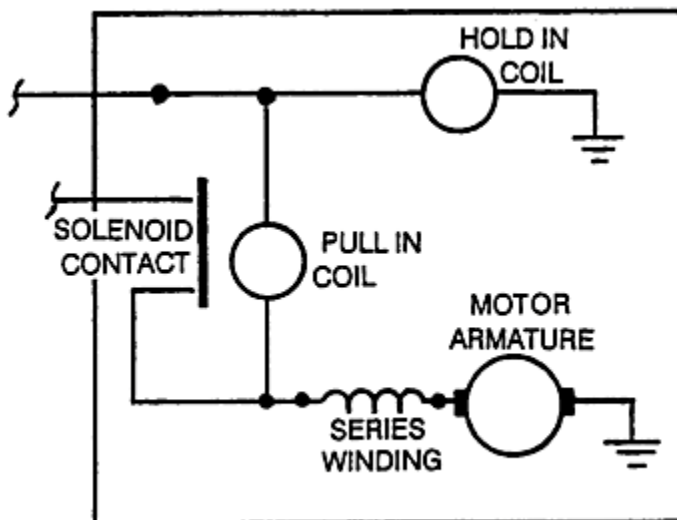
Page 4 of 10

[illegible]

Now that some components and control devices have been identified on the line diagram, the wiring diagram must be consulted to locate the actual terminal connections and component locations. The figure below shows the actual equipment instrument panel. The equipment shows a complex system of wires and components, some of which you are seeking. The wiring diagram will simplify this search.



The wiring diagram shows the actual component location and the physical run of the wires. It also shows some component parts. The figure below shows the electrical interior of the starter motor and solenoid.



BASIC CIRCUIT LOGIC

Electrical components are confined by the series and parallel rules learned earlier. These rules are essential in the understanding of the electrical diagram. To place the series and parallel rules into perspective, it is necessary to reexamine the line diagram. Every resistor, motor, coil, or indicating lamp is

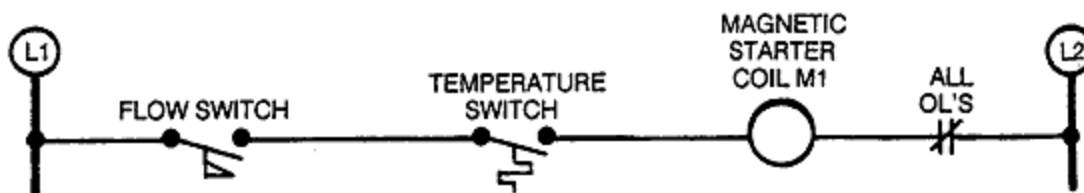
designed to operate at a specific voltage value. If all these loads require 24 volts DC and they are connected in parallel, then the voltage supply can properly provide 24 volts to each device. If as few as two 24-volt components were connected in series, the 24-volt power supply could not provide enough voltage to operate them properly. For this reason, loads are generally restricted to one load per line. Each component is provided with access to a positive potential and a negative potential. In alternating current, this is still true. AC provides alternating differences in potential 120 times a second at 60 hertz.

Control Device Locations

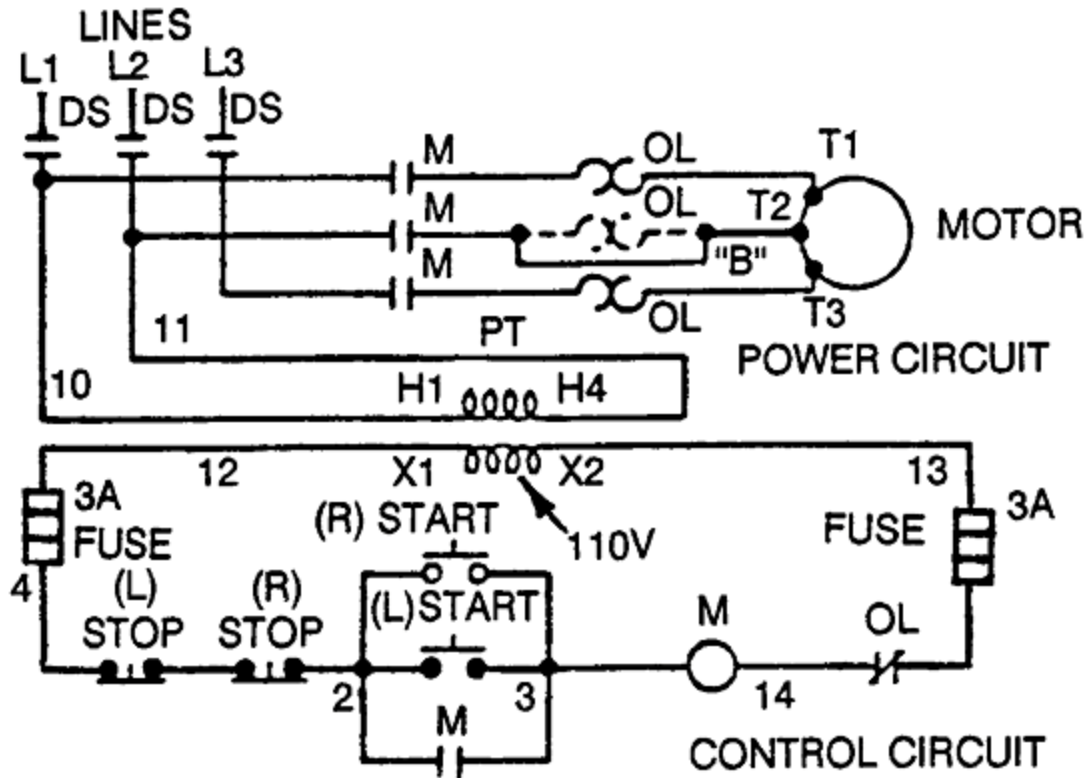
Components that consume power are always considered electrical loads. Control devices are those items that interrupt a circuit for specific reasons. Control devices should not consume power. A push button, contact, and pressure switch are components that do not consume power because there is no resistance to the flow of current when they are closed. When these devices are open, the circuit is broken, and current cannot flow. It is in the engineer's favor to locate all controlling devices in the same branch circuit as the component he is investigating. It is easier to troubleshoot a system when these components and their relationship to the load become identified. Control devices are generally located between L1 and the load. The location is subject to the constraints of room and cost and thus may be placed elsewhere in the circuit out of necessity.

Overload Placement

When overload protective devices are used in control circuits as a means of protecting motors from overload conditions, they will be located between the control circuit load and L2. The figure below shows the magnetic motor starter coil and an overload. The overload de-energizes the control circuit when it opens. This is not to protect the control circuit, but rather the motor located in the power circuit not shown.

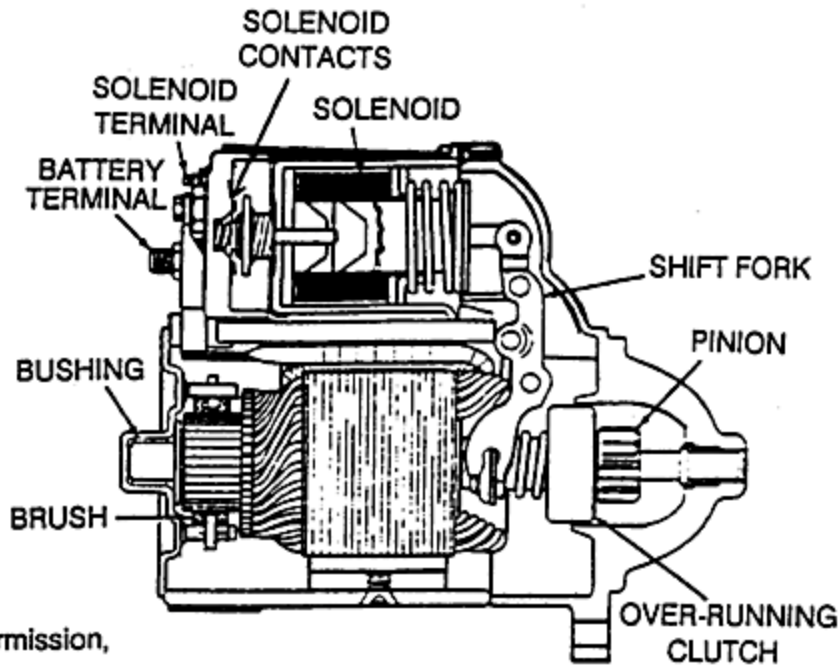


When the overload device is used to protect the control circuit, such as a fuse or circuit breaker, then it will be located in the power supply line before the control circuit wiring, see figure below.



STARTER MOTOR SOLENOID

The starter solenoid has two different coils. Both of these coils are needed to shift the starter pinion into mesh with the flywheel and to close the solenoid contacts.



(Reprinted with permission,
copyright by Goodheart-Willcox.)

Pull-In Coil

The pull-in coil is made of heavy copper conductors. This is necessary because the current that is going to go through the armature and series winding will also go through the pull-in coil. The armature, series winding, and pull-in coil are all heavy-gauge copper conductors of low resistance. The current draw by a slow-moving series motor is enormous.

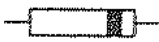
The high current going through the pull-in coil, acting in conjunction with the hold-in coil, pulls the shifting fork and moves the pinion into position with the flywheel. If this extremely high current were to pass through the pull-in coil for more than a moment, the pull-in coil would overheat and burn up. As the shifting fork is pulling the pinion into position with the flywheel teeth, contacts S-1 in the starter motor close and eliminate the pull-in coil from the circuit. Notice how both sides of the pull-in coil have the same positive polarity (and therefore no difference in polarity).



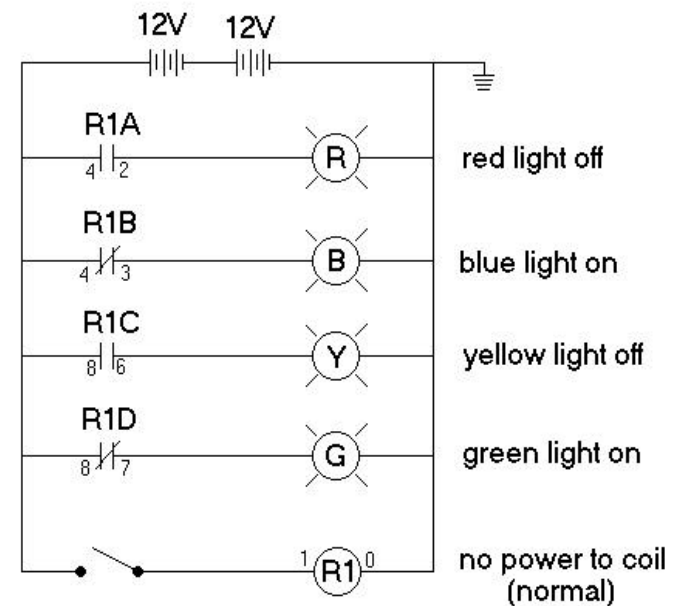
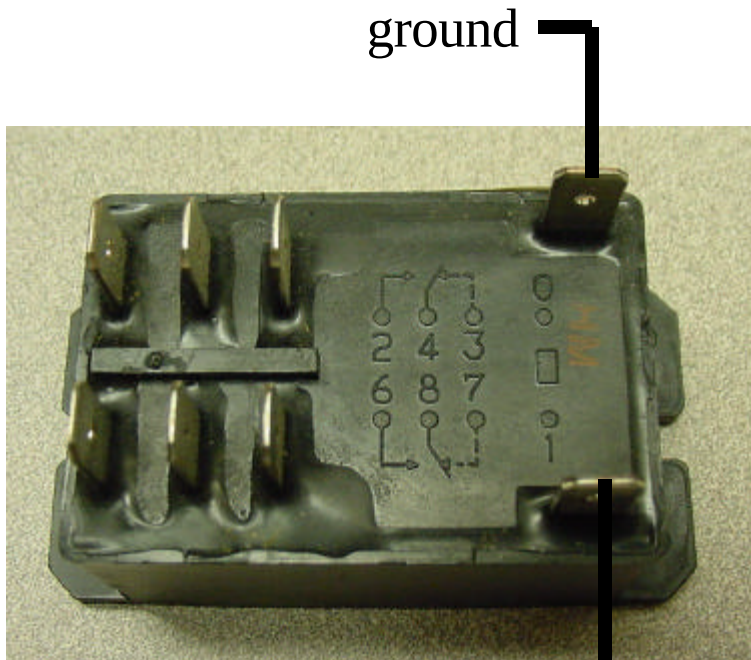
Hold-In Coil

Page 10 of 10

General T3W Electrical System and Murphy shutdown scheme

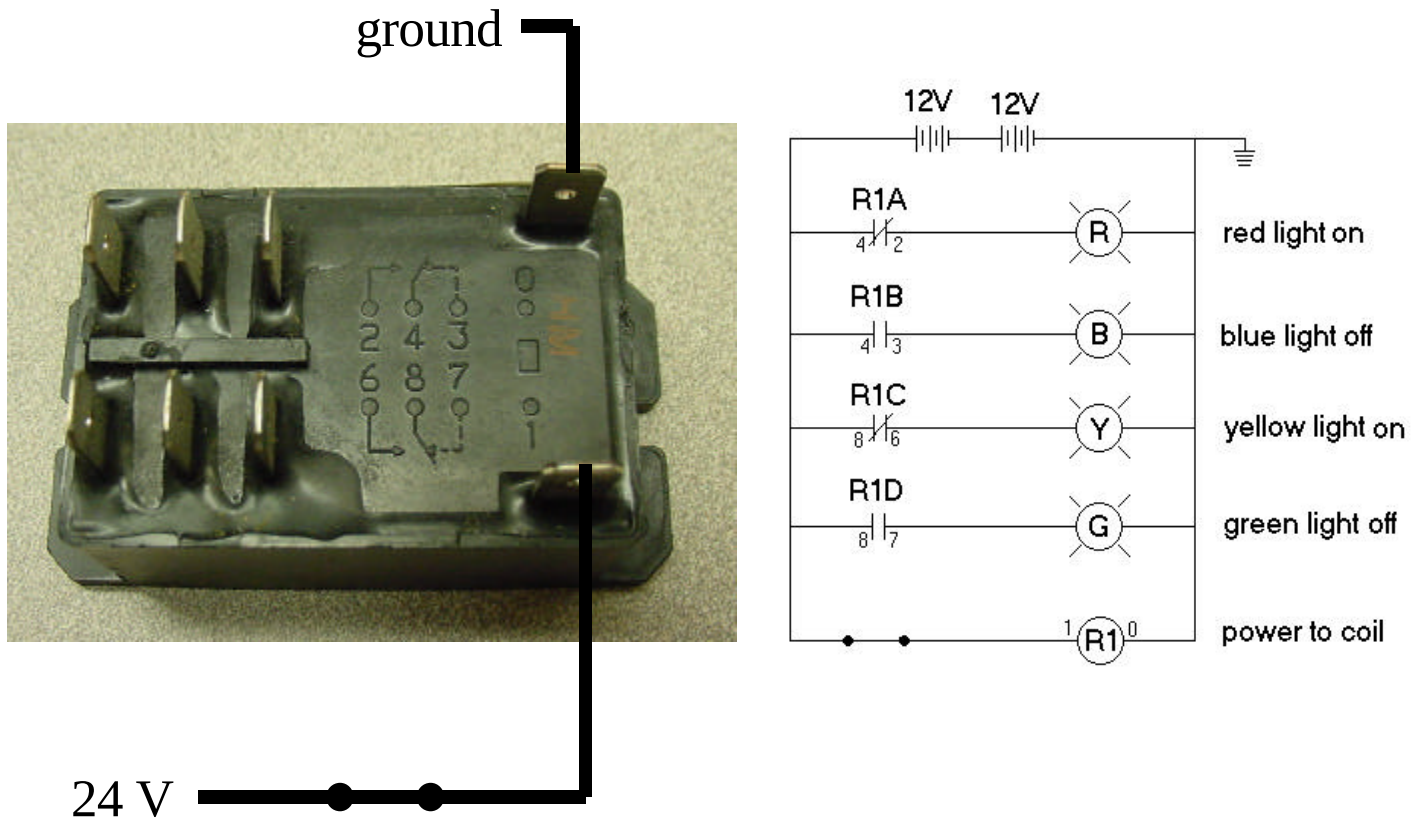
SYMBOL LEGEND	
	LIGHT
	FUSE
	CIRCUIT BREAKER
	MAGNETIC FIELD DEVICE
	SWITCH - OPEN
	SWITCH - CLOSED
	RELAY CONTACT - N.O.
	RELAY CONTACT - N.C.
	DIODE = 
	WIRE NUT

Relay Operation - No Power to Coil

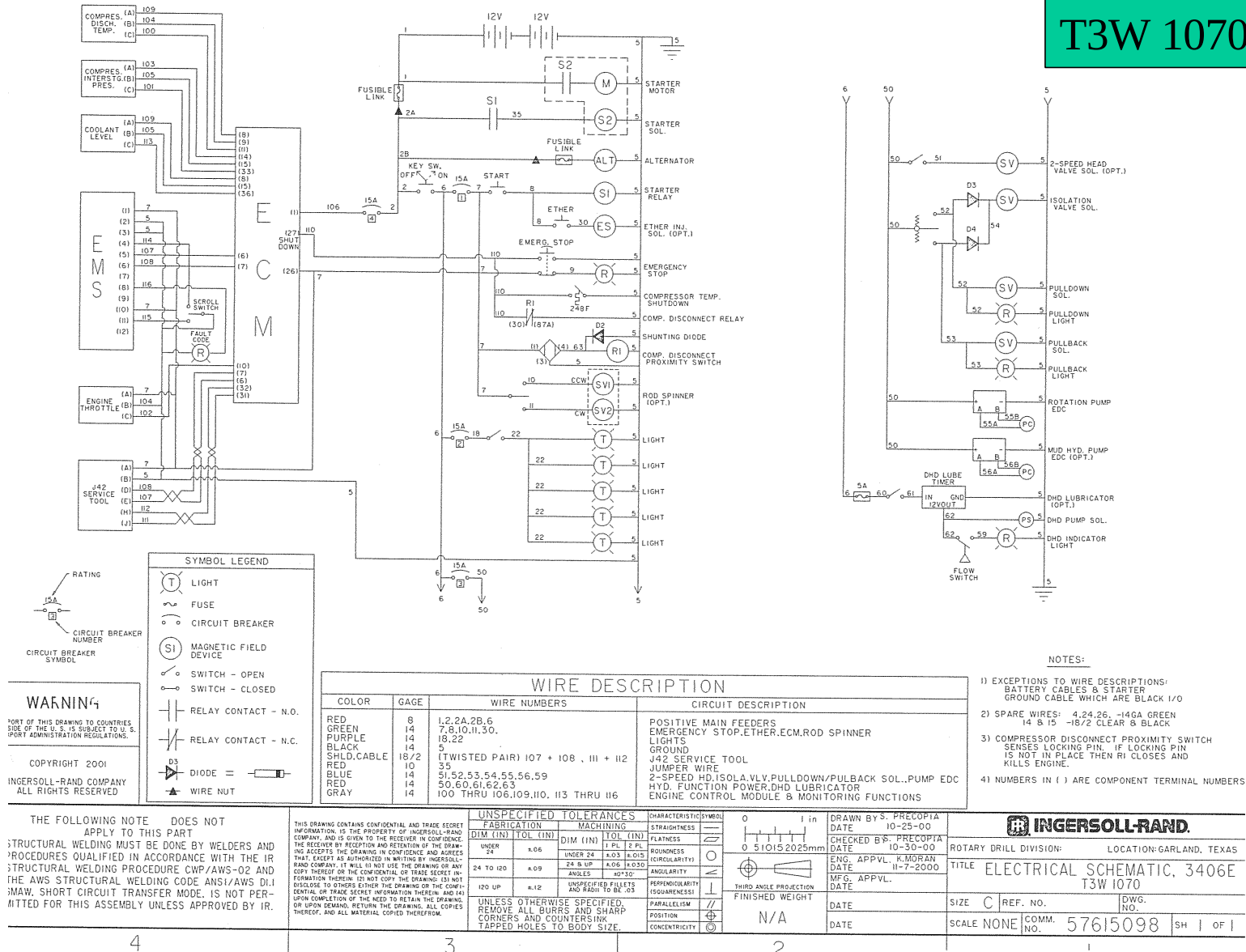


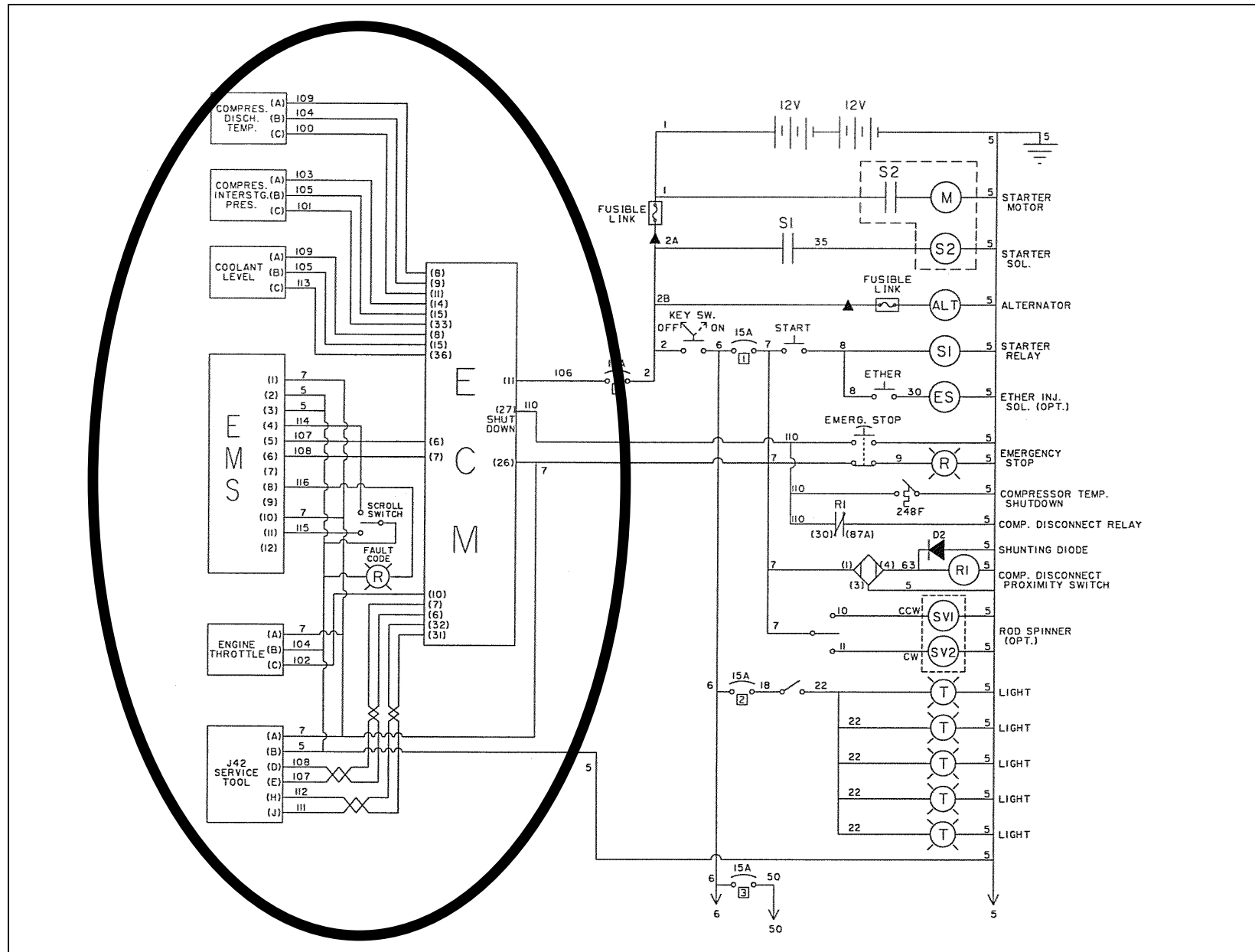
24 V —●—●—

Relay Operation - Power to Coil



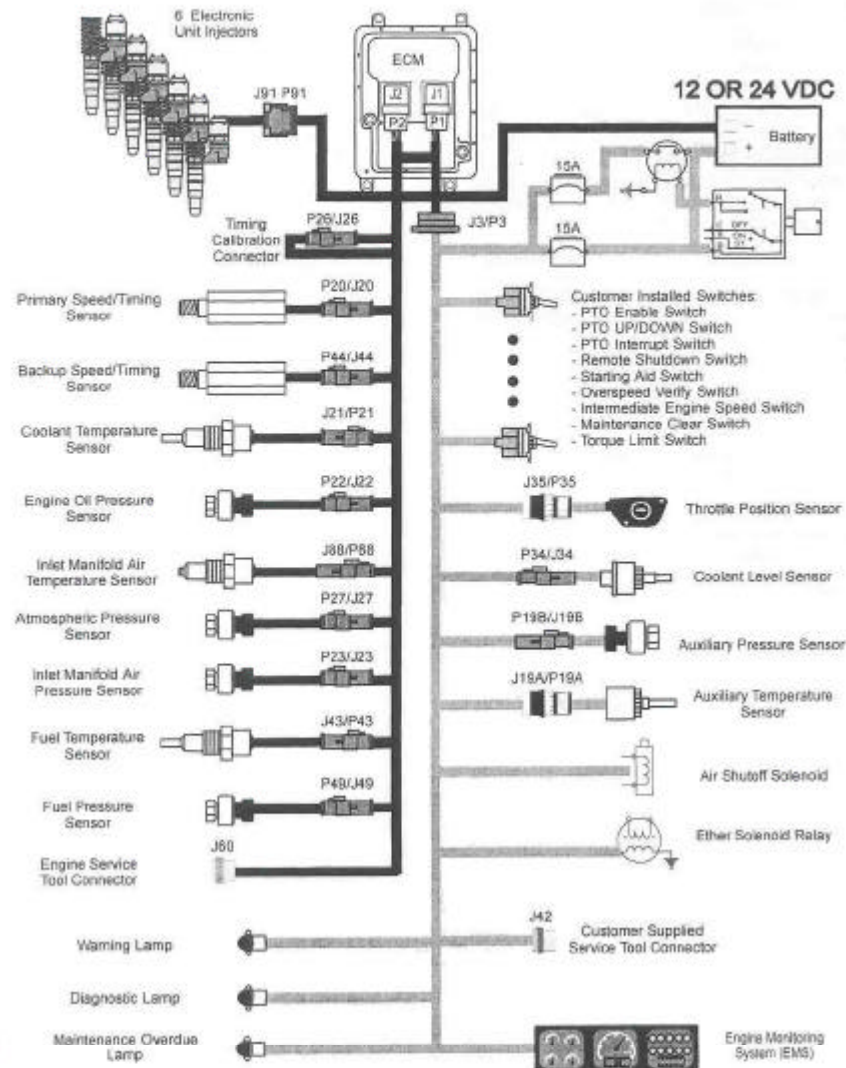
T3W 1070





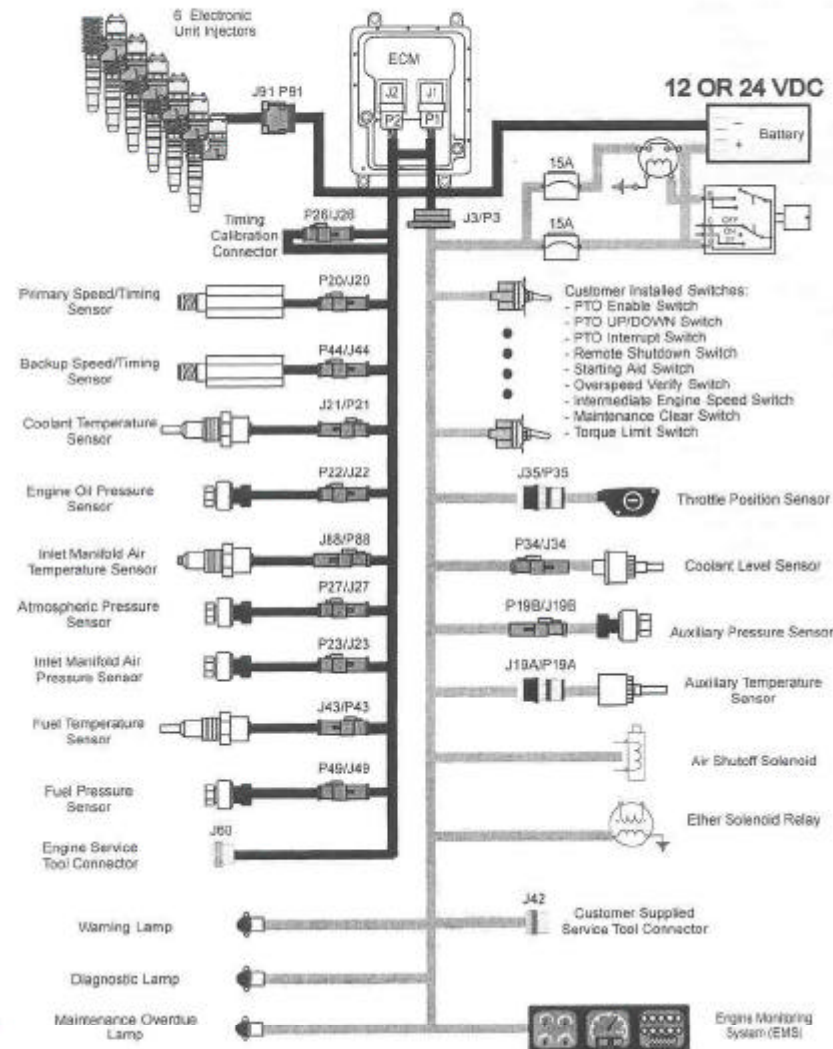
Electrical Component Diagrams

6 Cylinder Industrial Engines



Electrical Component Diagrams

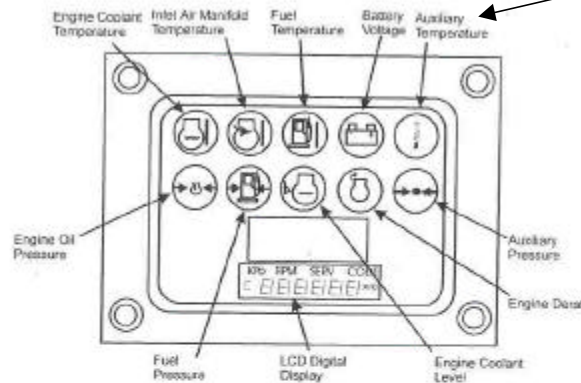
6 Cylinder Industrial Engines





Engine Monitoring System (EMS)

EMS Display Overview



Compressor
discharge
temperature

Compressor
interstage
pressure

Figure 18 - EMS Main Gauge Unit Display

EMS displays various engine parameters and provides excellent visibility in various light conditions and supports backlight connections.

The engine ECM monitors and processes engine operating parameters and diagnostic information. This information is then transmitted to EMS through the CAT Data Link. The Main Gauge Unit receives and displays information from the ECM. Only two wires are required from the ECM to the display to transmit/receive all engine operating parameters and diagnostic information.

EMS incorporates three individual gauge units which can be installed in various locations to enhance operation. One Main Gauge Unit is required for each desired operator station. The Tachometer and/or Quad-Gauge Units are optional and will NOT operate without connection to a Main Gauge Unit.

The following information describes the function and installation requirements of each gauge unit.

The Main Gauge Unit has ten (two rows of five) indicators to display system related diagnostics. A digital LCD readout displays the engine / auxiliary parameters monitored. The Main Gauge LCD displays metric values and units or U.S. values only. For example, Metric display mode would indicate 35 kPa and U.S. display mode would display 5 (PSI units NOT displayed).

Monitored parameters include the following:

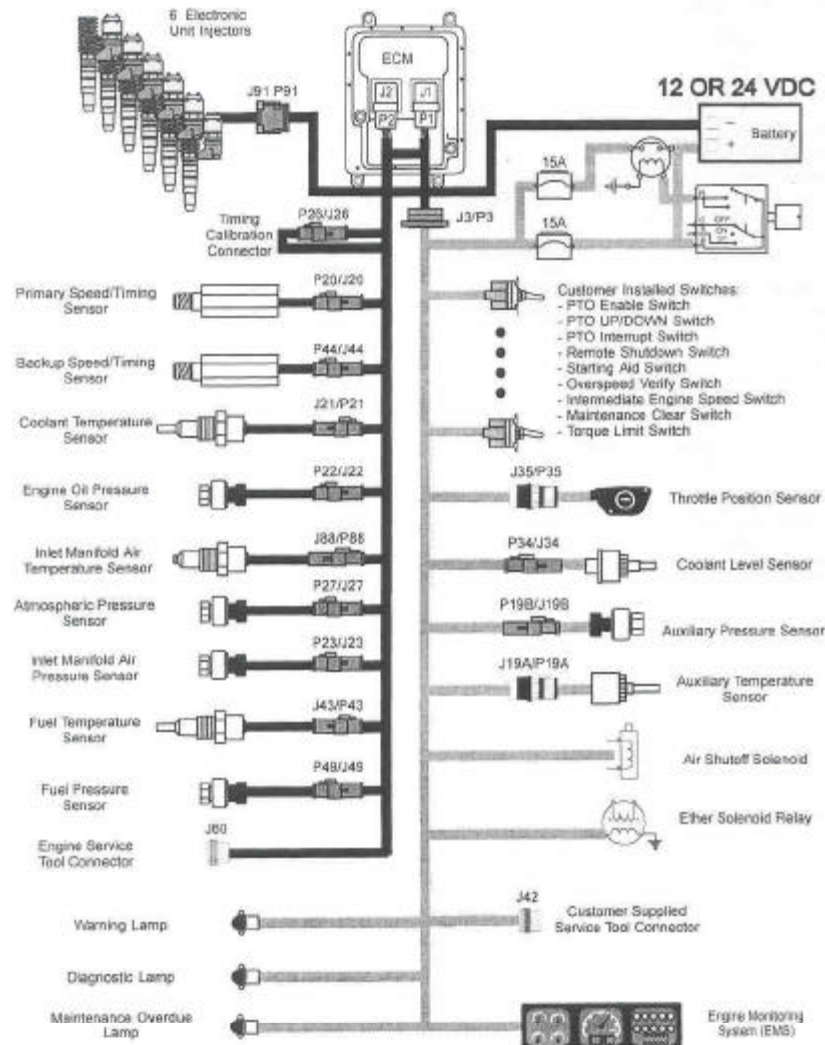
- Engine Speed
- Engine Oil Pressure
- Coolant Temperature
- Battery Voltage
- Fuel Pressure
- Inlet Manifold Air (Boost) Pressure
- Inlet Manifold Air Temperature
- Fuel Temperature
- Auxiliary Pressure
- Auxiliary Temperature
- Fuel Rate
- Engine Hours
- Engine (Percent) Load

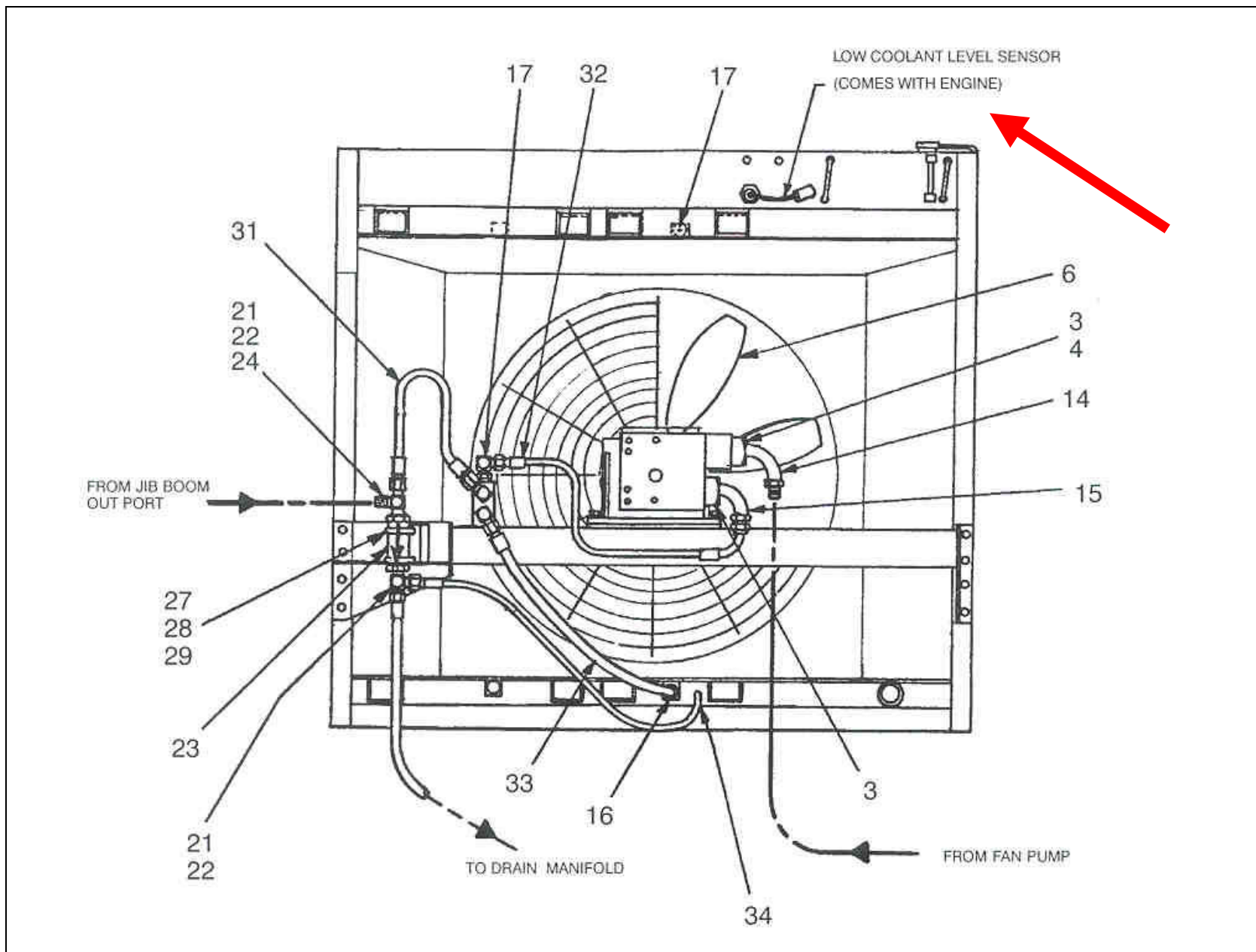
The Quad-Gauge Unit has scaled warning zones and displays engine oil pressure, engine coolant temperature, battery voltage, and fuel pressure (if sensor is installed) in analog format.

The Tachometer Unit displays engine rpm on an analog style gauge.

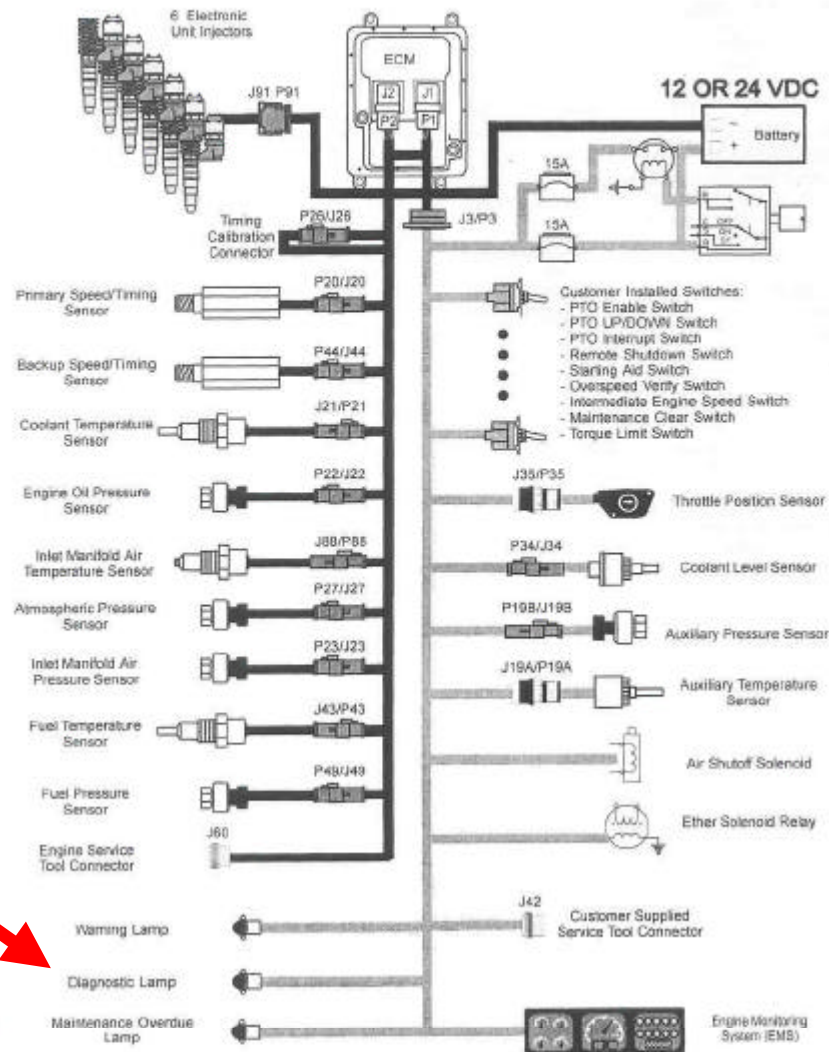
EMS DISPLAY	DESCRIPTION
6005 L	Inlet air boost
I AIR L	Inlet air manifold temperature
FUEL L	Fuel temperature
AccR P	Interstage pressure
AccR L	Compressor discharge temperature (243° F limit)
FUEL	Fuel rate
Hr5	Engine hours
LOAD	Engine % load
SPd	Engine RPM
GA-1	Engine oil pressure
GA-2	Coolant temperature
GA-3	Battery voltage
GA-4	Fuel pressure

**Electrical Component Diagrams
6 Cylinder Industrial Engines**





**Electrical Component Diagrams
6 Cylinder Industrial Engines**





Troubleshooting With A Diagnostic Code

Reference Sheet For Diagnostic Codes.

NOTE: The following diagnostic codes are for engine Electronic Control Module diagnostics ONLY. To obtain diagnostic codes for your electronic display module refer to the service manual for your electronic display module.

CID-FMI	FLASH CODES	DESCRIPTION	PROCEDURE NO
1-11	(72)	Cylinder 1 Fault	P-515
2-11	(72)	Cylinder 2 Fault	P-515
3-11	(73)	Cylinder 3 Fault	P-515
4-11	(73)	Cylinder 4 Fault	P-515
5-11	(74)	Cylinder 5 Fault	P-515
6-11	(74)	Cylinder 6 Fault	P-515
22-13	(28)	Check Timing Sensor Calibration	P-614
41-03	(21)	+8 Volt Supply Above Normal	P-522
41-04	(21)	+8 Volt Supply Below Normal	P-522
64-02	(21)	Loss of Backup Speed/Timing Signal	P-514
64-02	(21)	Loss of Backup Speed/Timing Signal (3456 Only)	P-516
91-08	(21)	Invalid Throttle Signal	P-504
91-13	(28)	Throttle Sensor Calibration	P-604
94-01	(63)	Low Fuel Pressure Warning	P-339
94-03	(37)	Fuel Pressure Sensor Open	P-591
94-04	(37)	Fuel Pressure Sensor Short	P-591
100-01	(46)	Low Oil Pressure Warning	P-329
100-03	(24)	Oil Pressure Sensor Open	P-591
100-04	(24)	Oil Pressure Sensor Short	P-591
100-11	(46)	Very Low Oil Pressure Warning	P-329
102-00	(25)	Boost Pressure Reading Stuck High	P-591
102-03	(25)	Turbocharger Compressor Outlet Sensor Open Circuit	P-591
102-04	(25)	Turbocharger Compressor Outlet Sensor Short Circuit	P-591
105-00	(64)	High Inlet Air Manifold Temperature Warning	P-348
105-03	(38)	Inlet Air Manifold Temperature Open	P-591
105-04	(38)	Inlet Air Manifold Temperature Short	P-591
105-11	(64)	Very High Inlet Air Manifold Temperature Warning	P-348
108-03	(26)	Atmospheric Pressure Sensor Open Circuit	P-591
108-04	(26)	Atmospheric Pressure Sensor Short Circuit	P-591
110-00	(61)	High Coolant Temperature Warning	P-331
110-03	(27)	Coolant Temperature Sensor Open Circuit	P-591
110-04	(27)	Coolant Temperature Sensor Short Circuit	P-591
110-11	(61)	Very High Coolant Temperature Warning	P-331
111-01	(62)	Low Coolant Level Warning	P-347
168-02	(51)	Intermittent Battery	P-346
174-00	(65)	High Fuel Temperature Warning	P-349

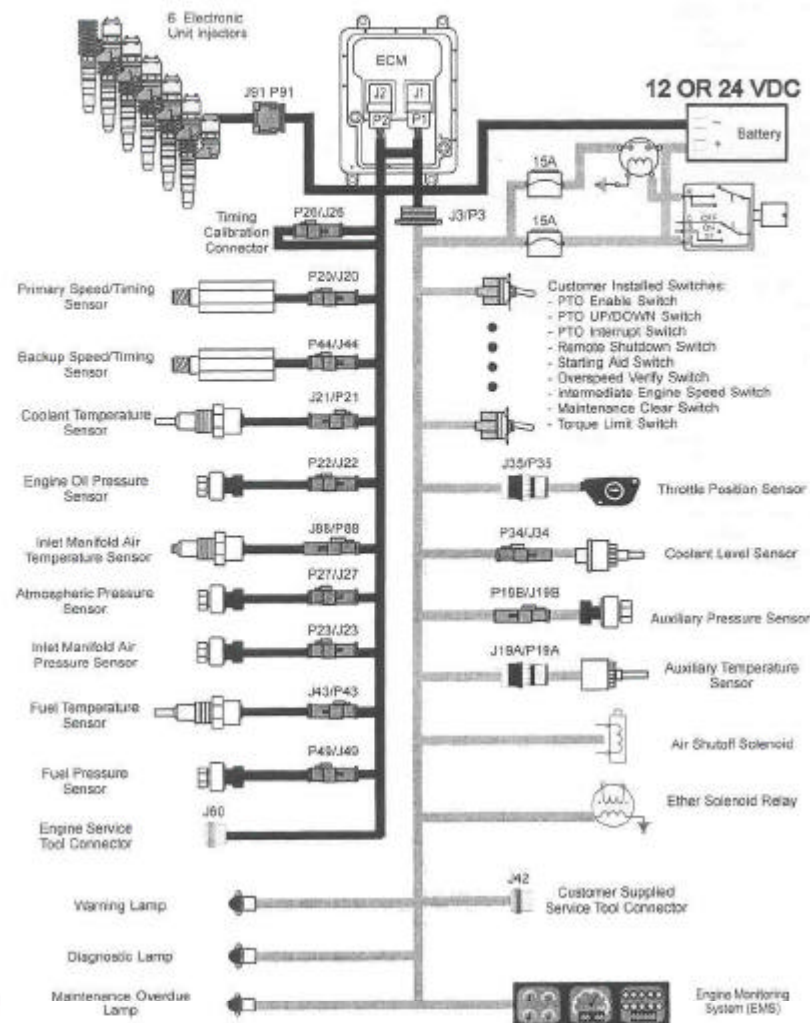
Reference Sheet For Diagnostic Codes.

NOTE: The following diagnostic codes are for engine Electronic Control Module diagnostics ONLY. To obtain diagnostic codes for your electronic display module refer to the service manual for your electronic display module.

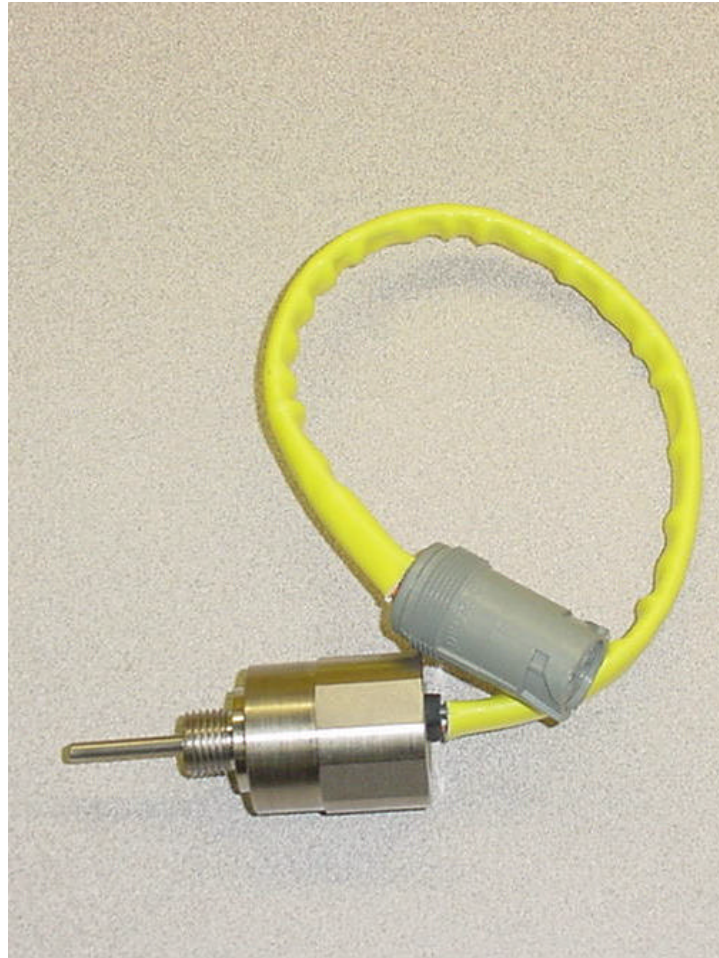
CID-FMI	FLASH CODES	DESCRIPTION	PROCEDURE NO
174-03	(13).....	Fuel Temperature Sensor Open Circuit.....	P-591
174-04	(13).....	Fuel Temperature Sensor Open Circuit.....	P-591
190-00	(35).....	Engine Overspeed Warning	P-303
190-02	(34).....	Loss Of Engine RPM Signal	P-514
190-02	(34).....	Loss Of Engine RPM Signal (3456 Only).....	P-516
232-03	(21).....	+5 VDC Supply Above Normal	P-521
232-04	(21).....	+5 VDC Supply Below Normal.....	P-521
252-11	(59).....	Incorrect Engine Software	P-346
252-12	(72).....	Personality Module Fault	P-513
253-02	(56).....	Check Customer or Systems Parameters	P-513

Electrical Component Diagrams

6 Cylinder Industrial Engines

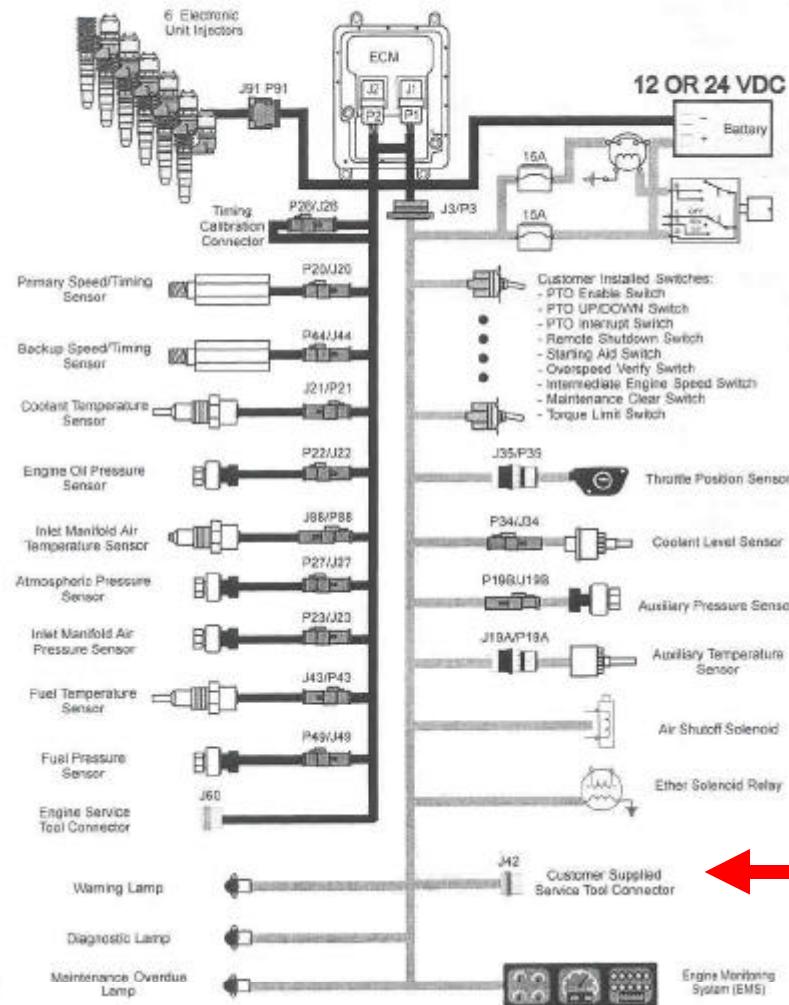


Compressor
Discharge
Temperature



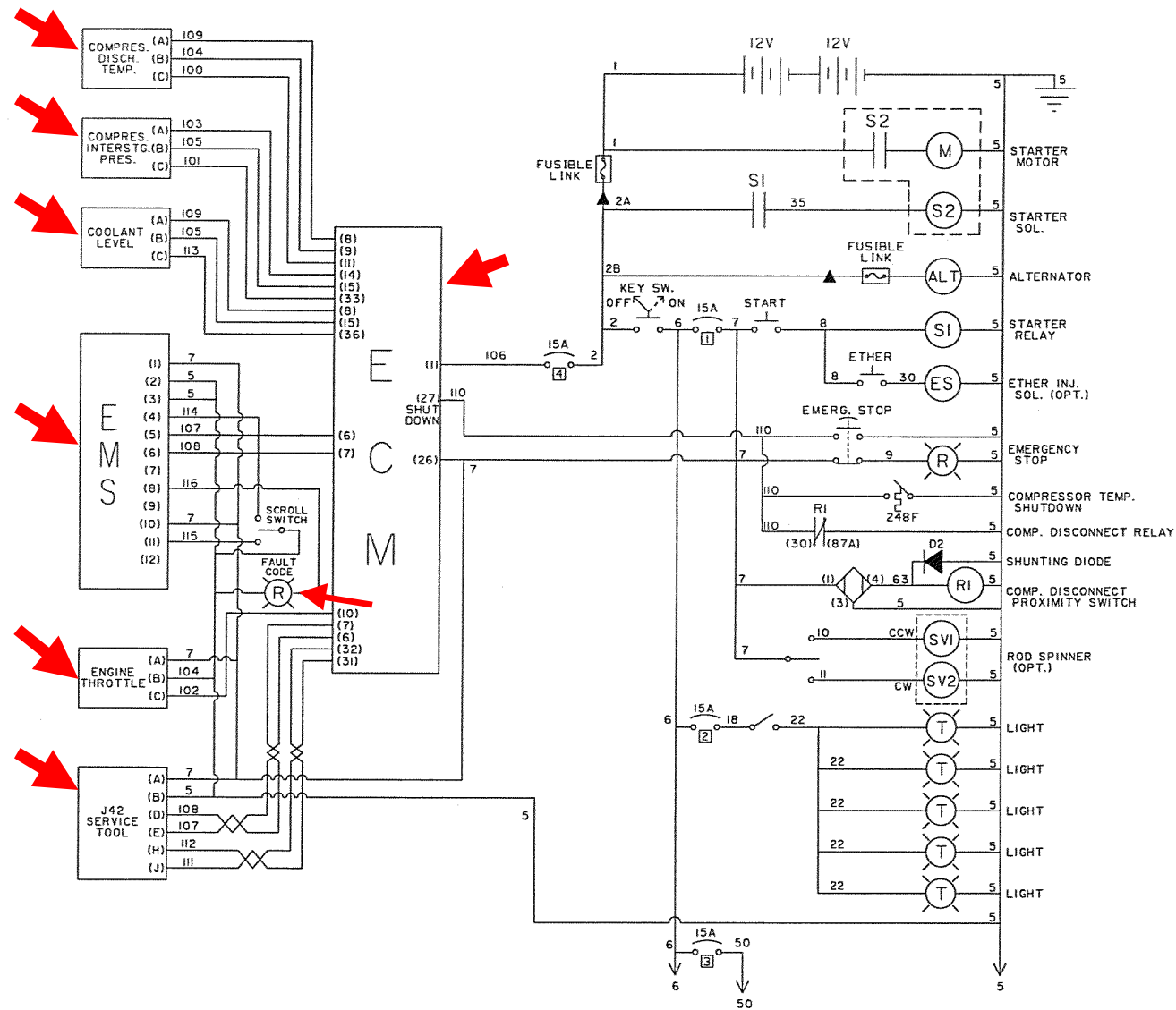
Compressor Discharge Temperture Sensor
57594269

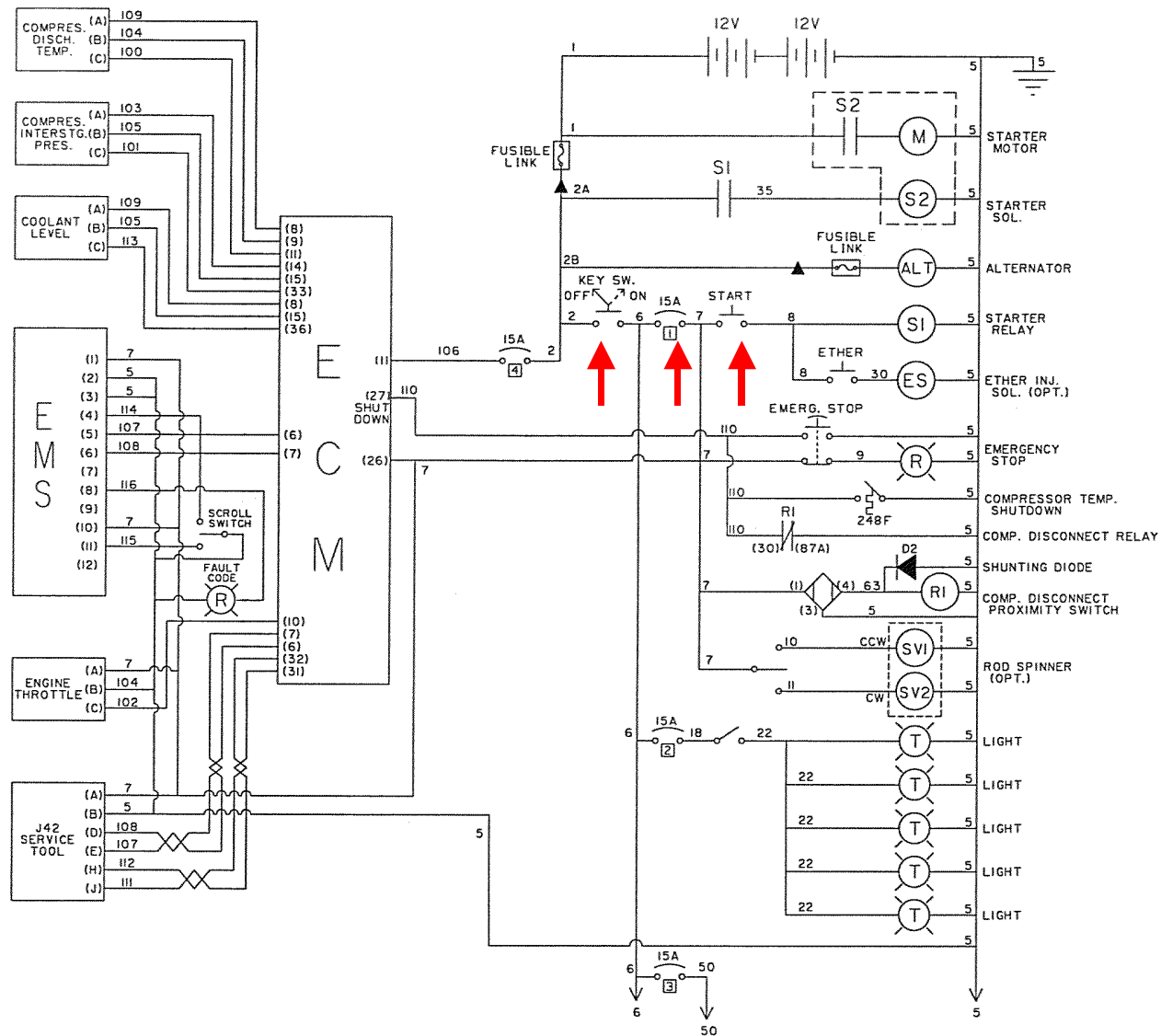
Electrical Component Diagrams
6 Cylinder Industrial Engines



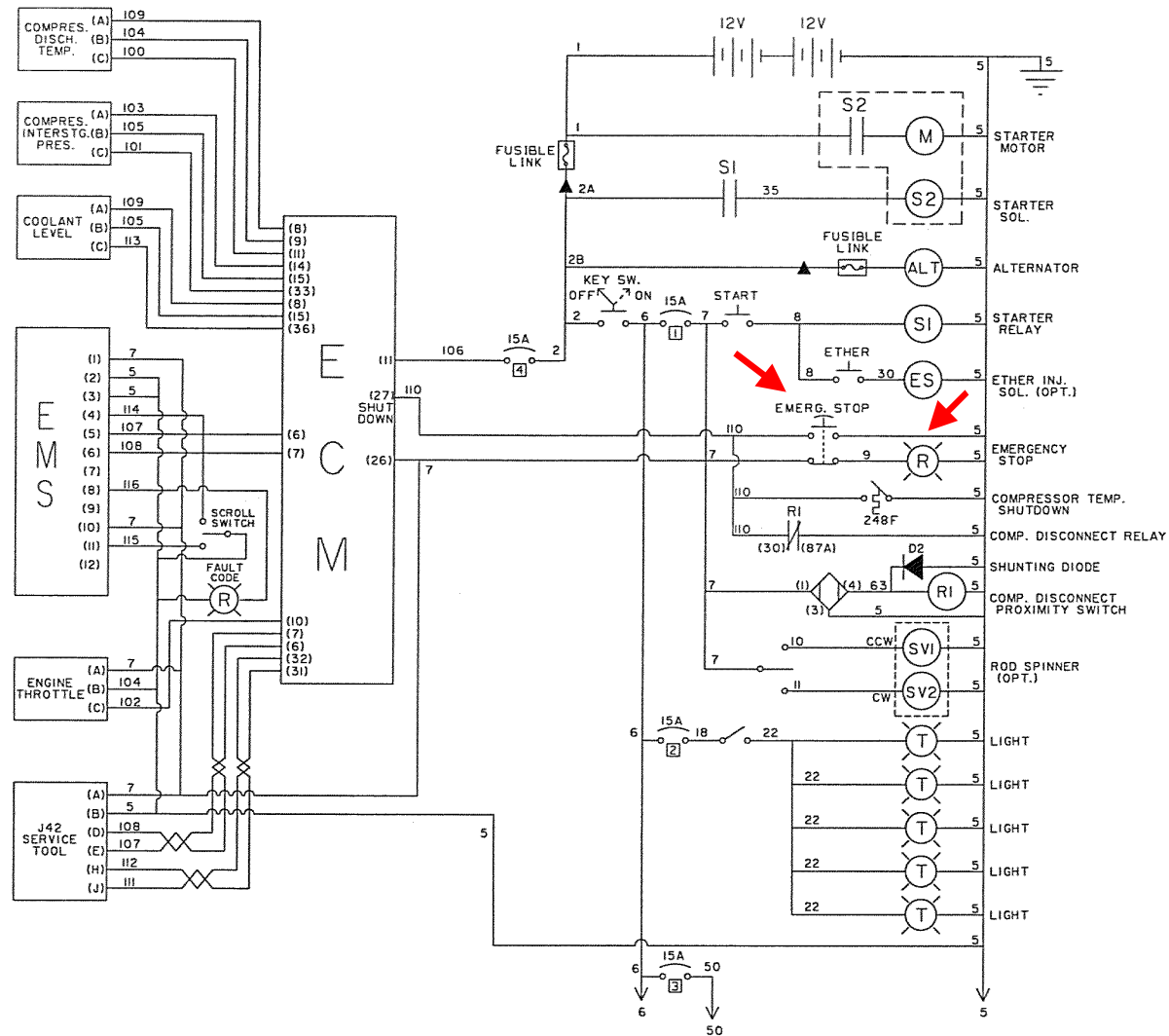
Compressor
Interstage

Laptop 6-pin
Connection

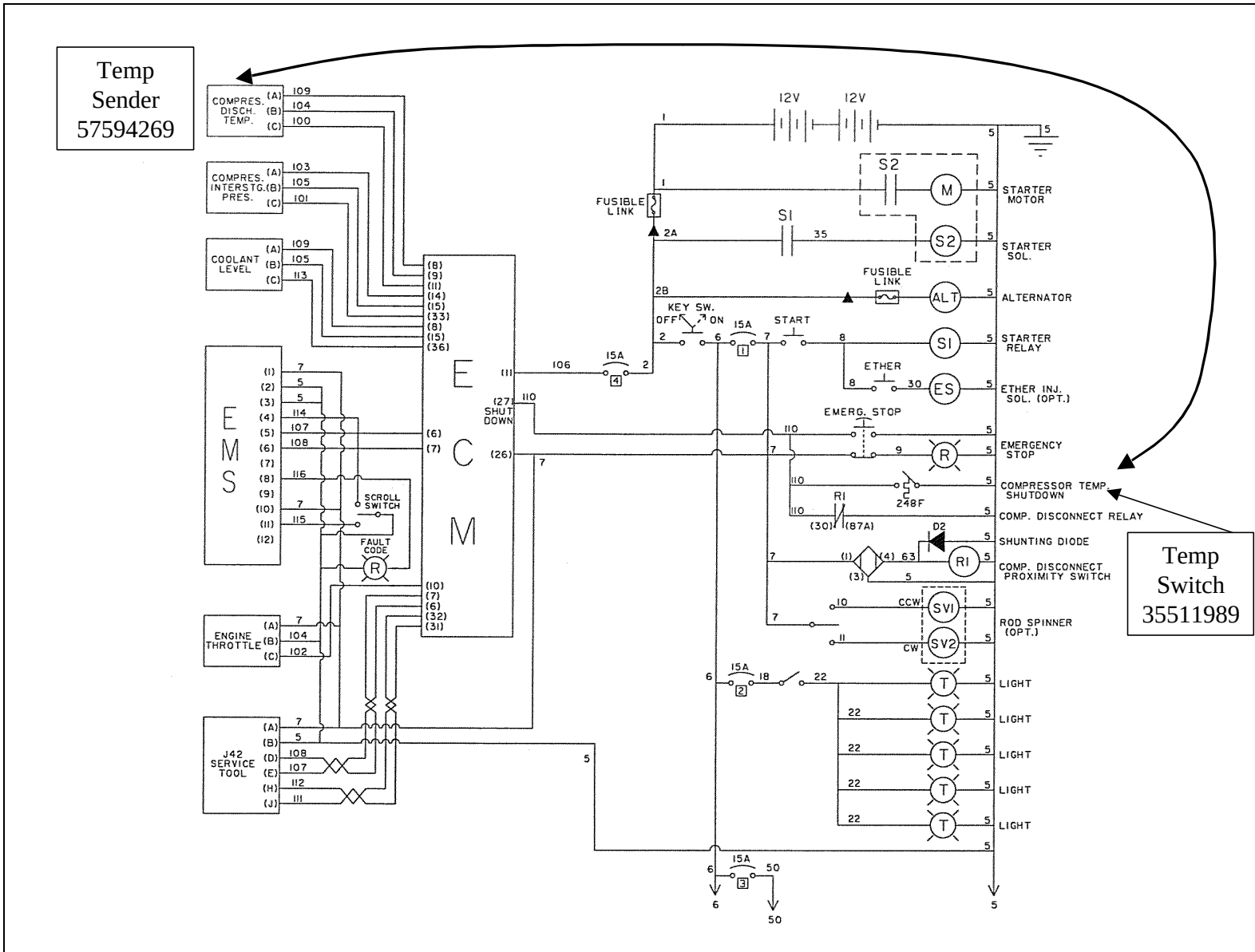


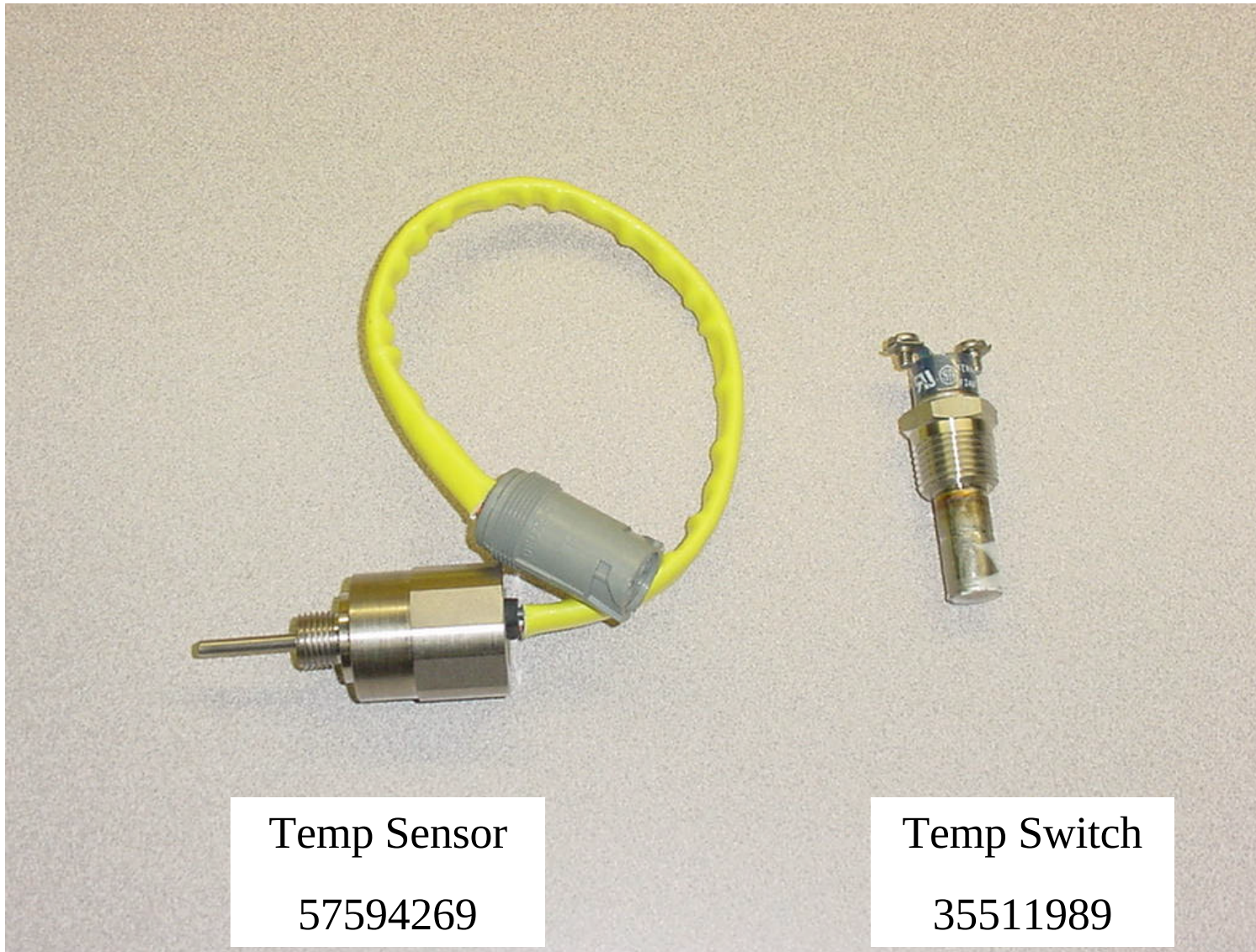


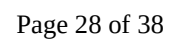






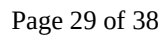


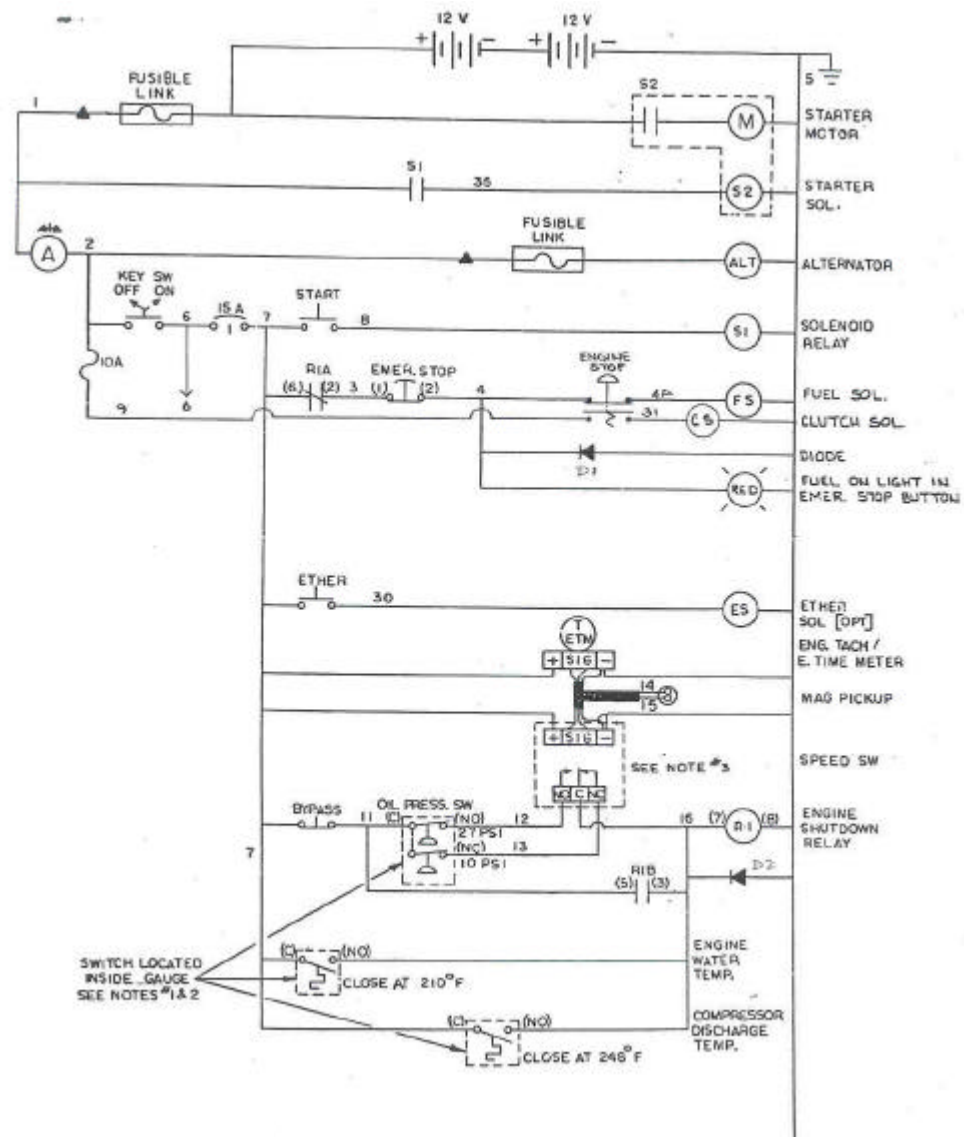




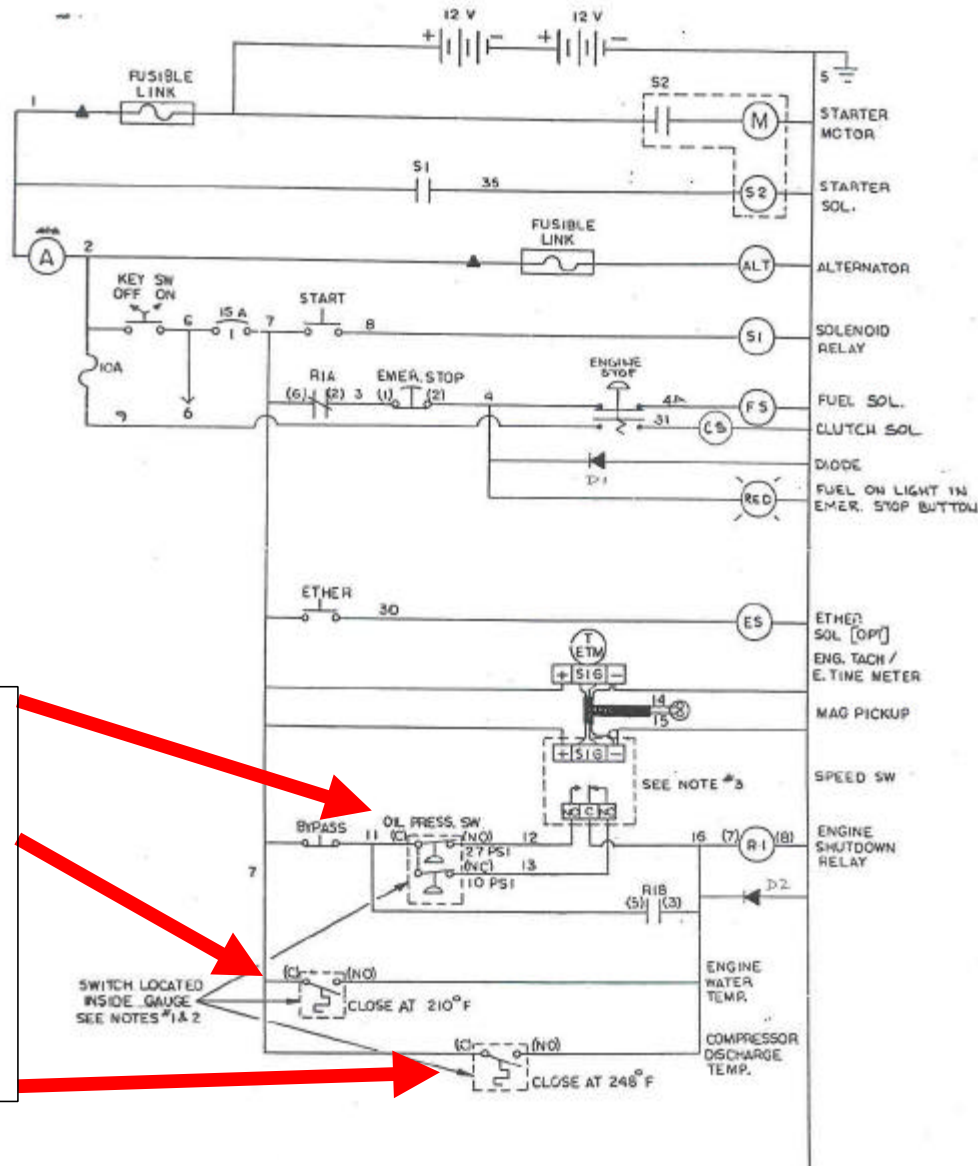
CHAPTER 13

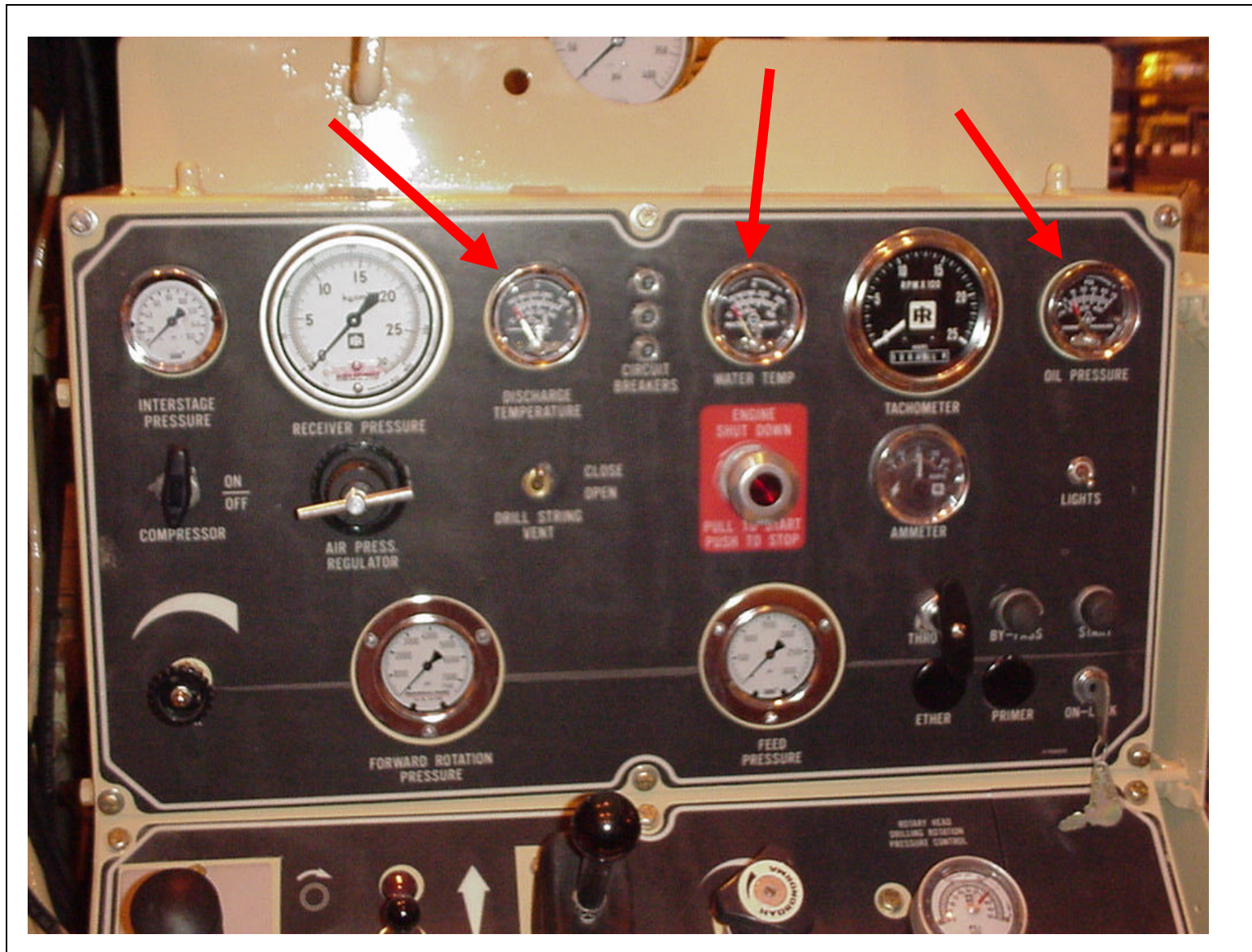
T3W & Murphy Scheme

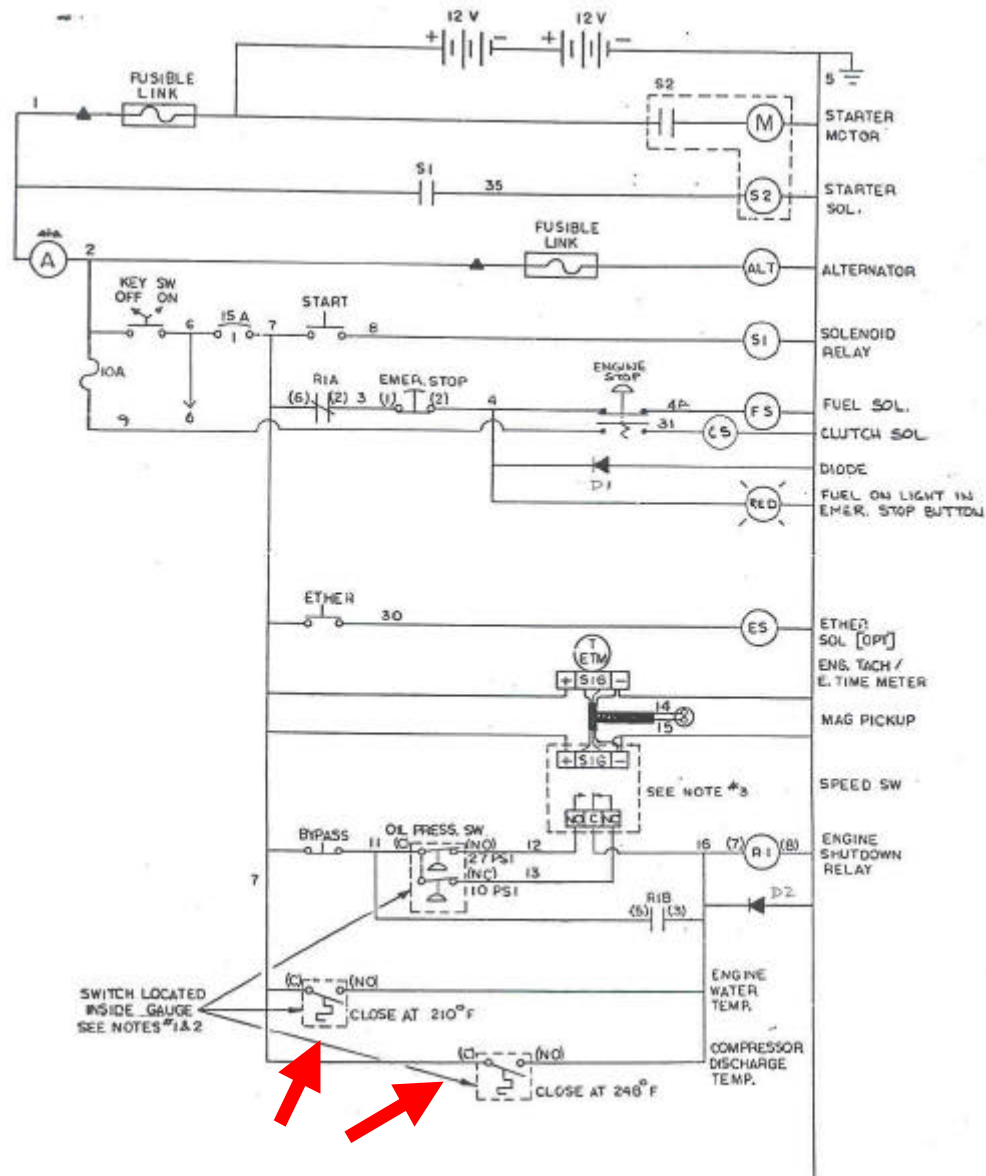


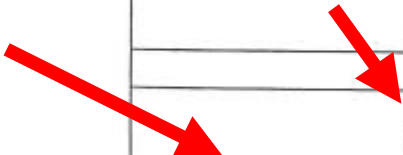


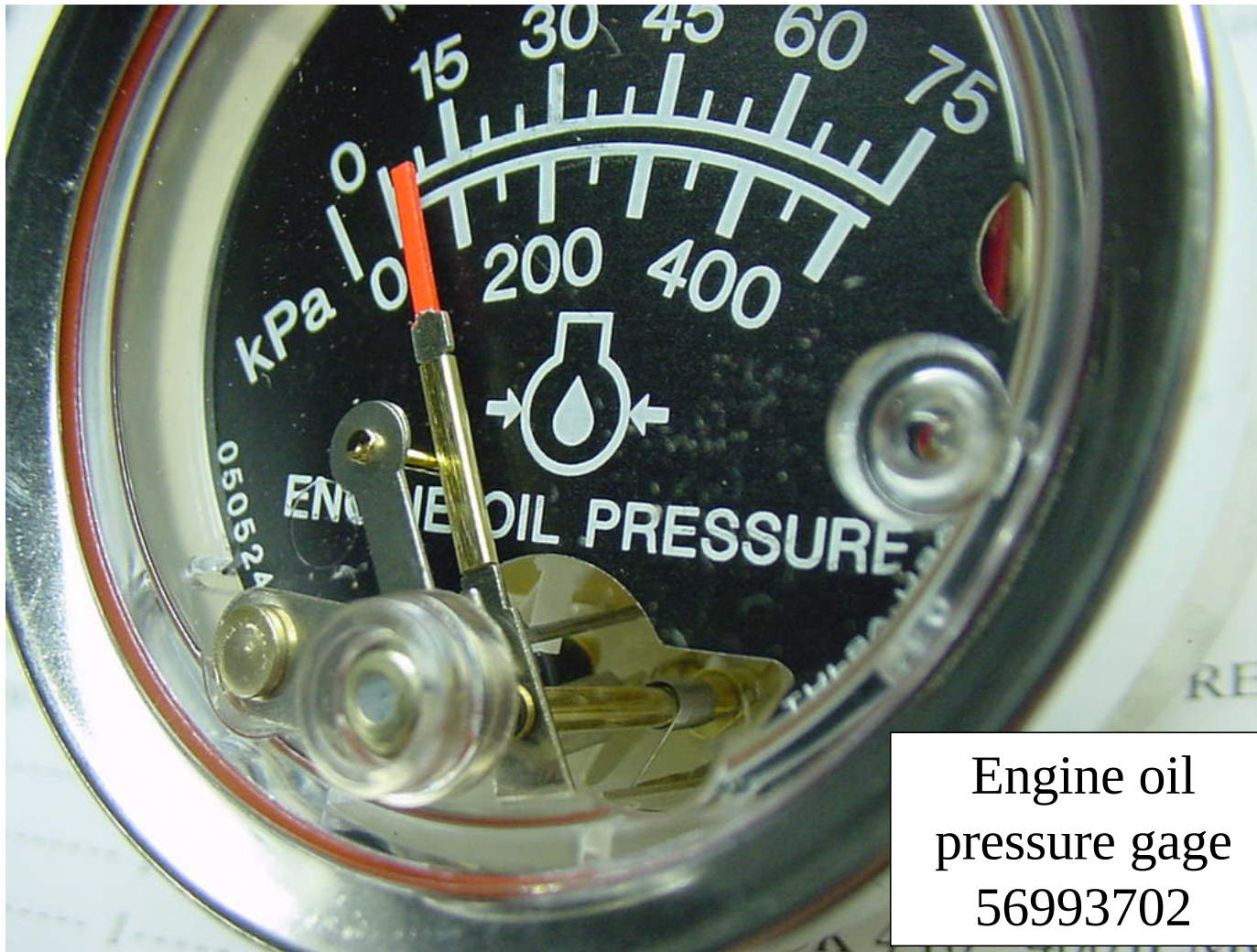
3 ways to
power the
R1 relay
and shut
down the
engine

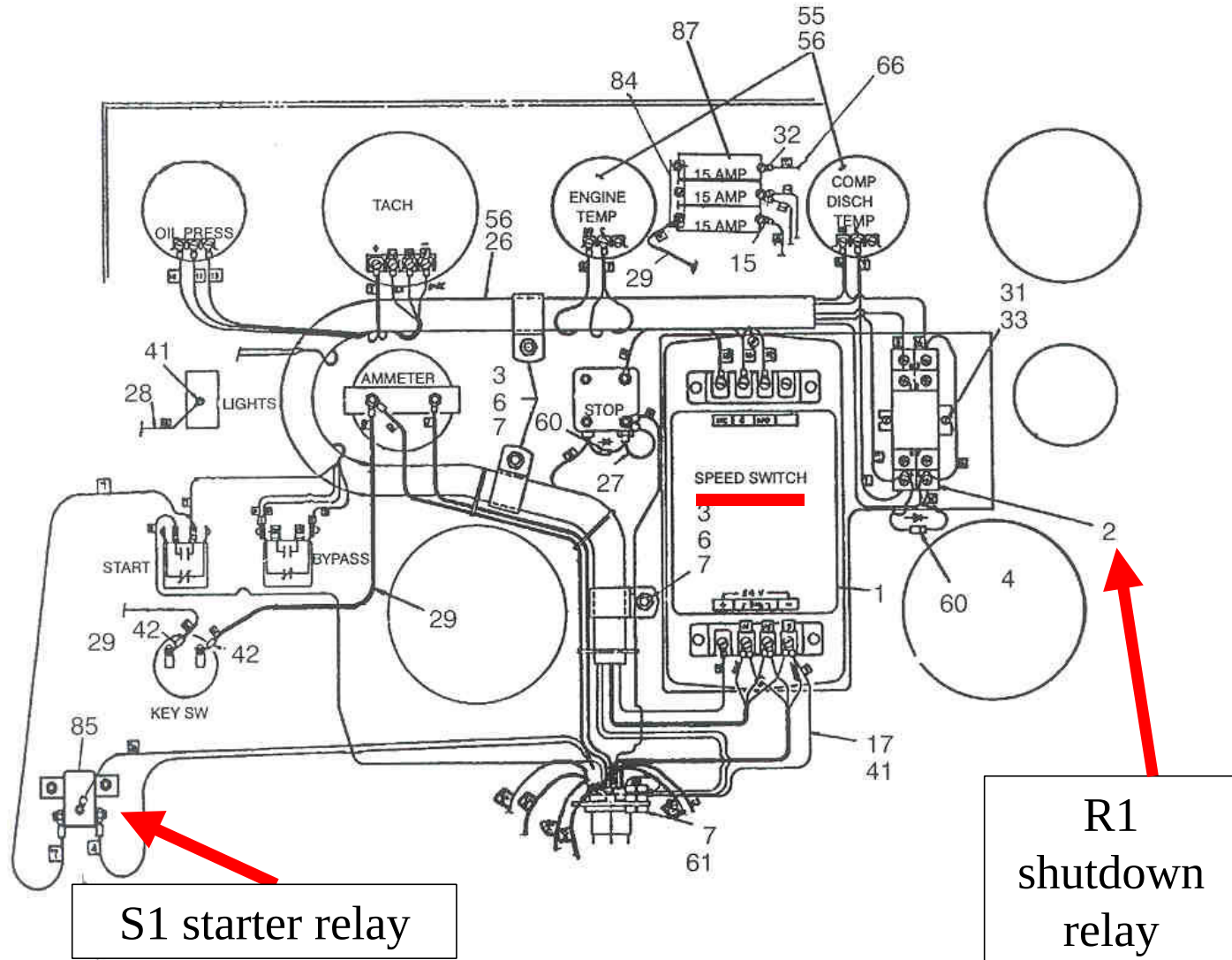


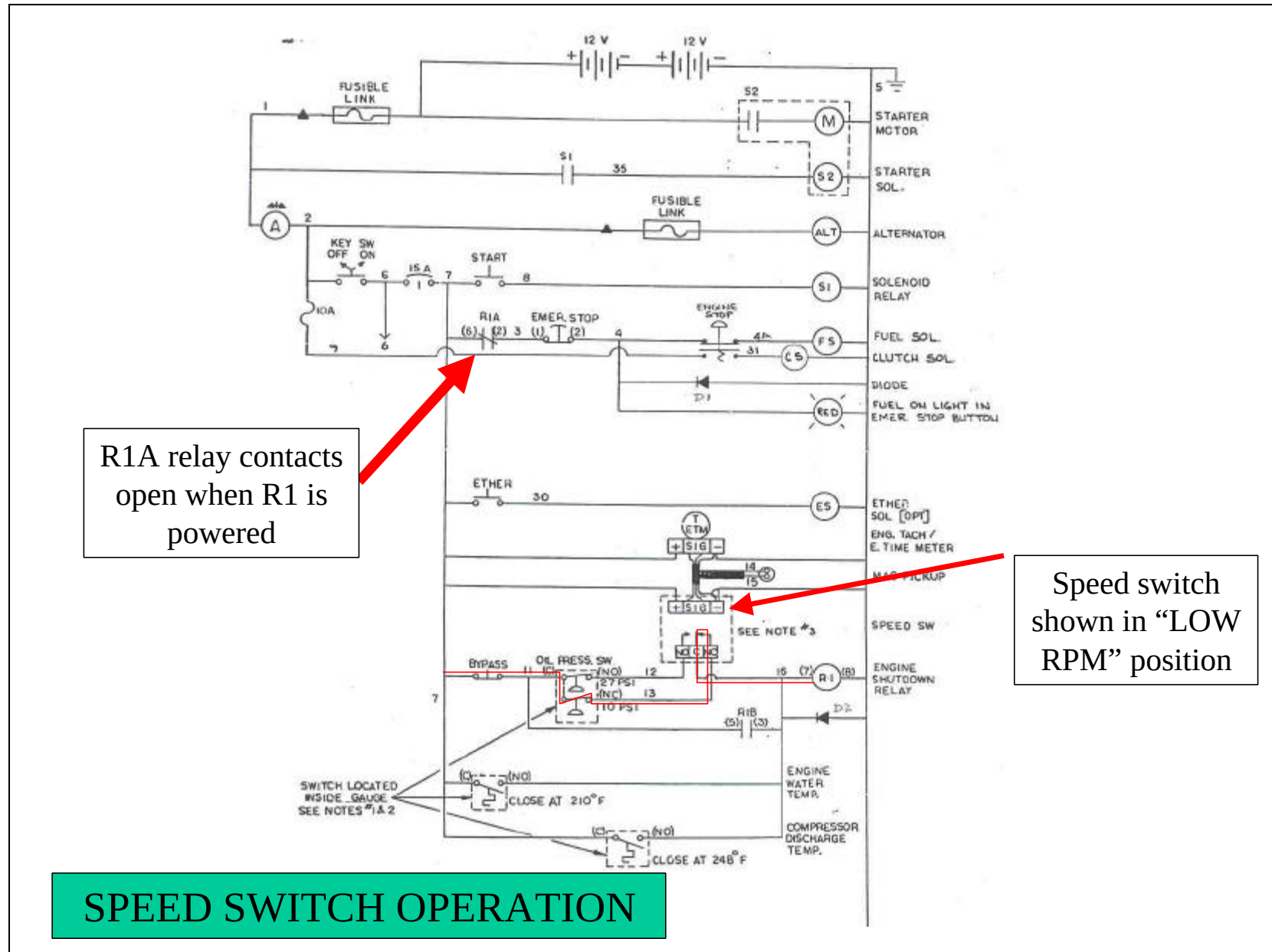


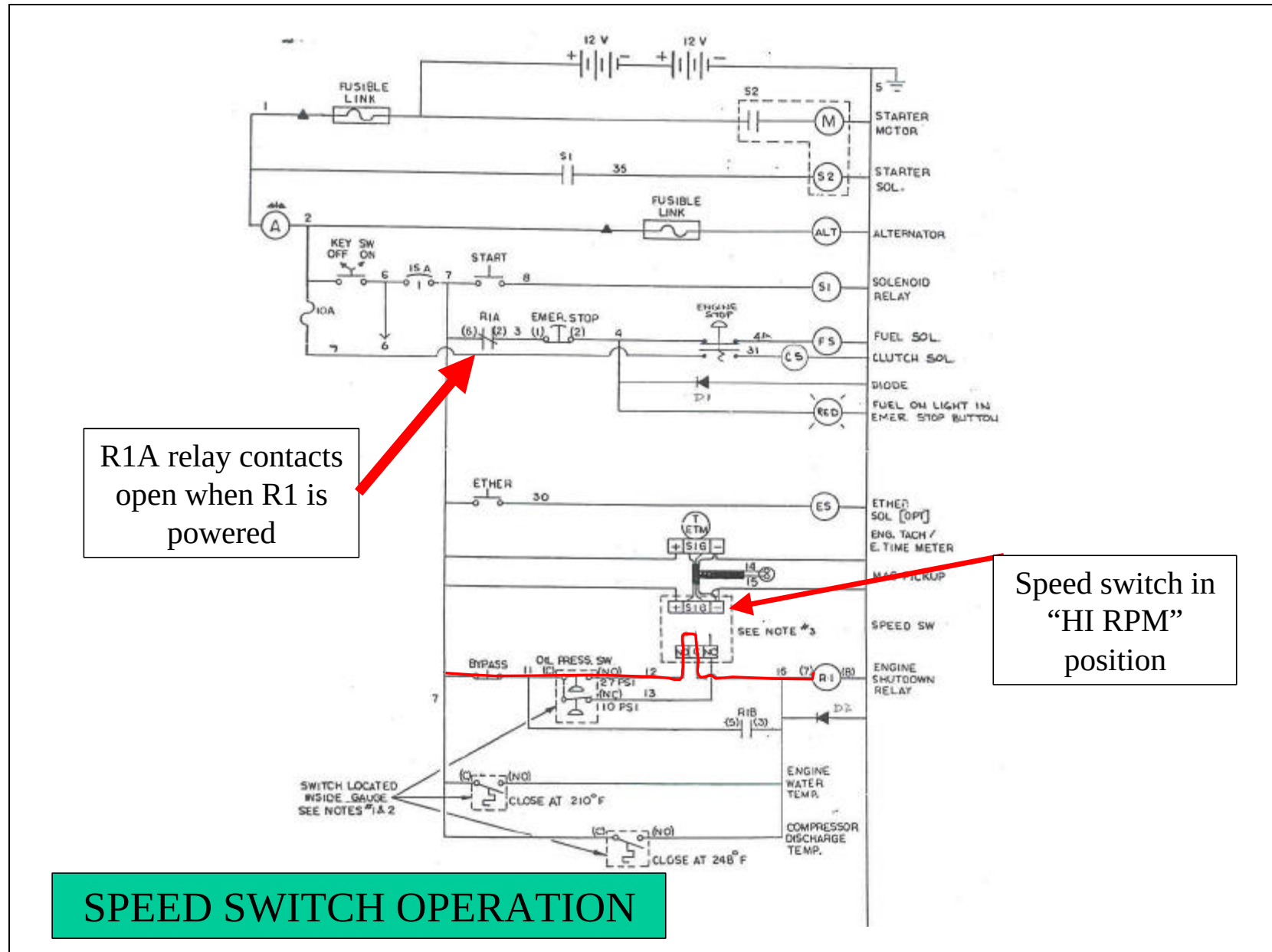












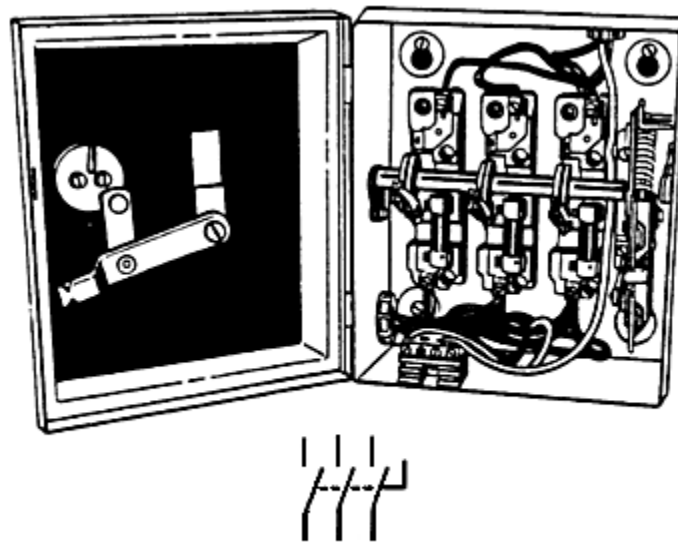


FIGURE A-1. Disconnect.

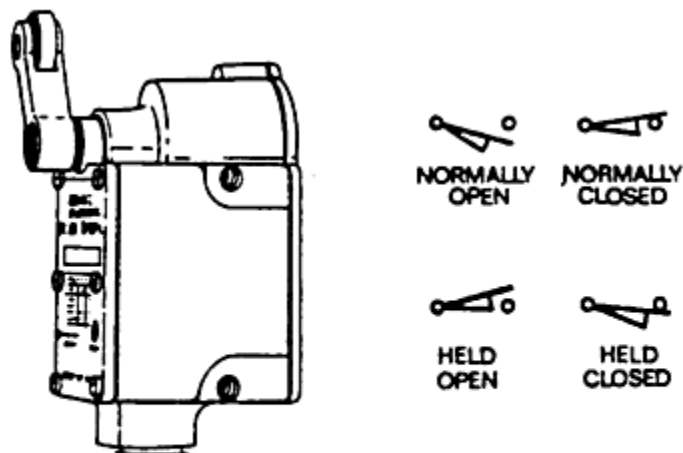


FIGURE A-2. Limit Switches.



FIGURE A-3. Flow Switch (Air, Water, and So Forth).

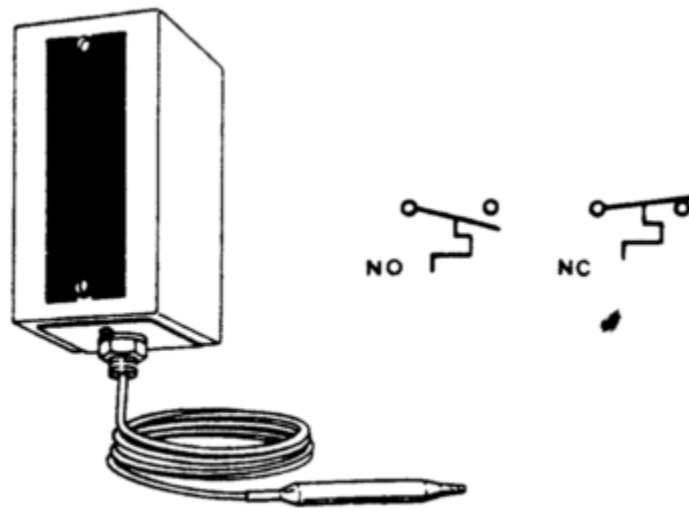


FIGURE A-4. Temperature-Actuated Switch.

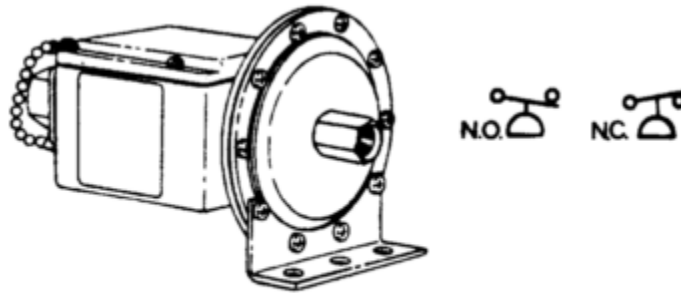
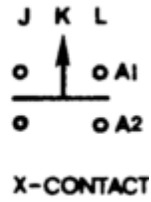


FIGURE A-5. Pressure and Vacuum Switches.

A1 = XO = closed in J position
A2 = OX = closed in K position



Selector switch, 2-position



A1 = XOO = closed in J position

A2 = OOX = closed in L position

Selector switch, 3-position

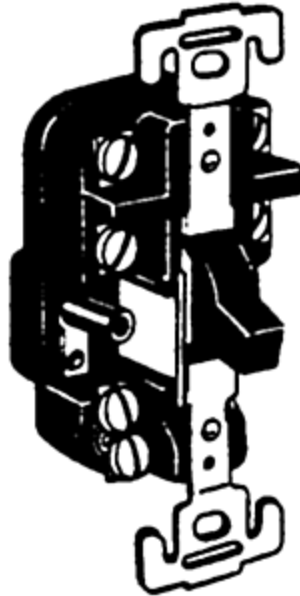


FIGURE A-8. Toggle Switch.

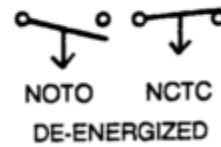
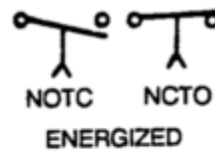
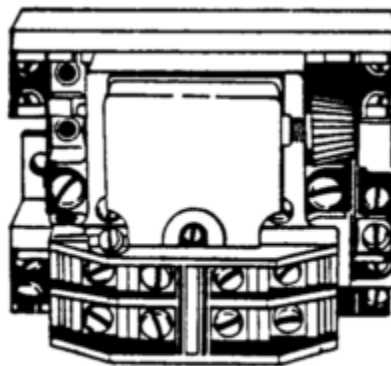


FIGURE A-9. Pneumatic Timer.

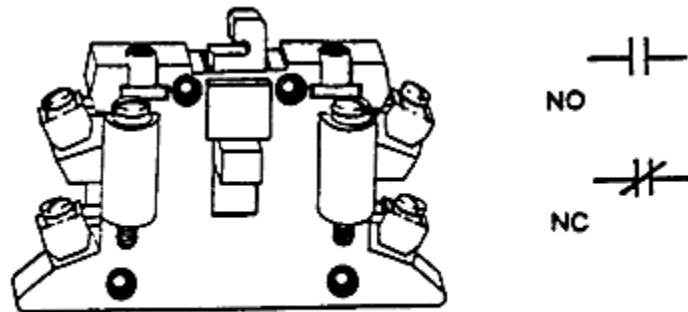


FIGURE A-10. Auxiliary Contacts.

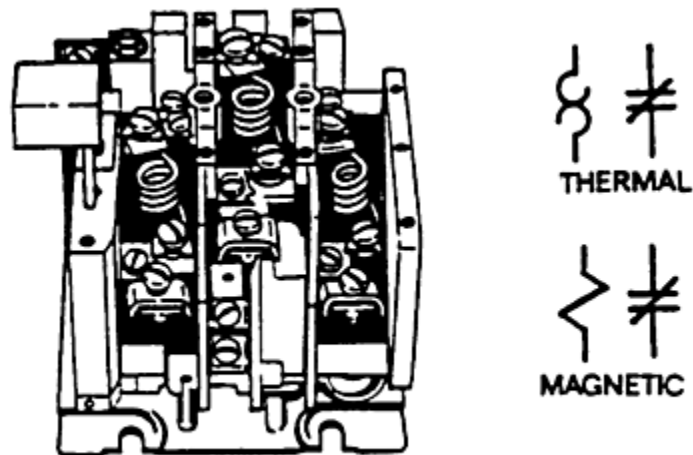


FIGURE A-11. Overload Relays.

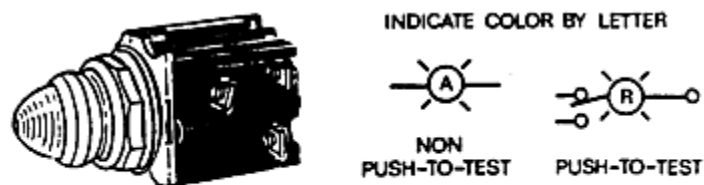


FIGURE A-12. Pilot Lights.

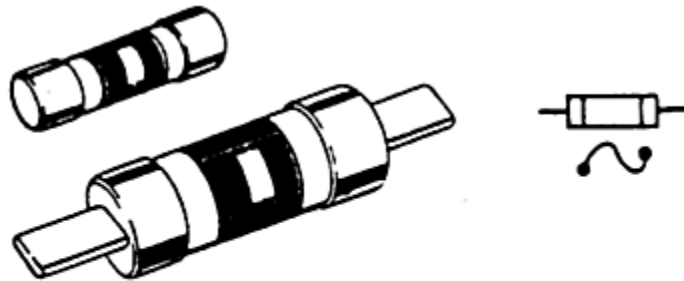


FIGURE A-13. Fuse Power or Control.

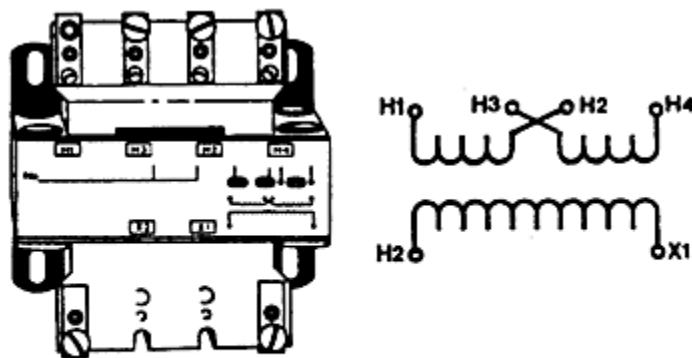


FIGURE A-15. Control Transformer.

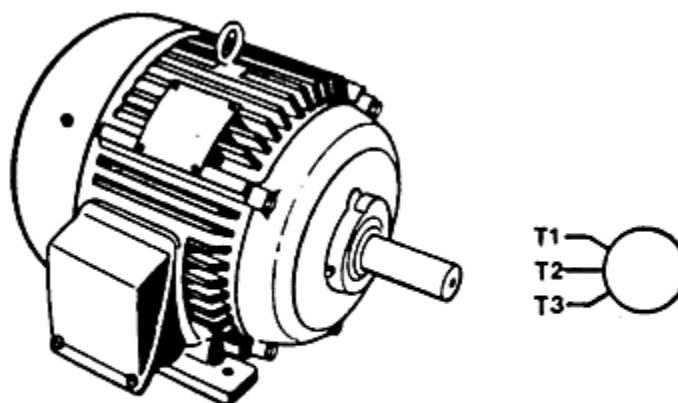


FIGURE A-16. Three-Phase Motor.

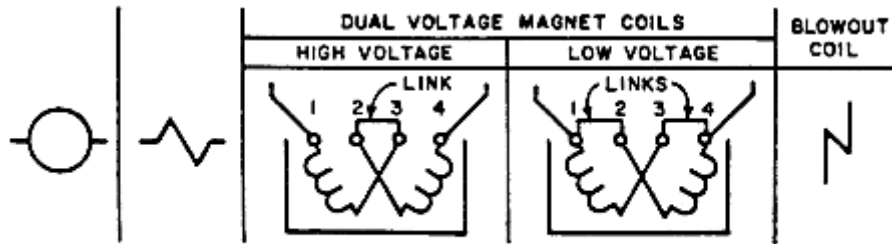


FIGURE A-17. Coil.

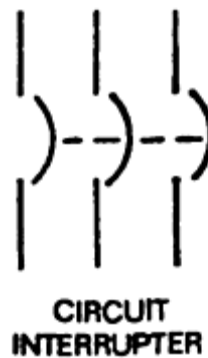


FIGURE A-21. Foot Switches.

STATIC SWITCHING CONTROL IS A METHOD OF SWITCHING ELECTRICAL CIRCUITS WITHOUT THE USE OF CONTACTS, PRIMARILY BY SOLID STATE DEVICES. USE THE SYMBOLS SHOWN IN TABLE EXCEPT ENCLOSED IN DIAMOND:

EXAMPLES —
INPUT "COIL"



OUTPUT N.O.



LIMIT SW. N.O.



LIMIT SW. N.C.



FIGURE A-23. Symbols for Static Switching Control Devices.

ARMATURE	SHUNT FIELD	SERIES FIELD	COMM. OR COMPENS. FIELD
	 (SHOW 4 LOOPS)	 (SHOW 3 LOOPS)	 (SHOW 2 LOOPS)

FIGURE A-26. DC Motors.



FIGURE A-32. Horn.

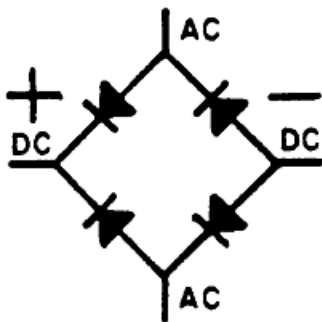


FIGURE A-34. Full-Wave Rectifier.



FIGURE A-35. Battery.



FIGURE A-36. Thermocouple.

DIODE	TUNNEL DIODE	UNIDIRECTIONAL BREAKDOWN (ZENER) DIODE
		

FIGURE A-37. Semiconductors.

Section I. ACRONYMS AND ABBREVIATIONS

AC alternating current	H henry
adj adjustment	HP horsepower
alt alternate	Hz hertz
amp ampere	IEEE Institute of Electric and Electronics Engineers
ANSI American National Standard Institute, Inc.	kHz kilohertz
assm assembly	kV kilovolt
auto automatic	kVa apparent power (thousands of volts x amps)
avg average	KW kilowatt (true power)
AWG American wire gauge	kWh kilowatt hour
bat battery	LCD liquid crystal display
CEMF counter electromotive force	LED light-emitting diode
COMA circular mil area	ltg lighting
comm communication	mA milliampere
cond condition	max maximum
CPR Cardiopulmonary resuscitation	MCC motor control center
CS centrifugal switch	mfr manufacturer
DC direct current	mho unit of conductance
Distr distribution	MPU magnetic pickup
DPDT double-pole, double-throw	mV millivolt
DPST double-pole, single-throw	NC normally closed
EFC electronic fuel control	NEC National Electrical Code
Eff efficiency	NEMA National Electrical Manufacturers Association
EMF electromotive force	NICAD nickel-cadmium
Exc exciter	NO normally opened
FLC full-load current	

OBA oxygen breathing apparatus	RMS root mean square
PF power factor	RPM revolutions per minute
PMG permanent magnet generator	SPST single-pole, single-throw
press pressure	sw switch
psia pounds per square inch atmospheric	temp temperature
psig pounds per square inch gauge	uA microampere
PVC polyvinyl chloride	uV microvolt
RF radio frequency	VA volt-ampere (apparent power)
rheo rheostat	VAC volts alternating current
rm room	VAR volt-amperes reactive
	VDC volts direct current

Section II. TERMS

accuracy - limitation that a measurement may vary from its true value; usually represented as a percentage of full scale, such as +1%.

across-the-line starter - starting a motor when connected directly to the supply lines.

active power - true electrical power; power that is actually doing work.

air-core transformer - a transformer composed of two or more coils that are wound around a nonmetallic core.

air gap - the air space between two magnetically or electrically related components; for example, the space between the armature and poles in a motor.

alternating current - an electrical current that constantly changes amplitude and changes in polarity at regular intervals.

alternator - device mounted on a diesel engine to charge starting batteries; sometimes used as a term for alternating current generators.

ambient temperature - average temperature of the air surrounding an electrical device; usually expressed in degrees Celsius (C).

ammeter - an instrument for measuring the amount of electron flow in amperes.

ampere - the basic unit of electrical current.

Ampere-hour (Ah) - a unit of measure for a battery's electrical storage capacity, obtained by multiplying the current in amperes by the time in hours of discharge. (Example: a battery which delivers 5 A for 20 hours = 100 Ah of capacity).

amplification - production of an output larger than the corresponding input.

amplifier - an electrical device producing an output signal larger than its input signal.

analog device - device that measures continuous information (voltage, current). The analog has an infinite number of possible values; its limitation is the accuracy of the measuring device. It uses a meter with a needle and scale.

analog signal - a signal having a continuous and smooth signal over a given range.

AND logic - control circuits where all inputs must have a signal for the circuit to operate. For example, with two NO inputs in a series, both must be closed to energize the circuit.

anode - a positive electrode of an electromagnetic device, such as a primary or secondary electric cell, toward which the negative ions are drawn.

apparent power - that power apparently available for use in an AC circuit containing a reactive element. It is the product of effective voltage times effective current expressed in volt-amperes. It must be multiplied by the power factor to obtain true power available.

arc chute - cover around contacts to prevent arcs from reaching surrounding parts.

arc hood - separate cover over a relay. The function is the same as an arc chute.

armature - a winding that has an EMF induced (or produced) into it.

armature reaction - reaction of the magnetic field coils to the magnetic field produced by current in the armature windings of a DC generator.

attraction - the force that tends to make two objects approach each other. Attraction exists between two unlike magnetic poles (north and south) or between two unlike static charges (plus and minus).

automatic controller - a motor control device that uses automatic pilot devices to turn the circuit on and off.

autotransformer - a transformer with a single coil. The entire length of the coil acts as a primary winding; only part of the winding functions as a secondary winding. It is used primarily as a device to reduce inrush current for motor starting.

average value of AC - The average of all instantaneous values of one-half cycle of alternating current.

AWG (American wire gauge) - a standard for wire size used by industry, replaced by the circular mil by the military.

back voltage - a term sometimes used to refer to counter EMF.

battery - a device for converting chemical energy into electrical energy.

battery capacity - the amount of energy available from a battery. Battery capacity is expressed in ampere-hours.

blowout coil - a coil in a relay used to stretch the arc (blow it out) when opening.

branch - an individual current path in a parallel circuit.

brush - a sliding contact, normally made of carbon, and riding on a commutator or slip ring to provide a mechanical contact between the rotating and stationary portions of an electrical device.

Capacity of a battery - the ability of a fully charged battery to deliver a specific quantity of energy (Ah), at a given rate (A), over a definite period of time (Hr).

capacitance - the property of an electrical circuit that opposes changes in voltage.

capacitive reactance - the opposition offered to the flow of alternating current by capacitance, expressed in ohms. The symbol for capacitive reactance is X_c .

capacitor - an electrical device capable of storing electrical energy in an electrostatic field.

capacitor start motor - an alternating current split-phase motor using a capacitor to achieve a phase shift between the start and run windings. It uses a centrifugal switch to disconnect the start winding when the motor achieves between 75 and 90 percent running speed.

cathode - the general name for any negative electrode.

cell - a single unit that transforms chemical energy into electrical energy. Batteries are made up of cells.

charge - represents electrical energy. A material having an excess of electrons is said to have a negative charge. A material having an absence of electrons is said to have a positive charge.

charge cycle - the period of time that a capacitor in an electrical circuit is storing a charge.

choke - a coil used in a direct current circuit to smooth out ripples or a pulsating waveform.

circuit - the complete path of an electric current.

circular mil - an area equal to that of a circle with a diameter of 0.001 inch. It is used for measuring the cross-sectional area of wires.

coil - an inductive device created by looping turns of wire around a core.

Cold cranking rating - the number of amperes a battery at 0°F can deliver for 30 seconds and maintain at least 1.2 volts per cell.

combination circuit - a series-parallel circuit.

commutator - a segmented bar section on an armature providing a place for the brushes to make contact with the armature windings.

compensating windings - windings embedded in the face of the pole pieces of a DC machine to oppose armature reaction and control arcing at the brushes.

compound generator - a generator using both series and shunt windings on each pole piece.

compound motor - direct current motor with both series and shunt windings.

conductance - the ability of a material to conduct or carry an electric current. It is the reciprocal of resistance of the material and is expressed in mhos or siemens.

conductivity - ease with which a substance transmits electricity.

conductor - a material with a large number of free electrons; a material that permits electric current to flow.

control point - the level at which a system will be maintained (such as temperature and pressure).

control voltage - voltage level used in a control circuit to actuate coils and other devices.

controller - a device for starting a motor in either direction of rotation or adjusting the speed of rotation.

copper loss (I^2R loss) - the power lost due to the resistance of the conductors. In transformers, the power is lost because of current flow (I) through the resistance (R) of the windings.

core - any material that affords a path for magnetic flux lines in a coil.

coulomb - a measure of the quantity of electricity. One coulomb equals $6.242 \times 1,018$ electrons.

Coulomb's Law - also called the law of electric charges or the law of electrostatic attraction. Coulomb's Law states charged bodies attract or repel each other with a force that is directly proportional to the product of their individual charges and inversely proportional to the square of the distance between them.

counter EMF (counter electromotive force) - an electromotive force (voltage) induced in a coil that opposes applied voltage; voltage induced in the coils of a load.

coupling, coefficient of - an expression of the extent to which two inductors are coupled by magnetic lines of force. This is expressed as a decimal or percentage of maximum possible coupling and represented by the letter K .

cross-sectional area - the area of a slice of an object. When applied to electrical conductors, it is usually expressed in circular mils.

current - the drift of electrons past a reference point; the passage of electrons through a conductor. It is measured in amperes.

current, inrush - current flowing into a circuit immediately upon energizing the circuit. It is normally used in conjunction with inductive loads.

cycle - one complete positive and one complete negative alternation of a current or voltage.

damper windings - windings embedded in the pole pieces of generators used to oppose changes in frequency or speed of the rotor. They allow generators to remain in parallel operation.

dead short - a short circuit having minimum resistance.

delta connection - three-phase circuit where the windings are connected in the form of a closed ring or end to end. It is often used to connect windings in three-phase transformers and motors.

delta-delta connection - a transformer connection where both the input and output windings are delta-connected.

delta-wye connected - a transformer connection where the input is delta-connected and the output is wye-connected.

dielectric - an insulator; the insulating material between the plates of a capacitor.

dielectric constant - the ratio of capacitance of a capacitor with a dielectric between the electrodes to the capacitance of a capacitor with air between the electrodes.

dielectric field - the space between and around charged bodies in which their influence is felt; also called electric field of force or electrostatic field.

dielectric hysteresis loss - power loss of a capacitor due to the changes in orientation of electron orbits in the dielectric caused by rapid reversal in polarity of line voltage. The higher the frequency, the greater the loss.

dielectric leakage - power loss of a capacitor due to leakage of current through the dielectric. It also relates to leakage resistance. The higher the leakage resistance, the lower the dielectric leakage.

digital - a class of devices in which outputs vary in discrete or distinct steps, such as pulses; test equipment that displays readings in the form of LCD or LED readouts.

direct current - an electric current that flows in one direction.

displacement current - the current that appears to flow through a capacitor.

domain theory - a theory of magnetism based upon the electron-spin principle. Spinning electrons have a magnetic field. If more electrons spin in one direction than another, the atom is magnetized.

doping - the process in which a crystalline structure is altered by replacing existing atoms with those atoms from other elements. For example, germanium and silicon are base elements used in electronics. To give these base elements a more positive or negative quality, bismuth or boron atoms can be added, respectively.

dot notation - a system used by drafters to indicate relative instantaneous polarity in AC motor and transformer windings.

drum switch - a type of motor controller using switches in the form of fingers actuated by a cam to control various contractors in a control circuit. It is usually used in reversing or braking controllers.

dry cell - an electric cell in which the electrolyte is not a liquid. In most dry cells, the electrolyte is in paste form.

dynamic braking - braking a motor by using the motor as a generator and dissipating the generated voltage through resistors. Dynamic braking uses motor reaction to slow the motor.

eddy current - induced circulating currents in a conducting material that are caused by a varying magnetic field.

eddy current loss - losses caused by random current flowing in the core of a transformer. Power is lost in the form of heat.

effective value - same as root mean square.

efficiency - the ratio of output power to the input power; generally expressed as a percentage.

electric current - electric energy stored on or in an object. It is the negative charge caused by an excess of electrons or the positive charge caused by a deficiency of electrons. Its symbol is Q, q.

electrochemical - the action of converting chemical energy into electrical energy.

electrode - the terminal at which electricity passes from one medium into another, such as in an electrical cell where the current leaves or returns to the electrolyte.

electrolyte - a solution of a substance that is capable of conducting electricity; may be either a liquid or a paste.

electromagnet - an electrically excited magnet capable of exerting mechanical force or performing mechanical work.

electromagnetic - describes the relationship between electricity and magnetism; having both magnetic and electrical properties.

electromagnetic induction - the production of a voltage in a coil due to a change in the number of magnetic lines of force (flux linkages) passing through the coil.

electromagnetism - the generation of a magnetic field around a current-carrying conductor.

electron - the elementary negative charge that revolves around the nucleus of an atom.

electron shell - a group of electrons that have a common energy level that forms part of the outer structure (shell) of an atom.

electrostatic - pertaining to electricity at rest, such as charges on an object (static electricity).

electrostatic field - the field of influence between two charged bodies.

element - a substance in chemistry that cannot be divided into simpler substances by any means normally available.

EMF (electromotive force) - the force that causes electricity to flow between two points with different electrical charges; or when there is a difference in potential between the two points, the unit of measurement in volts.

energy - the ability or capacity to do work.

equivalent resistance - a resistance that represents the total ohmic values of a circuit component or group of circuit components. It is usually drawn as a single resistor when simplifying complex circuits.

excitation - creating a magnetic field; passing current through a conductor to create an electromagnetic field.

excitation current - the current that produces the magnetic field in a generator; the current that flows in the primary winding of a transformer, which produces a magnetic flux field. It is also called magnetizing current.

farad - the basic unit of capacitance. A capacitor has a capacitance of 1 farad when a voltage change of 1 volt per second across it produces a current of 1 ampere.

ferromagnetic material - a highly magnetic material, such as iron, cobalt, nickel, or alloys.

field - the winding in rotating machines that accounts for the magnetic properties necessary to induce an EMF.

field intensity - the amount of magnetizing force available to produce flux lines in the core of a magnet.

field of force - describes the total force exerted by an action-at-a-distance phenomenon, such as gravity upon matter, electric charges acting upon electric charges, and magnetic forces acting on other magnets or magnetic materials.

filter - device used to smooth a signal; electrical device used to suppress undesired noise.

fixed resistor - a resistor having a definite resistance value that cannot be adjusted.

flashing - the field passing current through the windings of a field oil to establish residual magnetism.

flat compounded generator - a compound generator wound so that the series and shunt fields produce an almost constant voltage output for current values from no load to full load.

flux - in electrical or electromagnetic devices, a general term used to designate collectively all the electric or magnetic lines of force in a region.

flux density - the number of magnetic lines of force passing through a given area.

frequency (f) - the number of complete cycles per second existing in any form of wave motion, such as the number of cycles per second of an alternating current.

gaseous - one of the four states of matter; having no fixed shape or volume. For example, steam is a gas.

generator - a rotating machine that uses magnetic induction to produce an EMF, converting mechanical energy into electrical energy.

generator action - inducing a voltage into a wire that is cutting across magnetic lines of force.

graph - a pictorial presentation of the relationship between two or more variable quantities, such as between applied voltage and current it produces in a circuit.

ground - an electrical or mechanical connection, either intentional or accidental, connected from a conductor to earth. The conductor may or may not carry current.

ground potential - zero potential with respect to the ground or earth.

heat sink - a piece of metal used to mount components and draw heat away from them. It is usually made of finned aluminum.

henry (H) - the electromagnetic unit of inductance or mutual inductance. The inductance of a circuit is 1 henry when a current variation of 1 ampere per second induces 1 volt. It is the basic unit of inductance. In radio, smaller units are used, such the millihenry (mH), which is one-thousandth of a henry (H), and the microhenry (uH), which is one-millionth of a henry.

hertz (Hz) - a unit of frequency equal to one cycle per second.

high side - in a transformer, designates the high voltage coil.

horsepower - the English unit of power, equal to work done at a rate of 550 foot-pounds per second, equal to 746 watts of electrical power.

horseshoe magnet - a permanent magnet bent into the shape of a horseshoe or having a U-shape to bring the two poles near each other.

hydrometer - an instrument used to measure specific gravity. In batteries, hydrometers are used to indicate the state of charges by the specific gravity of the electrolyte.

hysteresis - the time lag of the magnetic flux in a magnetic material behind the magnetizing force producing it; caused by the molecular friction of the molecules trying to align themselves with the magnetic force applied to the material.

hysteresis loss - the power loss in an iron-core transformer or other alternating-current device as a result of magnetic hysteresis.

impedance - the total opposition offered to the flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance. The symbol for impedance is Z.

inching - applying reduced power to a motor to move a motor or its load slowly to a desired position.

induced charge - an electrostatic charge produced on an object by the electric field that surrounds a nearby object.

induced current - current that flows in a conductor because of a changing magnetic field.

induced electromotive force - the electromotive force induced in a conductor due to the relative motion between a conductor and a magnetic field.

induced voltage - see induced electromotive force.

inductance - the property of a circuit that tends to oppose a change in the existing current flow. The symbol for inductance is L.

induction - the act or process of producing voltage by the relative motion of a magnetic field across a conductor.

inductive coupling - coupling of two coils by means of magnetic lines of force. In transformers, it is coupling applied through magnetic lines of force between the primary and secondary windings.

inductive reactance - the opposition to the flow of an alternating current caused by the inductance of a circuit, expressed in ohms. It is identified by the letter X.

in phase - applied to the condition that exists when two waves of the same frequency pass through their maximum and minimum values of like polarity at the same instant.

infinite - extending indefinitely, endless; boundless having no limits; an incalculable number.

instantaneous value - the magnitude at any particular instant when a value is continually varying with respect to time.

insulation - a material used to prevent the leakage of electricity from a conductor and to provide mechanical spacing or support to protect against accidental contact; a material in which current flow is negligible, used to surround or separate a conductor to prevent loss of current.

insulator - material of such low conductivity that the flow of current through it can usually be neglected; device having high-electrical resistance, used for supporting or separating conductors so as to prevent undesired flow of current from the conductors to other objects.

integrated circuit - a solid state circuit made up of transistors, resistors, and similar components. All components are packaged into a single device called a chip or one piece of semiconductor material.

interlock - mechanical connection between electrical devices. It may be used to open and close contacts together or prevent components from energizing together.

interpole - a separate winding and pole piece, connected in series and 180 degrees out of phase with the armature of a DC machine. It is used to oppose armature reaction.

inversely - inverted or reversed in position or relationship.

inverter - circuit that changes direct current into alternating current.

ion - an electrically charged atom or group of atoms. Negative ions have an excess of electrons, positive ions have a deficiency of electrons.

ionize - to make an atom or molecule of an element lose an electron, as by X-ray bombardment, and thus be converted into a positive ion. The freed electron may attach itself to a neutral atom or molecule to form a negative ion.

isolation - separation; the value of insulation resistance, measured between the input and output, input to case, or output to case.

jogging - rapid application of full power to a motor to move it or its load into position desired.

junction - the connection between two or more conductors; the contact between two dissimilar metals or materials, as is in the thermocouple.

kilo - a prefix meaning one thousand.

kinetic energy - energy that a body possesses by virtue of its motion.

Kirchhoff's Laws - the talebearing sum of the currents flowing toward any point in an electrical network is zero; the algebraic sum of the products of the current

and resistance in each of the conductors at any closed path in a network equals the algebraic sum of the electromotive forces in the path.

lag - the amount one wave is behind another in time, expressed in electrical degrees.

laminated core - a core built up from thin sheets of metal insulated from each other and used in transformers.

law of magnetism - like poles repel; unlike poles attract.

lead - the opposite of lag; also a wire or connection.

lead-acid battery - a cell in an ordinary storage battery, in which electrodes are grids of lead containing an active material consisting of certain lead oxides that change composition during charging and discharging. The electrodes are plates that are immersed in an electrolyte of diluted sulfuric acid.

leakage flux - magnetic lines of flux produced by the primary winding that do not link the turns of the secondary winding.

leakage resistance - the electrical resistance that opposes the flow of current through the dielectric of a capacitor. The higher the leakage resistance, the slower the capacitor will discharge or leak across the dielectric.

left-hand rule for generators - a rule or procedure used to determine the direction of current flow in a generator.

Lenz's Law - the current induced in a circuit due to its motion in a magnetic field or to a change in its magnetic flux in such a direction as to exert a mechanical force opposing the motion or to oppose the change in flux.

light-emitting diode (LED) - a diode that emits light when energized in a forward bias; may be used as a control device or in a digital display.

line diagram - industry standard method of representing control circuits. It is also called a ladder diagram.

lines of force - a line in an electric or magnetic field that shows the direction of the force.

liquid - one of the four states of matter that has a definite volume but no definite form. For example, water is a liquid.

liquid crystal display (LCD) - a semiconductor device used for displaying digital readouts.

load - a device through which an electric current flows and that changes electrical energy into another form; power consumed by a device or circuit in performing its function.

local action - a continuation of current flow within an electrical cell when there is no external load. It is caused by impurities in the electrode.

locked rotor current - the current level in the motor the instant power is applied, before the motor starts to turn and build CEMF. It is the maximum current level in a motor in good condition.

locked rotor torque - the torque developed by the motor as it is first energized; the greatest amount of torque a motor produces.

logic - a method of using the symbols AND, OR, NAND, NOR, and NOT to represent the function of a circuit.

low side - the low voltage side of a transformer.

magnetic contactor - a switching device actuated by a magnetic coil. It is usually used in AC circuits.

magnetic field - region in which the magnetic forces created by a permanent magnet or by a current- carrying conductor or coil can be detected.

magnetic lines of force - imaginary lines used for convenience to designate the direction in which magnetic forces are acting as a result of magnetomotive force.

magnetic motor starter - a magnetic contactor with an overload section added. It is used to start AC motors.

magnetic poles - the section of a magnet where the flux lines are concentrate also where they enter and leave the magnet.

magnetism - the property possessed by certain materials by which these materials can exert mechanical force on neighboring masses of magnetic materials and can cause currents to be induced in conducting bodies moving rotative to the magnetized bodies.

magnetomotive force - the force that produces magnetic lines of force in a magnetic circuit.

matter - any physical entity that possesses mass.

mechanical energy - in moving objects, the force of motion they possess.

mega - a prefix meaning one million.

memory - characteristic of a motor control circuit that makes it continue to follow the last input; the part of a programmable controller where data and instructions are stored.

mho - unit of conductance; the reciprocal of the ohm.

micro - a prefix meaning one-millionth.

microfarad - one-millionth of a farad. It is the most commonly used unit of measurement of capacitors for motor starting.

microprocessor - a central computer unit that processes input information.

milli - a prefix meaning one-thousandth.

motor controller - device used in a motor circuit to control starting, stopping, direction, breaking, overloads, and inrush current.

motor efficiency - ratio of input power to output power.

motor reaction - magnetic reaction developed in a generator as the armature windings are energized. As the armature builds current and a magnetic field, it reacts with the energized field windings, opposing the generator's direction of rotation.

mutual flux - The total flux in the core of a transformer that is common to both the primary and the secondary windings. The flux links both windings.

mutual inductance - a circuit property existing when the relative position of two inductors causes the magnetic lines of force from one to link with the turns of another. The symbol for mutual inductance is M.

NAND logic - circuit where there are two or more NC inputs in parallel.

NEC (National Electrical Code) - regulatory guidance for electrical devices and shore installations.

negative alternation - the negative half of an AC waveform.

negative electrode - a terminal or electrode having more electrons than normal. Electrons flow out of the negative terminal of a voltage source.

negative temperature coefficient - the temperature coefficient expressing the amount of reduction in the value of a quantity, such as resistance for each degree of increase in temperature.

NEMA (National Electrical Manufacturers Association) - organization that standardizes electrical devices.

network - a combination of electrical components. In a parallel circuit, it is composed of two or more branches.

neutral - in a normal condition, hence neither negative or positive. A neutral object has a normal number of electrons.

neutron - one of the principle parts of the atom. It has no electrical charge and is found in the nucleus of the atom.

newton - metric unit of measure of force. The symbol is N. It is the force that causes a kilogram of mass to accelerate at 1 meter per second. It equals about 1/4 pound.

node - used to indicate an electrical connection of two or more conductors. An electrical node can be considered to extend throughout the circuit where all connections, components, switches, and conductors maintain the same source potential.

no-load condition - the condition that exists when an electrical source or the secondary of a transformer is operated without an electrical load.

no-load test - test of a motor or generator with no electrical load on the device.

NOR logic - two or more NC contacts in series, such as multiple stop buttons.

normally closed (NC) contacts - a set of contacts that are closed in the resting position (no outside force applied).

normally open (NO) contacts - a set of contacts that are open in the resting position (no outside force applied).

NOR logic - a single NC contact in a circuit.

ohm - the unit of electrical resistance. It is that value of electrical resistance through which a constant potential difference of 1 volt across the resistance will maintain a current flow of 1 ampere through the resistance.

Ohm's Law - the current in an electrical circuit is directly proportional to the electromotive force in the circuit. The most common form of the law is $E = IR$,

where E is the electromotive force or voltage across the circuit, I is the current flowing in the circuit, and R is the resistance in the circuit.

open circuit - the condition of an electrical circuit caused by the breaking of continuity of one or more of the conductors of the circuit, usually an undesired condition; a circuit that does not provide a complete path of current flow.

open circuit voltage - the voltage of a battery when it is not delivering or receiving power. It is 2.11 volts for a fully charged battery cell, or 12.66 V for a fully charged 12-volt battery.

OR logic - two or more NO inputs in parallel; either input will energize the load.

out of phase - two or more phases of alternating current that are changing in direction and amplitude at different times.

over compounding - in a compound wound machine, placing more emphasis on the series winding and the series characteristics.

overload relay - a device for protecting electrical circuits and loads from excess current levels. They may be magnetic, thermal, or bimetallic type.

parallel circuit - two or more electrical devices connected to the same pair of terminals so separate currents flow through each. Electrons have more than one path to travel from the negative to the positive terminal.

peak to peak - the measure of absolute magnitude of an AC waveform, measured from the greatest positive alternation to the greatest negative alternation.

peak value - the highest value, either positive or negative, in an alternating current system.

period - time the time required to complete one cycle of a waveform.

permanent capacitor motor - a single-phase motor using a capacitor to create a phase shift in one set of windings.

permanent magnet - a magnet that retains its magnetic properties indefinitely.

permeability - the measure of the ability of a material to act as a path for magnetic lines of force.

phase - the angular relationship between two alternating currents or voltages when the voltage or current is plotted as a function of time. When the two are in phase, the angle is zero and both reach their peak simultaneously. When out of phase, one will lead or lag the other. At the instant when one is at its peak; the other will not be at peak value and (depending on the phase angle) may differ in polarity as well as magnitude.

phase angle - the number of electrical degrees of lead or lag between the voltage and current waveforms in an AC circuit.

phase difference - the time in electrical degrees by which one wave leads or lags another.

phase sequence - the order in which the different phases rise to peak voltage. It may be ABC or CBA.

phase shift - creating a lag or lead in time between the current wave and the voltage wave in an alternating current system. Voltage is the constant.

phase voltage - voltage across a coil in a transformer or generator.

photoelectric voltage - a voltage produced by light.

piezoelectric voltage - the effect of producing a voltage by placing stress, either by compression, expansion, or twisting, on a crystal and, conversely, producing a stress on a crystal by applying a voltage to it.

plate - one of the electrodes in a storage battery.

polarity - the condition in an electrical circuit by which the direction of the current flow can be determined, usually applied to batteries and other direct current voltage sources; two opposite charges, one positive and one negative, a quality of having two opposite poles, one north and one south.

polarization - the effect of hydrogen surrounding the anode of a cell that increases the internal resistance of the cell; the magnetic orientation of molecules in a magnetizable material in a magnetic field, whereby tiny internal magnets tend to line up in the field.

polyphase - a multiple phase alternating current system. The term has been mostly replaced with the term "three-phase."

positive alternation - the positive half of an AC waveform.

potential energy - energy due to the position of one body with respect to another body or to the relative parts of the same body.

potentiometer - a three-terminal resistor with one or more sliding contacts, which functions as an adjustable voltage divider.

pounds of force - English unit of measure for power.

power - the rate of doing work or the rate of expending energy. The unit of electrical power is the watt.

power factor - the ratio of the actual power of an alternating or pulsating current, as measured by a wattmeter, to the apparent power, as indicated by ammeter and voltmeter readings. The power factor of an inductor, capacitor, or insulator is an expression of their losses.

primary cell - an electrochemical cell in which the chemical action eats away one of the electrodes, usually the negative electrode.

primary windings - the winding of a transformer connected to the power source.

prime mover - the driving force for a generator. It may be a diesel engine, a gas or steam turbine, or even an electric motor.

program - the sequence of instructions used to tell a computer how to operate.

prony brake - a device for loading a motor and measuring torque.

proton - one of the particles making up an atom and having a positive electrical charge. It may be found in the nucleus.

pulsating current - direct current that has been rectified from an alternating current. It has a waveform but does not generally drop below the zero plane.

radio frequency (RF) - any frequency of electrical energy capable of propagation into space.

ratio - the value obtained by dividing one number by another, indicating their relative proportions.

RC constant - time constant of a resistor-capacitor circuit; equal in seconds to the resistance value in ohms multiplied by the capacitance value in farads.

reactance - the opposition offered to the flow of an alternating current by the inductance, capacitance, or both in any circuit.

reactive load - a load developing reactive power, such as an inductive or capacitive load.

reciprocal - the value obtained by dividing the number 1 by any quantity.

rectification - the process of mechanically or electronically converting an alternating current into direct current.

rectifier - a device that changes alternating current into direct current

reduced inrush starting - using motor starting circuits to limit inrush current.

reference point - a point in a circuit to which all other points in the circuit are compared.

regenerative braking - an inherent ability in a motor to generate a small current and develop motor reaction as the load slows when de-energized.

relay - an electromechanical device using a coil to actuate contacts to control current to a load. Normally, it is the term for magnetic devices in large direct current systems.

relay, solid-state - a solid-state switching device using a control signal to switch current on and off to a load.

reluctance - a measure of the opposition that a material offers to magnetic lines of force.

repulsion - the mechanical force tending to separate bales having like electrical charges or like magnetic polarity.

reserve capacity rating – the time in minutes that a new, fully charged battery will deliver 25 amps at 80° F and maintain a terminal voltage equal to, or higher than, 1.75 volts per cell.

residual magnetism - magnetism remaining in a substance after removal of the magnetizing force.

resistance - the property of a conductor that determines the amount of current that will flow as the result of the application of a given electromotive force. All conductors possess some resistance, but when a device is made especially for the purpose of limiting current flow, it is called a resistor. A resistance of 1 ohm will allow current of 1 ampere to flow through it when a potential of 1 volt is applied. It is the opposition that a device or material offers to the flow of current. The effect of resistance is to raise the temperature of the material or device carrying the current. Resistance also refers to a circuit element designed to offer predetermined resistance to current flow.

resistive load - a load that converts electrical energy into heat or light; a load characterized by having virtually no inrush current.

resistor - the electrical component that offers resistance to current flow. It may be a coil of fine wire or a composition rod.

resonance - the condition existing in a circuit when values of inductance, capacitance, and the applied frequency are such that the inductive reactance and capacitive reactance cancel each other.

retentivity - the ability of a material to retain its magnetism.

reverse current relay - device in a DC switchboard that senses current being delivered to a generator and removes the generator from the circuit. This prevents the generator from being driven like a motor.

reverse polarity protection - devices used to protect generators from being driven like a motor.

reverse power relay - device in an AC switchboard that senses current being delivered to a generator and removes the generator from the circuit. This prevents the generator from being driven like a motor.

rheostat - a resistor whose value can be varied; a variable resistor that is used for the purpose of adjusting the current in a circuit.

ripple - a series of peaks in current or voltage value when alternating current has been rectified to direct current.

RLC circuit - an electrical circuit that has the properties of resistance, inductance, and capacitance.

root mean square (RMS) - the equivalent heating value of an alternating current or voltage, as compared to a direct current or voltage. It is 0.707 times the peak value of the same sine wave.

rotating armature generator - an alternating current generator having the output voltage generated in the rotating windings (rotor).

rotating field generator - an alternating current generator using the rotating windings (rotor) as the field and having the output voltage developed in the stationary windings (stator).

rotational losses - power lost in rotating equipment due to windage and friction.

rotor - rotating windings or the rotating portion of AC machines.

salient pole - the pole pieces bolted to the shaft in AC generators.

saturation - the condition or point where a magnetic or electrical device can take no more magnetic flux.

saturation curve - a magnetization curve showing the relationship between current and magnetic flux.

schematic circuit diagram - a diagram using symbols to indicate devices in a circuit. Schematics show function, not location.

SCR (silicon-controlled rectifier) - a three-lead semiconductor used as a switching device. Normally an open circuit, when a signal is delivered to the gate, the device rapidly allows current to flow. It is an extremely rapid operation.

secondary - the output coil of a transformer.

secondary cell - a cell that can be recharged bypassing a current through the cell in a direction opposite to the discharge current.

self-excited - a generator that uses residual magnetism to develop its magnetic field and output voltage.

self-induction - the production of a counter electromotive force in a conductor when its own magnetic field collapses or expands with a change in current in the conductor.

separately excited - a generator that needs an outside power source to energize its field windings.

series aiding - when power sources are connected so the positive terminal of one source is connected to the negative terminal of another source. The voltage developed is the sum of the two voltages.

series circuit - an arrangement where electrical devices are connected so that the total current must flow through all the devices. Electrons have one path to travel from the negative to the positive terminal.

series field - a winding in a rotating machine that is connected in series with the armature of the machine.

series motor - a rotating machine with the field winding in series with the armature. It develops a high starting torque and may be either AC or DC.

series opposing - power sources that are connected positive terminal to positive terminal.

series-parallel circuit - a circuit that consists of both series and parallel networks.

shaded pole motor - a single-phase squirrel cage motor using slotted stator poles with copper bands to create a phase shift. The copper band creates an auxiliary winding and a slight delay in the magnetic field.

shading coil - a coil with a slotted pole piece wrapped with a copper band. The copper band causes a delay in the magnetic field. It may be used to create a rotating magnetic field or to keep AC contractors from chattering.

shelf life - the period of time that a cell or battery may be stored and still be useful.

shell-type transformer - a transformer using a coil constructed to surround the coil as well as pass through the center of the coil.

shielding - a metallic covering used to prevent magnetic or electromagnetic fields from affecting an object.

short circuit - a low-resistance connection between two points of different potential in a circuit, usually accidental and usually resulting in excessive current flow that may cause damage.

shunt - a parallel connection a device used with an ammeter to direct most of the current around the meter movement.

shunt field - a field coil in a DC machine connected in parallel with the armature.

shunt wound - a DC machine having the field coils in parallel with the armature windings.

shuttle power - power stored in the inductive or capacitive load and returned to the circuit.

siemens - the new and preferred term for conductance, replacing the mho.

sine wave - the curve traced by the projection on a uniform time scale of the end of a rotating arm or vector. It is also known as a sinusoidal wave.

single phase - an alternating current system using a single voltage and current sine wave.

slip - the difference in speed between synchronous speed and rotor speed.

slip rings - rings of copper on the rotor of an AC machine to provide a path of current from brushes to the rotor windings.

solder pot - the device in a thermal overload that holds the device in a normal operating condition. Heat generated by excess current causes the solder to melt, releasing springs that open the overload contacts.

solid - one of the four states of matter, which has a definite volume and shape. For example, ice is a solid.

solid-state - another term for electronic devices.

source of voltage - the device that furnishes the electrical energy used by a load.

specific gravity - the ratio between the density of a substance and that of pure water at a given temperature.

split-phase (resistance-start) motor - an induction motor using greater resistance in one winding to create the phase shift necessary for the motor to start.

squirrel cage rotor - a rotor using bars that are shorted at the ends. Current is induced into the rotor.

stall torque - the point at which the torque demanded of a motor exceeds the motor's torque output.

state of charge - the amount of electrical energy stored in a battery at a given time expressed as a percentage of the energy when fully charged.

static electricity - stationary electricity that is in the form of a charge. It is the accumulated charge on an object.

stator - the stationary windings in an AC machine.

stator field - the magnetic field setup in the stator windings.

stroboscopic effect - used to measure speed of a rotating shaft. When a strobe light flashes on the shaft, the shaft will appear to stop if the flash speed and rotating speed are the same.

switch - a device to connect, disconnect, or change the connections in an electrical circuit.

synchronous - in step or in phase as applied to currents, voltages, or two different rotating machines.

synchronous speed - the rate of travel of a stator field of a three-phase machine; determined by the frequency and number of poles.

synchroscope - a device used to determine phased differences between two AC generators. It allows aligning phases of generators for parallel operation.

tapped resistor - a wire-wound fixed resistor having one or more additional terminals along its length, generally for voltage divider applications.

taps - terminals added to fixed resistors to allow connections at various points along the resistor with varied values.

temperature coefficient - the amount of change of resistance in a material per unit change in temperature.

terminal - an electrical connection.

tesla - measure of flux density.

thermistor - a temperature-controlled variable resistor.

thermocouple - a junction of two dissimilar metals that produces a voltage when heated.

thermostat - a device in a control circuit used to start and stop air conditioning, refrigeration, or heating systems based on temperature.

theta - the Greek letter (θ) used to represent phase angle.

three-phase - alternating current devices using three sine waves, 120 electrical degrees out of phase.

time constant - the time required to charge a capacitor to 63.2 percent of maximum voltage or discharge to 36.8 percent of its final voltage. It is the time required for the current in an inductor to increase to 63.2 percent of maximum current or decrease to 36.8 percent of its final current.

timer - a control device that turns on or turns off a control circuit based a preset time delay.

tolerance - the maximum error or variation from the standard permissible in a measuring instrument; a maximum electrical or mechanical variation from specifications that can be tolerated without impairing the operation of the device.

torque - the force that produces a twisting or rotating action.

total resistance (R_t) - the equivalent resistance of an entire circuit. For a series circuit $R_t = R_1 + R_2 + R_3 + \dots R_n$. For parallel circuits: $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \frac{1}{R_n}$

transducer - a device that converts physical parameters, such as pressure and temperature, into an electrical signal.

transformer - a device composed of two or more coils, linked by magnetic lines of force, used to transfer energy from one circuit to another.

transformer efficiency - the ratio of output power to input power, generally expressed as a percentage:

$$\text{Efficiency} = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100$$

transformer, isolation - a transformer with the same number of turns in the primary and secondary windings. This construction will deliver the same voltage in the secondary winding as in the primary windings. Isolation transformers are used to protect circuits or portions of the distribution system.

transformer, step-down - a transformer so constructed that the number of turns in the secondary winding is less than the number of turns in the primary winding. This construction will provide less voltage in the secondary circuit than in the primary circuit.

transformer, step-up - a transformer so constructed that the number of turns in the secondary winding is more than the number in the primary winding. This construction will provide more voltage in the secondary winding than in the primary winding.

transient - a temporary current or voltage that occurs randomly in the AC sine wave.

true power - the power dissipated in the resistance of the circuit or the power actually used by the circuit.

turn - one complete loop of a conductor about a core.

turns ratio - the ratio of number of turns in the primary winding to the number of turns in the secondary winding of a transformer.

two-capacitor motor - an induction motor using two capacitors to develop the starting phase shift. One is the start capacitor, which is taken out of the circuit by a centrifugal switch. The other capacitor is the run capacitor, which remains in the system at all times.

Under-compounded - a compound wound DC machine with the emphasis on the shunt winding.

unidirectional - in one direction only.

unity power factor - when all the generated power in a system is being used to drive loads. The voltage and current waves are in phase. Unity is expressed as a power factor of 1 (100 percent efficiency).

universal time constant - a chart used to find the time constant of a circuit if the impressed voltage and the values of R and C or R and L are known.

valence - the measure of the extent to which an atom is able to combine directly with other atoms. It is believed to depend on the number and arrangement of the electrons in the outermost shell of the atom.

valence shell - the electrons that form the outermost shell of an atom.

variable resistor - a wire-wound or composition resistor, the value of which may be changed.

vector - a line used to represent both direction and magnitude; the angular difference in the direction the conductors which are moving in relation to the magnetic lines of flux.

volt - the unit of electromotive force or electrical pressure; 1 volt is the pressure required to send 1 ampere of current through a resistance of 1 ohm.

voltage - signifies electrical pressure. Voltage is a force that causes current to flow through an electrical conductor. The voltage of a circuit is the greatest effective difference of potential between any two conductors in the circuit.

voltage divider - a series circuit in which desired portions of the source voltage may be tapped off for use in equipment.

voltage drop - the difference in voltage between two points. It is the result of the loss of electrical pressure as a current flows through a resistance.

watt - the practical unit of electrical power. It is the amount of power used when 1 ampere of DC flows through a resistance of 1 ohm.

wattage rating - a rating expressing the maximum power that a device can safely handle.

watt-hour - a practical unit of electrical energy equal to one watt of power for one hour.

wattmeter - a device used to measure electrical power.

waveform - the shape of the wave obtained when instantaneous values of an AC quantity are plotted against time in a rectangular coordinate.

wavelength - the distance, usually expressed in meters, traveled by a wave during the time interval of one complete cycle. It equals the velocity of light divided by the frequency.

Weber's theory - a theory of magnetism that assumes that all magnetic material is composed of many tiny magnets. A piece of magnetic material that is magnetized has all of the tiny magnets aligned so that the north pole of each magnet points in one direction.

windage - rotational losses in a generator that are due to the friction as the armature or rotor passes through the surrounding air.

wire - a solid or stranded group of solid cylindrical conductors having a low resistance to current flow, with any associated insulation.

wiring diagram - a diagram intended to show as closely as possible the placement and actual connections of electrical devices.

work - the product of force and motion.

working voltage - the maximum voltage that a capacitor may operate at without the risk of damage.

wye or star connection - an electrical connection in three-phase machines where all terminals having the same instantaneous polarity are joined at the neutral junction. It is shown as coils connected to form a symbol resembling the letter Y.

wye-delta - a transformer connection where the primary windings are connected wye and the secondary windings are connected delta.

wye-wye - a transformer connection where both primary and secondary windings are connected in a wye pattern.

yoke - the framework or housing in a DC motor that the field windings are attached to.

