CDC 3E151

Heating, Ventilation, Air Conditioning, and Refrigeration Journeyman

Volume 3. Electrical and Controls Concepts

Air Force Career Development Academy

The Air University

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THIS THIRD VOLUME of CDC 3E151, *Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC/R) Journeyman*, introduces you to air and hydronic distribution systems.

Unit one discusses eletctrical theory, safety, wiring, wiring diagrams and troubleshooting.

Unit two discusses protective and control devices and motors.

Unit three teaches air compressors, control fundamentals, electrical and electronic controls and direct digital control, energy monitoring control systems, and system and subsystem strategies.

This CDC has four additional volumes. Volume 1, HVAC/R Fundamentals; Volume 2, Air and Hyrdonic Systems; Volume 4, Heating Systems; and Volume 5, Cooling Systems.

This course must be completed before you can obtain a 5-skill level in the 3E1X1 career field.

A glossary is included for your use.

Code numbers on figures are for preparing agency identification only.

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Acknowledgment

PREPARATION of this volume was aided through the cooperation and courtersy of Honeywell, Inc. who furnish technical materials for Microprocessor-Based/DDC Fundamentals (77–1123) from their manual, *Honeywell Engineering Manual of Automatic Control*. The following figure has been reproduced by Honeywell, Inc.'s permission and this permission is gratefully acknowledged:

Figure 3–18, Simple Electronic Control System

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Unit 1. Electrical Concepts

MOST OF US KNOW something about electricity because electrical devices and appliances are a part of our everyday life. We flip a switch and a lamp gives us light. We turn a radio knob and hear music. We turn on an electric fan or a washing machine, and parts begin to move. We know, then, that we can put electrical energy to work. In heating, ventilation, air conditioning, and refrigeration, electrical energy drives motors, operates controls, and opens valves.

Since humans cannot neccesarily see electricity, we can only study the effects of what it does. We do know that electricity is created by free electrons moving along conductors and units of resistance. Its effects we can see and measure by the use of instruments. In this unit, we discuss fundamentals of electricity, types of electrical circuits, relationship of voltage current and resistance in circuits, wiring requirements, wiring diagrams, and circuit protective devices.

1–1. Electrical Theory and Safety

In any profession, individuals must have a comprehension of the basic theory of their work. In heating, ventilation, air conditioning, and refrigeration (HVAC/R), the required comprehension is of electrical theory. Electricity not only drives the world but also drives our career field. If you do not have a basic understanding of electrical theory, you will not be successful. Electrical theory is covered in this section.

Besides having a basic understanding of a concept, you must be safe while practicing that concept. If you injure or kill yourself while performing a task, you can no longer perform ANY task. Safety is top priority in any job; therefore, safety is also covered in this section.

401. Electrical theory

Electricity is the flow of electrons from a source of power through conductors (wires) to the load device (HVAC/R equipment, light bulbs, motors, etc.). To have an operating electrical circuit, you must have voltage, resistance, and current.

Voltage

Voltage is the force that moves electrons through a conductor. It is important to remember that voltage doesn’t really flow through a conductor. Voltage is the force that pushes current through a conductor. To understand this, think of the pressure in a water line. The pressure itself does not flow through the water pipe but rather forces the water through the pipe.

Voltage results from having more electrons at one place than at another. Voltage, potential difference, electromotive force (EMF), and electrical pressure are all used interchangeably and mean the same thing. Electrical pressure can be obtained by converting heat, mechanical, or chemical energies. There are three principal devices that enable us to get voltage or a difference of potential between two points: a battery, a thermocouple, and a generator.

Storage battery

When two different types of metals are placed in an acid solution, the acid reacts with the metals. This acid is called an *electrolyte* solution. The acid reacts with the molecules of the metals, causing ionization. Once the reaction starts, some molecules in the solution have an extra electron (negative ion), and others are short an electron (positive ion). This causes an ion drift across the battery and results in the negative terminal having a high concentration of electrons while the positive terminal of the battery has an equal shortage of electrons. When we attach conductors and a unit of resistance from the negative terminal to the positive terminal, the electrons that gathered at the negative terminal pass to the positive terminal, and current flow results (fig. 1–1).

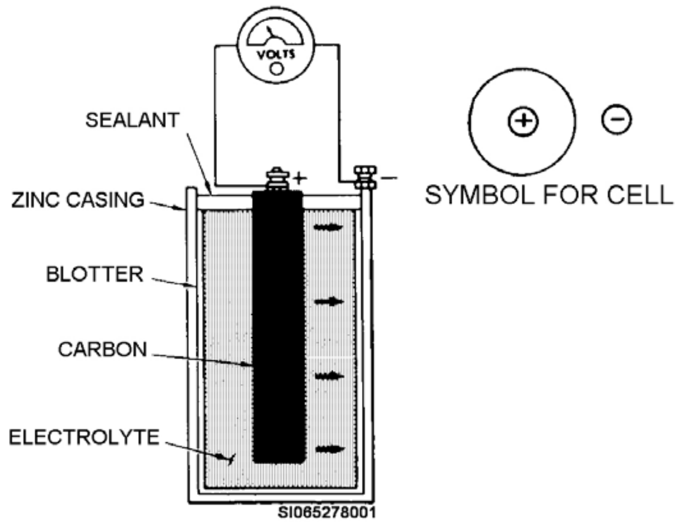


Figure 1–1. Battery cell.

Thermocouple

A thermocouple is probably the simplest unit the HVAC/R career field uses to produce electric current. A thermocouple works by means of heat. It operates on the principle that voltage is produced by heating the junction of two dissimilar metals. As the junction is heated, electrons begin to move. The electrons move in an orderly manner because the metals are dissimilar and respond to heat differently. When electrons move in this orderly manner, we say current flows. Because of the way the two different metals react to heat, current flows in only one direction. Heat energy is being converted to electrical energy.This principle is illustrated in figure 1–2.

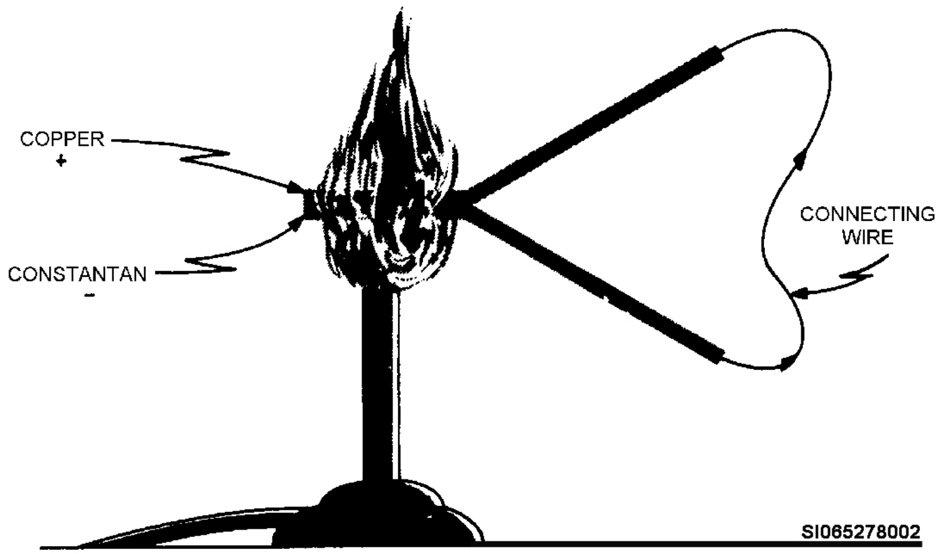


Figure 1–2. Thermocouple.

Thermocouples are used in various ways in HVAC/R. The following is a list of some of their uses:

- Air temperature readings in ducts.
- Fluid temperature readings.
- Flat surface temperature readings.
- Wet bulb temperature readings.
- Pipe clamp for superheat and subcooling readings.
- Air temperature readings using a multimeter.
- Safety device in furnaces.

As you can see, thermocouples are widely used. You need to know how they work and when and where they can be used.

Mechanical generator

Practically all electricity used for domestic and industrial purposes in this country is produced by generators. A generator is a rotating machine that converts mechanical energy into electrical energy. To generate voltage mechanically, three factors are required: a magnetic field, conductors, and relative motion between the two. The relative motion causes the conductors to cut through the magnetic field. The result is voltage. The voltage moves the electrons, causing current flow (fig. 1–3). In figure 1–3 the relative motion is supplied by the person’s hands who is holding the conductor. Note in figure 1–4 how the direction of the current flow changes as the conductor changes direction in the magnetic field. In the left picture in figure 1–4, the conductor is moving down and the current flow is from the negative on the left to the positive on the right. On the picture on the right hand side of figure 1–4, the conductor is moving up and the current is flowing from the negative on the right to positive on left. When the current flows, first in one direction and then in the opposite direction, we call it alternating current (AC).

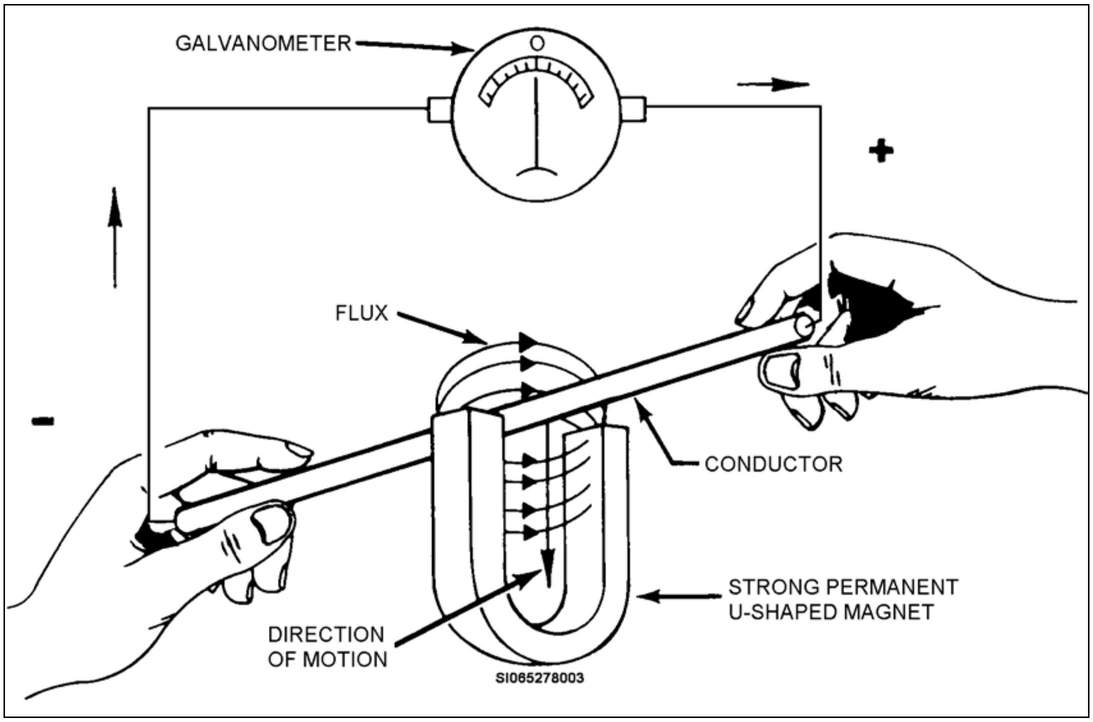


Figure 1–3. Generation action.

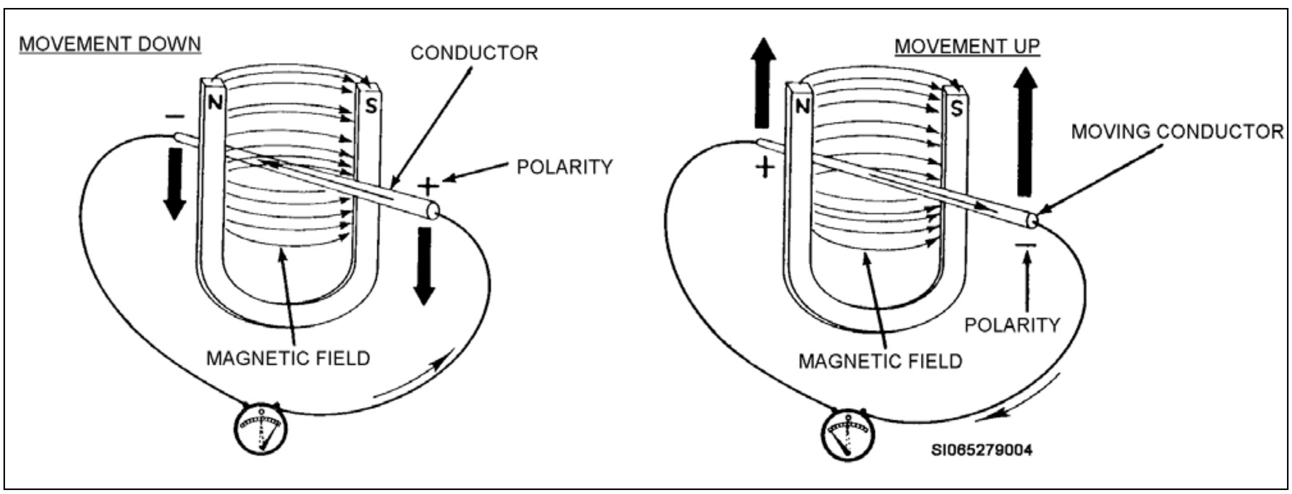


Figure 1–4. Voltage generation.

The machine that produces this current is an alternating current generator, or AC generator. A simplified diagram of an AC generator is shown in figure 1–5. In this figure, you can notice rotation clockwise from callout A to callout D. Since most AC is 60 cycle, it means that this pattern is being repeated in the alternating generator at the rate of 60 times per second. Figure 1–6 shows a graph of one complete cycle, 1/60 of a second. The graph breaks down each of four parts of the cycle. Notice how the power peaks at 120 volts (V) at the top and bottom peak. Power companies use water power, steam, or diesel and gasoline engines to produce electricity like this.

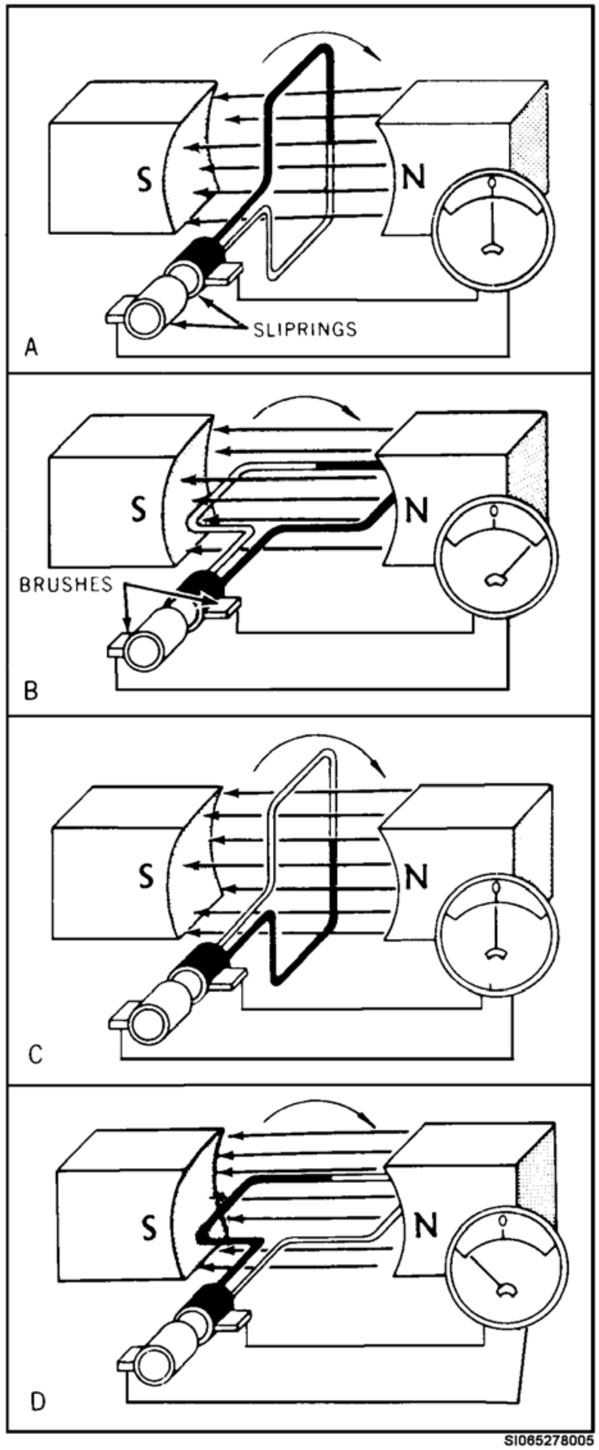


Figure 1–5. AC generator.

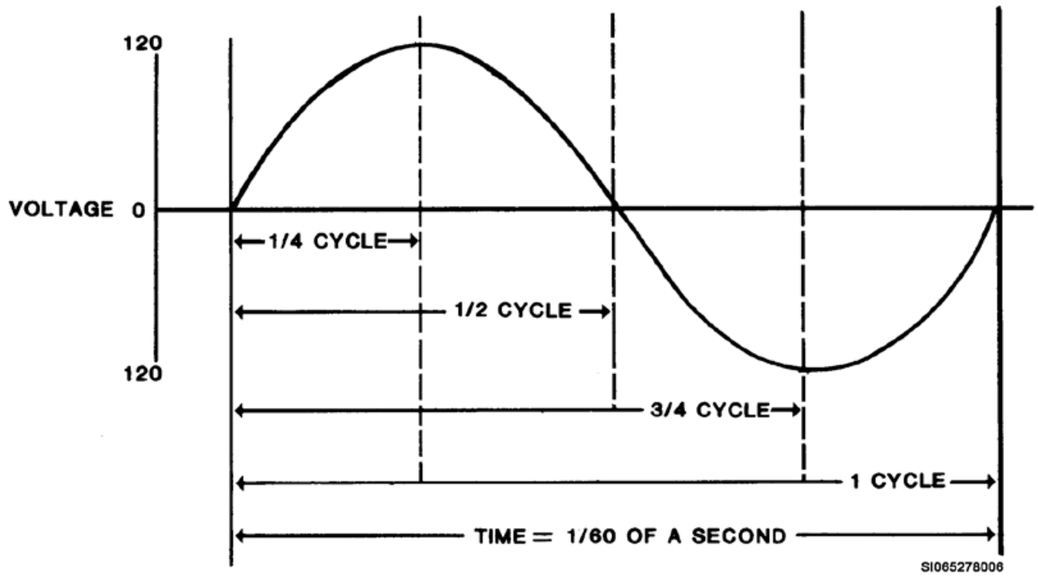


Figure 1–6. Graph of a complete AC cycle.

Measuring voltage

We measure potential difference between two points with the voltmeter. The unit of measurement is the volt.

Resistance

To resist means to oppose or retard. Resistance means the opposition to the movement of free electrons through a circuit or conductor. The resistance of the conductor is determined by four factors: kind of material, cross-sectional area, length, and temperature. An easier way to remember these four factors is by the acronym M.A.L.T.

- M – Material.
- A – Area.
- L – Length.
- T – Temperature.

Material

Resistance to electric current is present in all matter, but one material may have much more resistance than another. Air, rubber, glass, and porcelain have so much resistance that they are called *insulators,* and we use them to confine electricity in a circuit. The rubber covering on the wires to an electric lamp prevents the wires from touching each other and causing a short circuit. The rubber also protects a person who is using a lamp from receiving an electric shock. Air acts as an insulator whenever a light switch is opened. Air fills the gap between the open contacts of the switch, and no current flows because of the high resistance. However, even air may act as a conductor if the voltage is high enough; otherwise, there could not be the discharge that appears when lightning strikes.

Metals are good conductors of electricity, but some are better than others. Copper and silver are both good conductors of electricity because of their relatively low resistance. Aluminum is not as good but is used for long overhead spans because of its light weight. Steel is a poor conductor, although it is used in combination with aluminum for added strength. Alloys of nickel and chromium are used in heater elements to provide a specific resistance that passes enough current to heat the elements to a red glow. The alloy makes it possible to operate the elements at high temperatures without melting. Since copper is a good conductor and also relatively inexpensive, it is widely used in electrical circuits. However, copper is seldom used in its pure form. It is usually mixed with other metals to form a copper alloy.

Area (cross sectional area or size)

The size of the wire can be seen as similar to water flow through a pipe. A small diameter pipe offers a lot of resistance, and as a result, only a small amount of water can flow through it. In an electrical system, current flow is limited by the size of the wire and by the amount of force from the power supplier. A small diameter wire offers a lot of resistance; as a result, only a small amount of electrical current can flow through it. Therefore, for practical wiring conditions, assume that a larger conductor will carry more current (have less resistance) than a smaller wire of the same material.

Length

The length of the conductor contributes to the opposition of current flow in an electrical path (circuit). The longer the wire, the more pressure you need to force the electrons to the load device. Think about it, the longer distance the electrons need pushed, the more force required.

Temperature

In normal temperature ranges, the change in resistance is very small. A cold wire has less resistance than a hot wire.

Why M.A.L.T.?

Does M.A.L.T. seem too technical for the average technician? You must realize this is not a topic or concept you will deal with every single day. If you are running wire for an HVAC/R unit and the conditions are abnormal, you may have to take into account these factors. For example, you may usually run wire for a unit about five to 10 feet, but what if you need to run wire 300 feet for a particular job? The length may negatively affect current flow and more research will need to be done.

Also, don’t consider resistance as a bad thing. Even conductors offer resistance to current flow. What?! Yes, even the wires we use to pass power offer resistance, but it is still small enough to allow current to flow. Think of when you walk across a room. There is resistance to you walking across a room, and it is called *gravity*. You are still able to move even though gravity is acting as resistance. The reason you are moving is because you are overcoming the resistance of gravity to move. Voltage supplies the force necessary to overcome the resistance in an electrical circuit. If you have a preconception that resistance is bad, eliminate it from your thought process right now!

Measuring resistance

All forms of opposition to current flow are either measured or calculated in ohms. This unit of measurement states that when 1V of pressure pushes 1 ampere (amp) of current flow through an electrical path, then 1 ohm of resistance is present.

Current

Electrical current is the movement of electrons along an electrical conductor (wire). We measure the amount of current flow through an electrical circuit in amperes. We define one ampere as the flow of 6.25 billion electrons per second through the point of measurement. In practical work, we measure electron current with a meter, most often a clamp-on meter.

There are two common types of electric current: direct current (DC) and AC. DC represents electron flow along a conductor in one direction (fig. 1–7). The direction it flows is from negative to positive. DC circuits are covered more in depth in a later lesson.

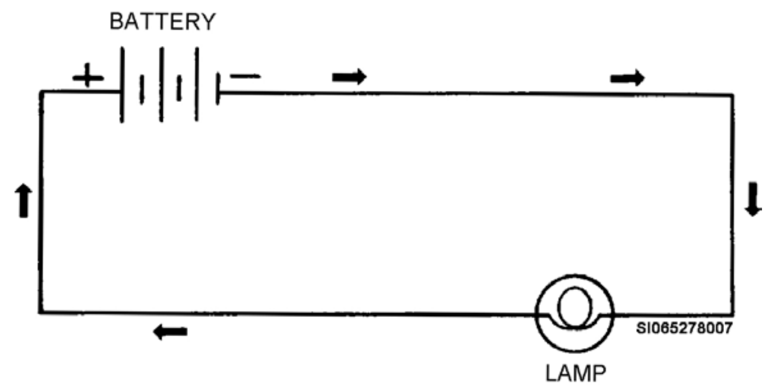


Figure 1–7. Electron flow in a DC circuit.

DC current is produced by a battery or thermocouple. AC is electron flow along a conductor, first in one direction, then in the other (fig. 1–8). Because the current changes its direction of flow, we call it AC. When an AC generator completes a positive and a negative alternation, it has completed one electrical cycle. Figure 1–9 shows a cycle diagram for AC. Looking at the figure, you can see that the current starts at zero, reaches its maximum at 120V at one-quarter of the cycle, and is back at zero at half cycle. The current then reaches its maximum in the opposite direction at three-quarters of the cycle, and again returns to zero at the end. Hertz (Hz) is the number of times each cycle occurs in 1 second.

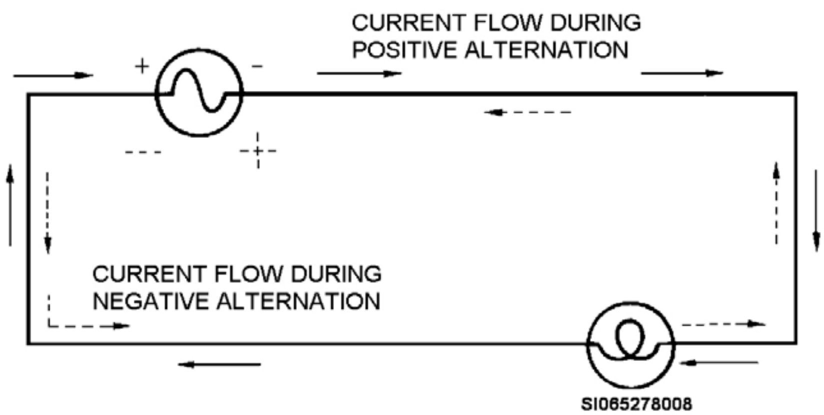


Figure 1–8. Electron flow in an AC circuit.

American power companies provide AC at 60 Hz, which means that the pattern is being repeated in the AC circuit at the rate of 60 times per second. Many foreign nations produce 50 Hz per second.Current has four effects:

- Heat.
- Magnetism.
- Chemical action.
- Physical shock.

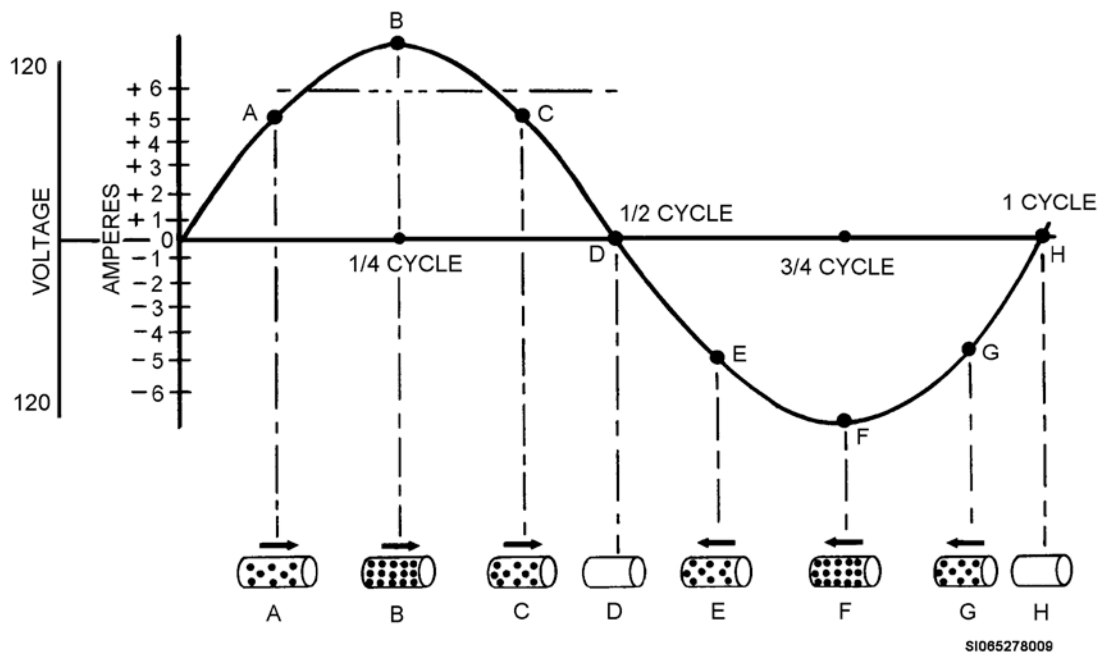


Figure 1–9. Graph of AC.

Heat

Heat is produced when current flows through a conductor. Because heat is a by-product of current, it is important that the circuit be installed properly. If not, the circuit could become overheated and eventually cause a fire. The amount of heat produced in an electrical circuit depends on the material of the conductor and the amount of current flow. The heat produced is used for the good of mankind. For example, electric irons and toasters have heating elements that produce enough heat so clothes can be ironed or toast can be made. The light produced by an electric lamp is caused by current flowing through a threadlike conductor called a *filament*. As the filament is heated, it glows and gives us light. The iron, toaster, and light bulb are units of resistance that make good use of the heat that is produced by current.

As long as the circuits supplying these units of resistance are installed properly, everything works fine. If not, there is a fire hazard because the heat from the current keeps increasing when the circuit is in use. Prolonged use allows the heat to become intense enough to start a fire.

Magnetism

Magnetism is produced when current flows in a conductor. This is a very important effect. Magnetism is the basis for millions of electrical machines such as generators, motors, and electromagnets. Without this effect, there is no known way to generate electricity cheaply and convert it into mechanical energy to do work.

Chemical action

Current produces a chemical action when it flows through a liquid. Examples of this effect are the charging of a storage battery and the electroplating process.

Physical shock

Physical shock is the unpleasant and sometimes dangerous sensation caused by coming into contact with a source of electric energy. We often speak of voltage as the cause of shock; however, the fact is that current flowing through the human body produces the physical shock. The pain and the muscular contractions are due to the effect of current on the nerve centers and on the nerves themselves.

Power

Power, used as a general term, is electricity doing a job. We discuss terms and their relationships to a circuit or device that will make a difference as you examine and troubleshoot circuits. Understanding these terms gives you the ability to make quick and accurate decisions.

Power is the rate of doing work and is abbreviated by the symbol "P." Forcing electrons through a resistor requires work; energy is expended in the resistor in the form of heat. If this heat is not too great, it can be radiated and does not damage the resistor. If there is too much heat, the heat cannot be radiated as quickly as it is generated. The resistor becomes too hot and burns out. As a precaution against too much heat, a resistor has a power rating, meaning that no more than a specified current (given number of electrons per second) can be allowed to flow through the resistor without damaging it. Electrical power is the rate at which electrons are forced through resistance by electromotive force.

You need to know the meanings of the following terms that are used with electricity: watt, horsepower, force, work, and energy.

Watt

The unit of electrical power is the *watt.* A larger unit of power is the *kilowatt*, which equals 1,000 watts.

Horsepower

Horsepower, the unit for measuring mechanical power, is equal to 746 watts.

Force

Force is energy that causes a change in the motion of a body. In electronics, electrical force causes electrons to move from one point to another. The unit of force is the *dyne.*

Work

Work is the production of motion against a resisting force. In electronics, electromotive force causes electrons to move against the opposing force offered by the resistance in a circuit. When an amp of current flows through a resistance of 1 ohm for 1 second, this creates a *joule* of work.

Energy

Energy is the capacity or ability to do work. We call energy that is due to motion of matter *kinetic* energy and energy that is due to the position of matter *potential* energy. As an example, the electrons on a negatively charged body have potential energy with respect to a less positively charged body because these electrons would flow if the two bodies were connected by a conductor. The electrons moving in the conductor connecting the two bodies have kinetic energy because such electrons are in motion.

Energy may be dissipated in such forms as heat, light, and motion. It may be transformed from one form to the other, as is done in producing electron flow by mechanical or chemical means. Since energy is the capacity to do work, *energy and work have the same unit* (joule).

Fundamentals of AC

Electrical current flow consists of electrons moving in a circuit. Since the electron is negatively charged, it is repelled at the negative end of the circuit and attracted to the positive point. Hence, it travels from negative to positive. In the DC circuit, current moves in one direction only. In the AC circuit, the voltage polarity changes at regular intervals. This causes the current to flow in one direction and then in the opposite direction. The alternations in current flow are shown in figure 1–8. The solid arrows show the direction of current flow during the positive alternation, and the dotted arrows show the current flow during the negative alternation. Since the current flow is continuously changing direction, we call it AC.

Cycle and frequency

When an AC generator completes a positive and a negative alternation, it has completed one electrical cycle. The cycle we represent by the symbol **~**. The number of times each cycle occurs in 1 second we call *frequency.* This is expressed as hertz per second or simply by *hertz.* We now say that the frequency of the power system is 60 hertz.

The wave forms of AC are shown in figure 1–10. We usually refer to this as a sine wave. The term *sine wave* comes from the operation of a generator. It is so named because the alternator output voltage at any one point on the wave is the product of the sine of the rotor angle and the peak voltage.

The frequency of the AC generator voltage output depends upon the speed of rotation of the rotor and the number of pairs of poles. With a given number of poles, the faster the speed of rotation of the rotor, the higher the frequency becomes; and, conversely, the lower the speed of rotation, the lower the frequency becomes.

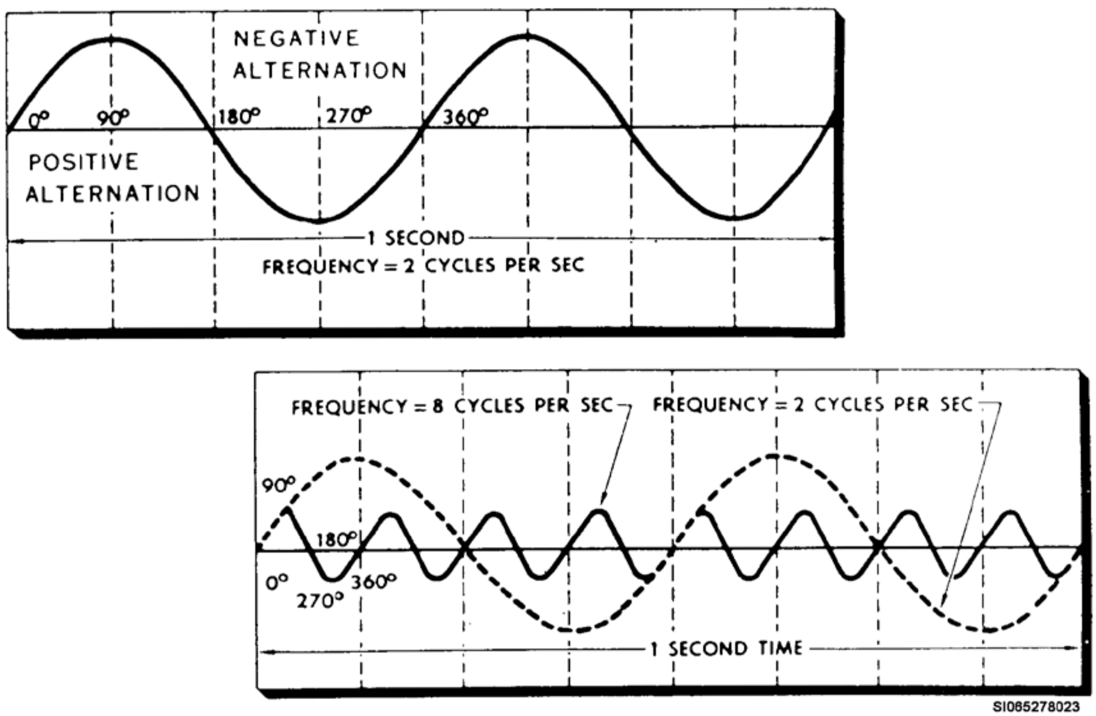


Figure 1–10. Relationship of frequency and cycles in AC.

Inductance

When an alternating current flows through a coil of wire, it sets up an expanding and collapsing magnetic field about the coil. The expanding and collapsing magnetic field induces a voltage within the conductor that is opposite in direction to the applied voltage.

This induced voltage opposes the applied voltage, thus serving to lessen the effect of the applied voltage. This results in the self-inducted voltage's tendency to keep a current moving when the applied voltage is decreasing and to oppose a current when the applied voltage is increasing.

This property of a coil that opposes any change in the value of the current flowing through we call inductance. We measure the *inductance* of a coil in *henrys*. The inductance depends on several factors. The three main inductances are below:

1. The number of turns of wire in the coil.
2. The cross-sectional area of the coil.
3. The material in the center of the coil or the core.

A core of magnetic material greatly increases the inductance of the coil. Remember, however, that even a straight wire has inductance, small though it may be when compared to the inductance of a coil. All AC motors, relays, transformers, and the like contribute inductance (or the inductive reactance) to a circuit. In an AC circuit with inductance, there is opposition to the flow of current in addition to the resistance normally present. The extent of this opposition depends on two things: the frequency of the applied voltage and the amount of inductance that is present in the circuit. This opposition we know as inductive reactance. Inductive reactance we identify by the symbol X_L, and we measure it in ohms.

The formula used to find inductive reactance for AC circuits is complicated and usually only used by engineers. For that reason your study of the formula is not necessary at this time. If, however, in the future you have a need to find the inductive reactance of an AC circuit, you can consult the *National Electrical Code®* book for the formulas.

Because of the nature of reciprocating EMF in an AC circuit, there is no actual loss of electrical energy. Therefore, even though inductive reactance is in opposition to alternating current flow, its result is not loss, but it does require a greater applied voltage to overcome this additional opposition. Because of the opposition by inductive reactance, current lags the voltage in an AC circuit.

If you multiply the instantaneous values of the voltage and current together when this out-of-phase condition exists, the power output diminishes greatly. Also, if the circuit is purely inductive, the current lags the voltage by 90 degrees. Figure 1–11 shows this current lag in a purely inductive circuit.

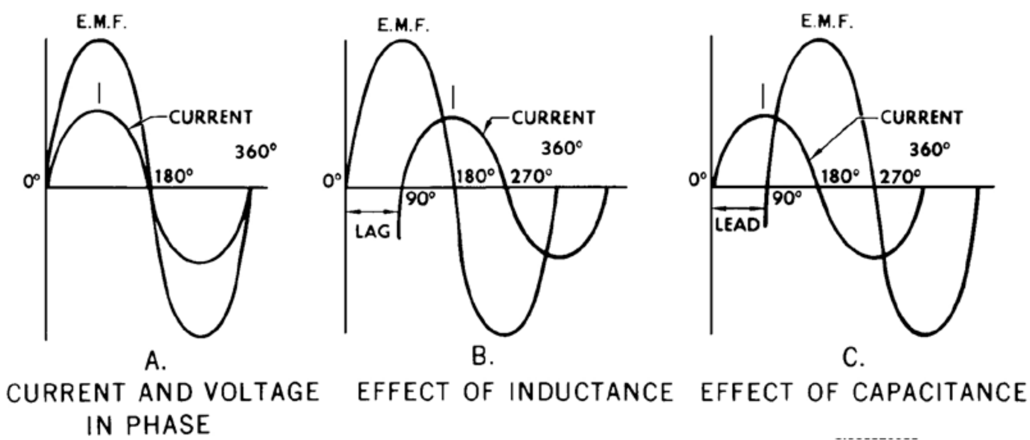


Figure 1–11. Sine wave of AC voltage and current.

Capacitance

While inductance is the property of a coil in an AC circuit, capacitance is the property of a capacitor. A capacitor is a device having the ability to store, or hold, a charge of electricity. We call the unit of capacitance *farad*.

When placed in an AC circuit, a capacitor stores electricity on one alternation (½ cycle); when the current reverses polarity on the other alternation, the capacitor discharges in the original current direction to continue the flow until it discharges.

It then recharges and repeats its action in the other direction on the second alternation. A common characteristic of an AC circuit with a capacitor is that the plates of the capacitor alternately change polarity.

In a circuit that has only capacitance, the current leads the impressed voltage by 90 degrees. This is in direct contrast to a circuit with pure inductance, where the current lags the voltage. Capacitance, like inductance, offers opposition to the flow of AC. We call this opposition *capacitive reactance*; we measure it in ohms, just as we do inductance.

Since inductive and capacitive reactance act in opposite directions, one can be used to cancel out the effects of the other. How is this done? We know that if a power circuit contains a large value of inductance, it causes the current to lag the voltage; by the same token, we know that a large amount of capacitance causes the current to lead the voltage (fig. 1–11, C).

Therefore, by adding just enough capacitance to the circuit to counteract the effects of the inductance, we can bring the current and voltage back in phase (fig. 1–11, A).

Impedance

Impedance is the term we use to identify the total opposition to current flow in an AC circuit. Notice that both inductive reactance and capacitive reactance cause current to be out of phase with voltage, and they both are measured in ohms. When a circuit contains resistors, inductors, and capacitors, it takes some rather complex mathematical equations to calculate the resulting force acting on voltage and current.

However, once we do the calculations, we call the result impedance. Its unit of measurement is also the ohm. The reason for this is that impedance is the cumulative result of all the forces opposing flow in the circuit.

402. Electrical safety

As an HVAC/R specialist, one of the major hazards you encounter in your job is that posed by electricity. We stay away from an area when we see a sign reading: DANGER HIGH VOLTAGE. Why? Because we have heard it takes high voltage to kill and that low voltage doesn’t kill. This is not true. Many people have been killed when they came into contact with a 120-volt house circuit. Others have been killed by even lower voltage. Still other people have been shocked by much higher voltages and suffered no injury. Since you never know what your body resistance is, avoid contact with *any* live circuit. When your body is wet, you offer less resistance to electrical shock than when you are dry. Never work with electricity when your body is wet. Even sweating can get you wet enough to lessen the resistance.

Electrical safety rules

Current flow through the body is actually the cause of electric shock. Since it is voltage that causes the current to flow through the body, you are more likely to get a fatal shock from a high-voltage circuit. A current flow of 100 milliamperes, or 0.10 ampere, through the human body is fatal. Electric shock interferes with your breathing process and paralyzes your muscles. When the shock is great enough, you lose consciousness in just a few seconds.

With your work in the HVAC/R field, you must know the hazards involved in working with electrical equipment. In fact, the more you know about electricity, the safer you can work. The rules given here are for your own safety and for the protection of the people who work with you. Study them carefully and practice them until they become second nature to you.

Among pilots, the term “forgiven error” refers to a mistake that did not result in disaster. You can also apply this term to your work in the electrical field. When you find that you have made one of these forgiven errors, review the events that led you to make this mistake. Knowing the source of the mistake helps you avoid a similar situation in the future.

Treat all electrical circuits as being “live.” Always test long lines that are opened and grounded at some distant point to find out what conditions exist. Remember that someone may accidentally close the wrong breaker, connecting your circuit to high voltage. Furthermore, to keep anyone from accidentally closing the breaker to a circuit that is undergoing repair, lock the breaker in the OFF position and tag it to indicate that the system is being repaired.

Here are a few general rules to observe when you are doing electrical work:

1. Do *not* wear identification tags.
2. Do *not* wear jewelry or clothing with exposed metallic fasteners.
3. Use safety tools and devices whenever they are provided. This includes the following:
   a) Fuse pullers for removing or replacing fuses.
   b) Rubber floor mats around electrical panels.
   c) Rubber aprons when working on acid-type batteries.
   d) Rubber gloves when working on live electrical circuits.
4. Do *not* work alone on an energized electrical circuit.
5. Do *not* try to remove a person or a tool from a live circuit with your hands or a piece of material that may be a conductor. You can use insulating material, such as a shirt or piece of dry rope, as a loop to pull a person from a live circuit.
6. Do *not* lean against water pipes or other conductive devices.
7. If battery acid should splash on you, immediately flush the affected part of your body with water. If the acid gets in your eyes or on your face, flush the area thoroughly and immediately seek medical aid.

Working on energized circuits

Air Force Instruction (AFI) 32–1064, *Electrical Safe Practices*, specifically states: "When possible, electrical circuits and equipment will be de-energized before working on them." However, you may work on energized circuits and equipment when certified by the base civil engineer (BCE), or a designated subordinate supervisor of his or her organization, as necessary to support a critical mission, prevent injury to persons, or protect property. In such instances, at least two workers, fully qualified for hotline work, and all necessary protective equipment and special tools must be available.

As an exception to the above, you may work on low voltage control circuits (50V or less) while energized, and you may test low voltage power and control circuits (below 600V) while energized using voltmeters, voltage testers, ammeters, or other test equipment for purposes of calibrating or troubleshooting electrical circuits or equipment.

Another important precaution is to perform a visual inspection of the wires and devices you will be checking volts or amps on. In 2006, at a base in Texas, an Airman grabbed a wire nut assuming the wires were secured inside of it. Once he grabbed the wire nut, he was shocked because one of the wires was actually loose and outside of the nut. If he had performed a visual inspection, he would have realized this, powered down the unit, and placed the wire back in the wire nut.

Working on de-energized circuits

De-energized circuits do not present as great a hazard as do energized circuits. Nevertheless, you must be careful and observe safety rules. Make sure the circuit is de-energized by opening the switch. In some cases, you may be able to lock the switch in the OPEN position. If not, remove the fuses and attach a warning sign to the switch. Keep in mind that a circuit may become accidentally shorted to another circuit. For this reason, test the circuit with a voltmeter to make sure it isn't shorted and still "hot." You cannot afford to be careless, even when working on a "dead" circuit. There have been many HVAC/R technicians that have gotten shocked because they did *not* verify that the circuit was "dead."

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

401. Electrical theory

1. What causes ionization in a storage battery?

2. What causes an ion drift across a storage battery?

3. How is current flow achieved in a storage battery?

4. How does a thermocouple produce heat?

5. Why do the electrons in a thermocouple move in an orderly manner?

6. Why does current flow in only one direction in a thermocouple?

7. How does a mechanical generator produce voltage?

8. With what instrument is the potential difference between two points measured?

9. Why are air, rubber, glass, and porcelain considered insulators?

10. Why is aluminum used for long overhead spans even though it isn't the best conductor?

11. Why would steel be used with aluminum even though it is a bad conductor?

12. How is copper *usually* used as a conductor?

13. For practical wiring conditions, what size wire is able to carry the *most* current?

14. What happens to a wire’s resistance as the temperature goes up?

15. How is resistance overcome in an electrical circuit?

16. With what device is current *most often* measured?

17. How does alternating current get its name?

18. What could happen if circuit is *not* installed properly?

19. What effects the amount of heat produced in an electrical circuit?

20. In an AC circuit, what causes the current to flow in one direction and then in the opposite direction?

21. What affects the frequency of the AC generator voltage?

22. How is an expanding and collapsing magnetic field set up around a coil?

23. What effect does induced voltage have on applied voltage?

24. What three factors affect the inductance of a coil?

25. What source can you consult if you need to find the inductive reactance of an AC circuit?

26. How are the effects of inductance overcome?

27. In a capacitor, what happens when current reverses polarity on the other alternation?

402. Electrical safety

1. How should all electrical circuits be treated?

2. How can you remove a person from a live circuit?

3. What should you do if battery acid splashes on you?

4. When working on a de-energized circuit, what should you do to a switch to ensure the circuit is de-energized?

5. What should you do if you cannot lock a switch in the OPEN position when working on a de-energized circuit?

1–2. Electrical Wiring

Electrical wiring consist of multiple topics that fall under two main categories: wiring requirements and wiring connections. In this section, the topics that will be covered under wiring requirements are color codes, materials, size, location, and insulation. In the wiring connections lesson the topics will be splicing and terminal connections.

The importance of electrical wiring cannot be overstated. If the proper codes and regulations are not followed the result could be anywhere between equipment that doesn't function to electrical fires or shock.

403. Electrical wiring requirements

The repair of HVAC/R equipment frequently involves electrical problems. Whether you must repair a small section of wire or rewire a complete piece of equipment, you need to understand some electrical wiring requirements. Also, as we stated earlier, current flowing through a wire causes heat. The amount of heat varies as the amperage varies. For this reason, various types and sizes of conductors are used in wiring to carry different amperage loads. The amount of current a conductor can carry safely depends on four things: the material used, the size of wire, the type of insulation, and the location of the conductor. You must consider each of these when doing repair work. First, we will discuss wiring color codes which are crucial to wiring.

Wiring color code

Replacement wire used on electrical equipment should be the same type, size, and color as the original. Using the proper wire color helps to standardize wiring procedures and also aids in identifying and tracing wires. Installers of line voltage wiring (above 50V AC) have generally accepted that green or bare conductors are used for ground wires, white is used to represent grounded neutral wires, and other colors are used to represent the line or "hot" wires. The three most common colors for the line or "hot" wires are black, red, or blue.

Wire materials

Today wires are made from several materials or combinations of materials. The most common metals used are copper, copper alloy, aluminum, and copper-clad aluminum. Copper, although the most expensive, is still considered the best. If an aluminum or copper-clad aluminum wire is used in place of a copper wire, it must be one size larger to carry the same current safely.

Wire size

To work with different size wires, you must know something about the scheme used in wire numbering. Instead of referring to wires by the diameter or area of the wire, numbers have been assigned to represent sizes. The numbers used for electrical wire are called the American Wire Gage (AWG) numbers. The range of the AWG is from No. 40, the smallest, to No. 4/0 (read "4 aught" or 0000), the largest. The number is based on the diameter of the wire; we measure the size of wire by using the AWG (fig. 1–12). Figure 1–13 shows you the various sizes of wire in the AWG.

Wire can be either solid or stranded. Stranded wire is used when flexibility is desired. Each wire size has the ability to carry a limited amount of current. The chart below shows the maximum wire size at lengths up to 50 feet.

Wire Size	Current Capacity of Wire (Amperes)	
(AWG)	*Copper*	*Aluminum*
No. 14	15	–
No. 12	20	15
No. 10	30	25
No. 8	40	30

The wire size is the *minimum* gage to use for the amperage listed. Lengths greater than 50 feet require a larger wire size.

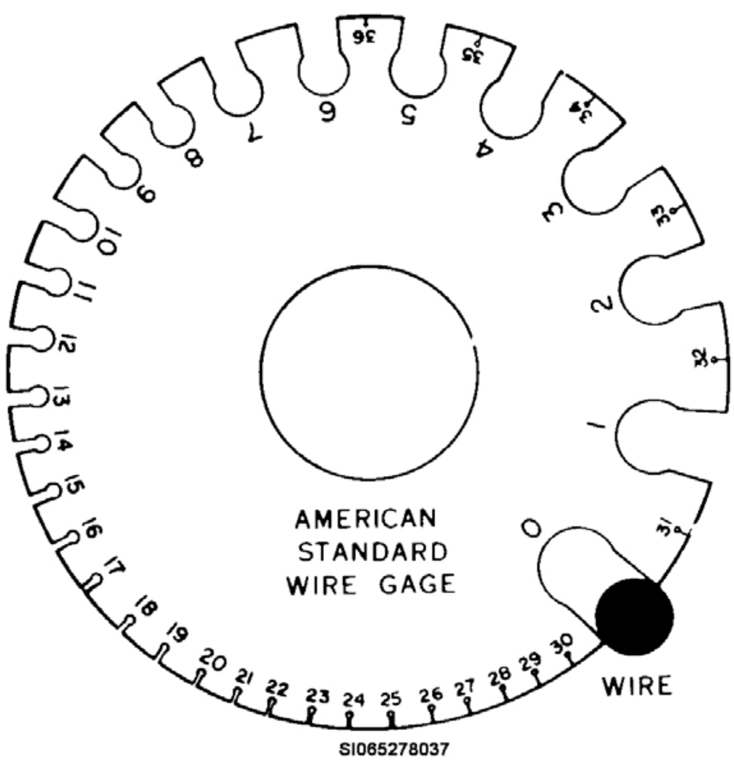


Figure 1–12. American wire gage.

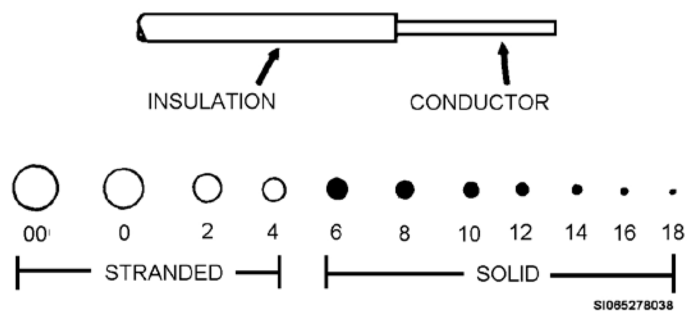


Figure 1–13. Conductor size without insulation.

Consult NEC to determine which wire size to use for a particular load. This reference book contains complete information such as wire current capacity, circuit overload protection, and other subjects related to safe wiring practices. For those unfamiliar with its use, the final chapters provide examples of how you can use the book and also indicate where you can find information in the book. It is recognized nationally by all Air Force and civilian authorities. Use this book as a guide for all electrical wiring practices.

Insulation

The type of insulation needed for a conductor is based primarily on where it is going to be used. For example, you would not use a rubber- or plastic-insulated wire in a place where it would be subjected to very high temperatures. The NEC book covers the types of insulation and where to use them. The code also requires manufacturers of wire and cables to properly identify their product. They must show the size of wire, the type of insulation, the maximum working voltage, and the manufacturer's name or trademark. This information is placed on the outer surface of the insulation. You can learn a great deal about wire or cable by just reading the markings. Some of the common letters manufacturers use to indicate a type of insulation or a characteristic are shown in the table below:

Common Identification Letters	Type of Insulation or Characteristic
H	Heat resistant
R	Rubber
T	Thermoplastic
V	Varnished cambric
W	Moisture resistant

These letters are often used in combination to indicate an insulation type. The following are examples:

a. TW – Moisture-resistant thermoplastic. Used in dry or wet locations.

b. RHW – Heat- and moisture-resistant rubber. Used in dry or wet locations.

Location

The location where the conductor is to be installed also has an effect on the current-carrying capacity. A conductor used in free air can safely carry more current than the same conductor installed along with other conductors in conduit or cable. The reason is that the conductor in free air is able to get rid of the heat caused by current flow much faster than if it were in conduit or cable. The number of conductors installed in conduit also has an effect on the current-carrying capacity. The more conductors there are, the lower is the safe current-carrying capacity.

NOTE: To determine the amount of current a specific size and type of conductor used in a certain location can carry, you must refer to the NEC.

404. Wiring connections

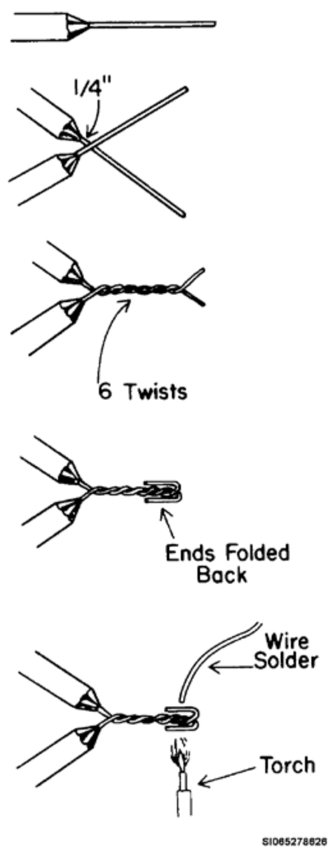


Figure 1–14. Insulation removed.

To have a complete understanding of the principles of electricity, you must have a firm grasp of wiring connections. To make repairs on HVAC/R equipment, you must be able to make various types of connections. A splice is one method of connecting wires in various parts of the circuit together to form complete circuits. The other method of connecting wires is to use terminal connections.

General wiring concepts

To make any type of wire connection, first remove the insulation from the ends of the conductors. On small conductors, No. 10 AWG and smaller, use a wire stripper. When you use a wire stripper, take care to use the cutting notch that matches the wire size to keep from nicking the wire. A nicked wire may break if you bend it. Cut through the insulation about 1¼ to 1½ inches from the wire's end and then use slight pressure to slip the cut insulation off the wire.

You can also remove insulation with a knife. In fact, many people prefer this method because of the frequency with which nicks occur when using a wire stripper. You must use a knife to take insulation off larger conductors and on the through wire for a tee splice.

When you use a knife, do not "ring" the insulation or cut straight through it to the wire. In either case, it is very likely that you will score or cut the wire. Start by cutting the insulation at an angle of about 30 degrees. Remove the insulation as you would sharpen a pencil, taking care not to cut the wire. After the insulation is off, the end of the conductor will look like the one shown at the upper left top of figure 1–14. Check the ends of the conductors to be sure they are free of insulation and oxidation. Use your blade to scrape the conductors if they are not completely clean.

Splicing

A great many of the wires you install for a piece of equipment have to be spliced. These splices are needed to connect wires in various parts of the circuits together to form complete circuits that provide power where it is needed. Splices also are used to connect and add ground wires so that all metal units in electrical circuits are joined together and grounded to reduce shock hazards. The splices you make most of the time are quite simple. The main thing to remember when making a splice is that it must be both mechanically and electrically secure. That is, the splice should be as strong as a continuous wire and must conduct electricity as well as if it were one piece. The splices you make, in most cases, can be classified as solderless pigtail splices, tee splices, and compression or crimp joints.

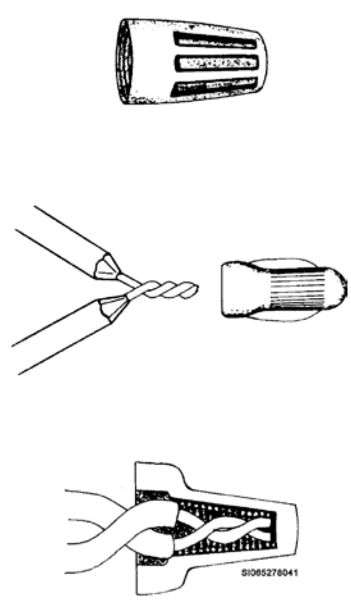


Figure 1–15. Wire nuts and splice.

Solderless pigtail splice

The solderless pigtail splice is quite a bit like a soldered pigtail but is easier to make. Strip the insulation from the wire ends as before, but make only about three twists in the wires. Then finish the splice with a wire nut.

Figure 1–15 shows wire nuts and their uses. The top of the figure shows the simplest form of a wire nut—a hard plastic shell with a coiled steel wire insert. The center illustration shows the two wires twisted together with a different wire nut ready to be put on. This wire nut has a flexible plastic cover over a threaded steel insert. It also has two small flanges to help you get it tight. The lower part illustration shows how a wire nut looks on the pigtail after it is tightened down to complete the splice. This wire nut has a hard plastic or nylon shell with two formed wings that allow you to tighten the nut more than you could a round one.

Tap splice

The tap or tee splice gets its name from the way it is tapped or teed off the through conductor. Cut about 1¼ inches of the insulation from the through conductor with a knife (fig. 1–16A). Taper the ends of the insulation as you would for a pigtail splice. Strip about 2 inches of insulation from the end of the tap wire. Place the tap wire over the through wire, as in figure 1–16B, so there is a quarter-inch space between the insulation and the cross point. Make the first wrap of the tap wire as a spread out or open wrap, as shown at the left center of the figure. Now, make two or three tight wraps of the tap wire, figure 1–16C, then finish with one or two more wraps that you pull tight with a pair of pliers as shown in figure 1–16D.

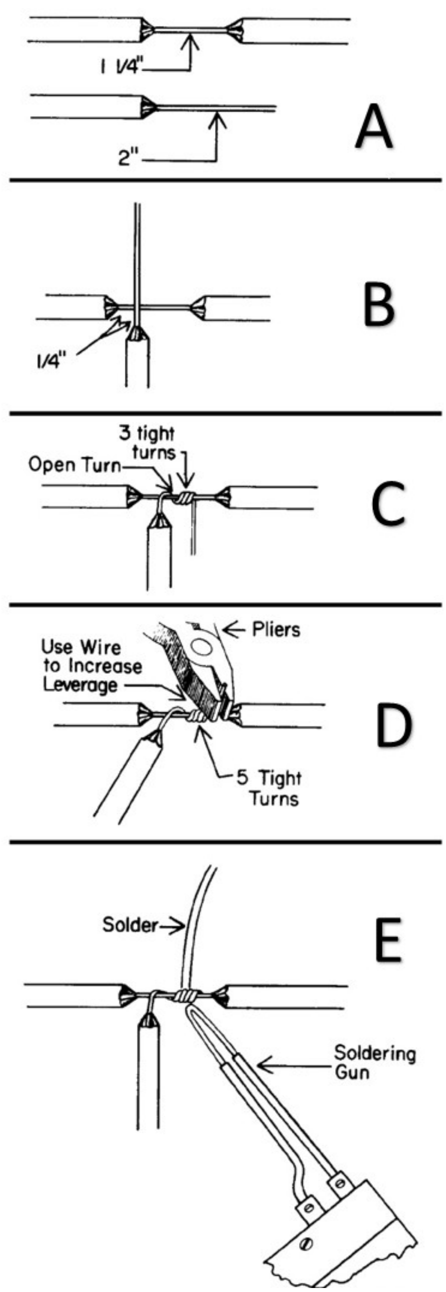


Figure 1–16. Making a tap splice.

Cut off the surplus end and squeeze the remaining end down tight. Solder the splice by applying heat under the tight turns until the wire melts the solder and it flows into the joint, as shown at the bottom of the figure 1–16E. Do not solder the open wrap, just the tight turns. This gives some flexibility to the splice, which prevents breakage in case of vibration.

A variation of the tap splice is the knotted tap. Some people like this splice since it locks tightly on the through wire where the tap wire joins to eliminate breaking the solder loose on the joint. As figure 1–17 shows, loop the tap wire back around itself after hooking it over the through wire. Finish the splice with five tight turns around the through wire and then solder.

Insulate the tap splice with plastic electrical tape in the same manner you used on a pigtail. You can start the tape at any of the spots where the insulation was cut. Most people find it easiest to start at the left end. Begin with two wraps of tape and tape to the other end, half lapping the tape on each turn. At the right end, make four wraps and tape back to the tee. Tape out to the end of the bare tee and back to the through wire. Finish by taping from the tee back to the left end. The result is a splice with four layers of tape put on in one continuous piece.

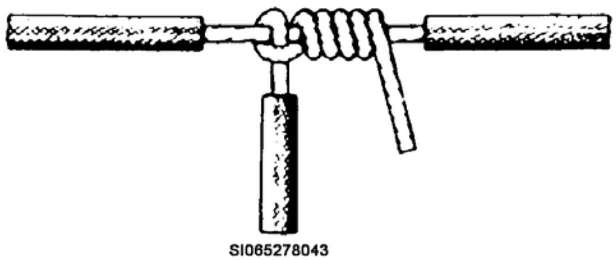


Figure 1–17. Knotted tap splice.

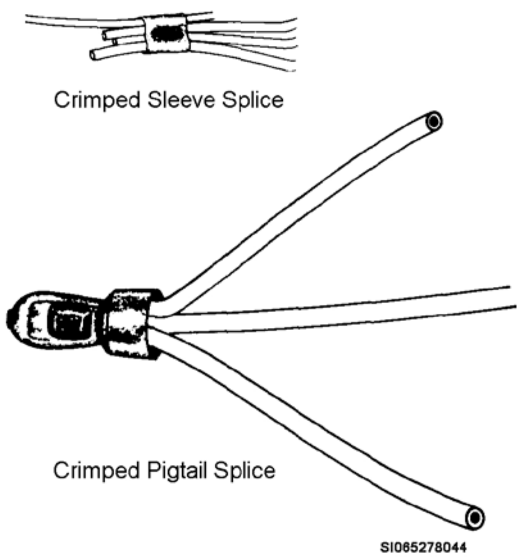


Figure 1–18. Crimp type splice.

Crimp-type splice

You make the crimp-type splice (also known as a compression splice) with a sleeve that you crimp in place with a special tool. Crimp type splicing sleeves come in quite a few different designs, with or without their own insulation. An example of how to make this type of splice is shown at the top of figure 1–18. To make the splice, place all the wires involved through the sleeve and crimp tightly with the special tool for that type of sleeve. Be sure to check that each wire is held securely in the sleeve. In this case, no insulation is put on the splice since all the ground wires are bare. A second example of a crimped splice is shown at the bottom of the figure. This splice is a pigtail and is similar to the ones we discussed earlier, except the wires are not twisted together. They are put in the sleeve (actually a closed cap) and crimped with the special tool. This sleeve is already insulated, so it does not have to be taped after it is crimped.

Terminal connections

Before connecting the terminals, you must check the circuit for operation. As we said earlier with splices, an electrical connection must be electrically and mechanically secure. Properly made terminal connections are very important for several reasons. The proper operation of the circuit, prevention of fire, and safety of personnel depend on good electrical connections. The types of terminal connections that you should be familiar with are terminal loops, compression connectors, push-in connectors, and mechanical connectors.

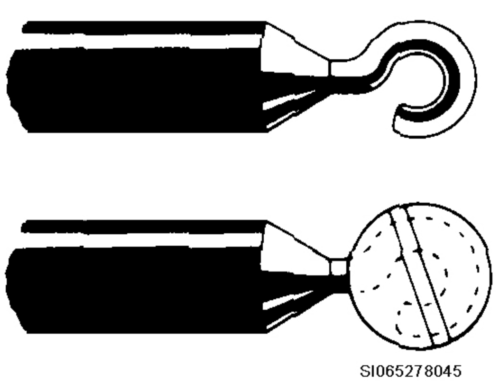


Figure 1–19. Wire terminal loop.

Terminal loops

One type of connection we use on electrical devices is the terminal loop and screw. To make the terminal loop, you must first remove about 3/4 inch of insulation from the end of the conductor that is to be connected. Then use a pair of longnose or needle nose pliers to make a loop in the end of the bare wire. Place the loop around the terminal post or where a mounting screw is used so that the bend is in a clockwise direction. Pass the screw through the loop and tighten as shown in figure 1–19.

Sometimes the loop holds the screw and makes the installation easier. Note that when you tighten the screw or binding nut, it also tends to tighten the conductor loop. If the loop is not placed around the terminal post or screw in a clockwise direction, the binding nut or screw tends to spread the loop as you tighten it. This results in an unsafe connection.

When you make this type of connection, the insulation must cover the wire close to the terminal screw. If you remove too much insulation, the bare wire is exposed and might come in contact with the box or another conductor and cause a ground or short.

Compression

Compression connections are known as the crimp type or solderless type. They are becoming popular for service and repair work. These types of connectors come in a kit that contains many types of terminals. Figure 1–20 shows the different terminals that come in the kit. You would use items A, D, and F when connecting the conductor to either a screw or bolt and use a washer and nut to tighten it. Use item E on male-type connections and item C on female-type connections. Use items B or G to connect two wires together or to extend a line.

When using any of these terminals, always ensure that they are large enough to carry the current in the circuit. Each terminal is marked with the size of wire that can be used on it. To make a connection with any of these terminals, strip the wire as we mentioned earlier, then insert it into the metal sleeve of the connector. Next crimp with a wiring tool using the proper crimp slot (fig. 1–21). Make sure your final product looks like the example in figure 1–22. Always ensure that you have a tight connection by pulling slightly on the wire. If the wire is loose or pulls out, you have to redo the process.

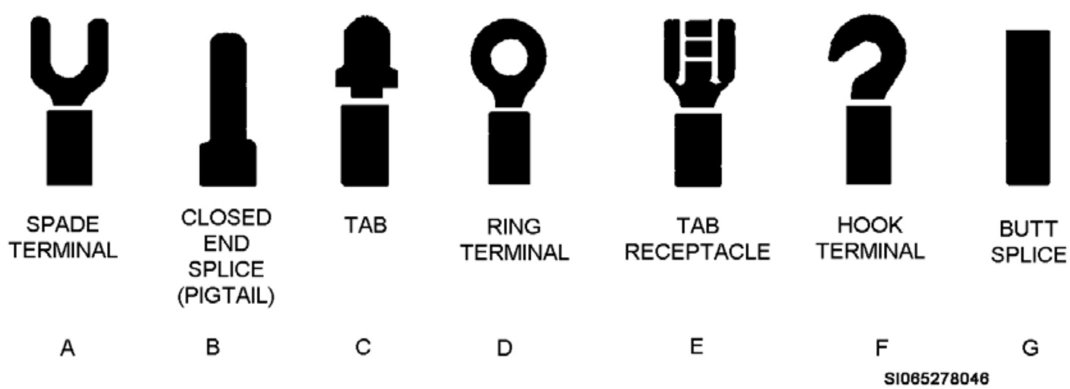


Figure 1–20. Solderless connectors.

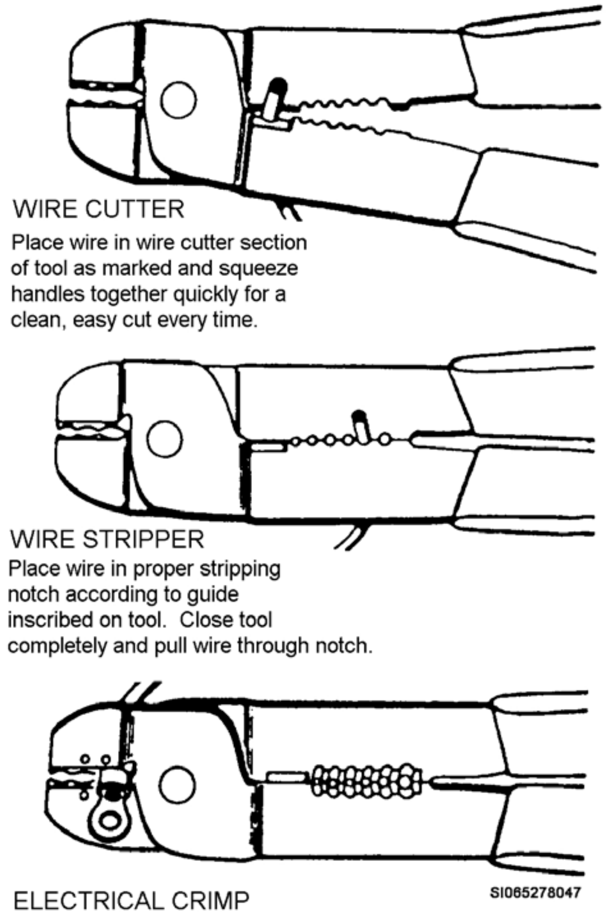


Figure 1–21. Making a solderless connection.

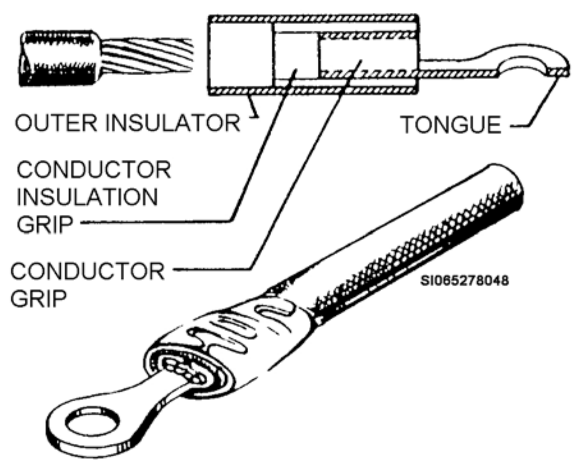


Figure 1–22. Finished solderless connection.

Push-in

This type of connection is found on many different controls. One type of control used on warm air furnaces that has push-in terminals is shown in figure 1–23. In connecting a wire to this type, you first strip the wire. If the wire is solid or you have soldered the tip, you can insert the wire in the terminal by pushing. When the wire is stranded, you would insert a small screwdriver into the slot (fig. 1–23) by the terminal and then push the wire into the terminal and remove the screwdriver. Always ensure the wire is in tightly by pulling slightly on it. If it comes out, repeat the process.

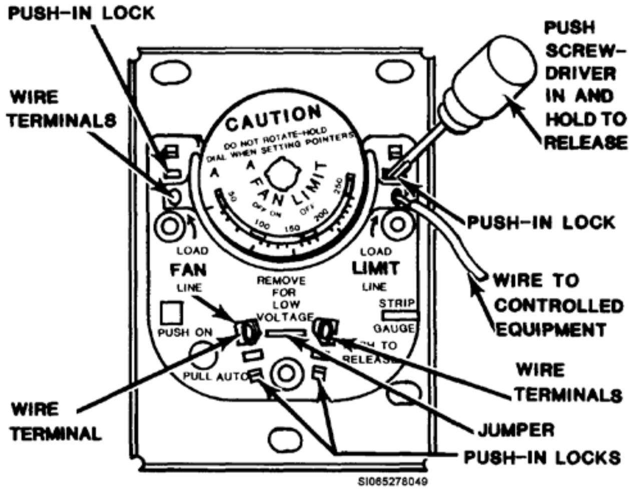


Figure 1–23. Push-in connection.

Mechanical connector

When a large wire (generally No. 6 or larger) must be connected to switches or other devices, a mechanical connector is provided. Figure 1–24 shows one type of mechanical connector. We also refer to these types of connectorsas solderless connectors. To use this type of connector, you simply place the bare end of the wire in the connector and tighten the screw. As with the loop connection for smaller wire, you must extend the insulation up close to the connector.

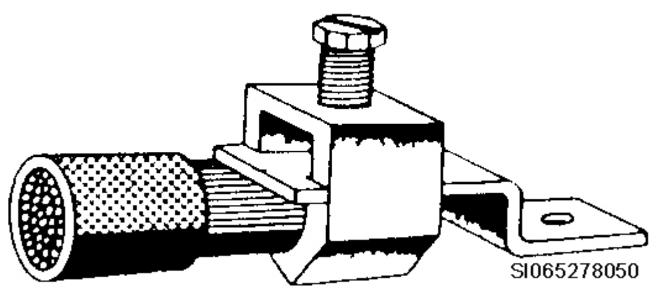


Figure 1–24. Mechanical connector.

Receptacles

Receptacles come in many forms. The most common that you have probably seen up to this point is the ones that are installed in the walls of your home. This was most likely a 110V alternating current (VAC) outlet. These outlets give you a convenience point into which you can plug an electrical device. Outlets are made in different styles according to the voltage and maximum amperage draw for the circuit. Remember that if your appliance does not fit into the outlet, it is not the right type or it may draw too many amps for the circuit in the wall. If the need arises to install or replace an outlet, consider the voltage and amperage ratings.

Voltage rating

Outlets are rated at a usable voltage and amperage. The screw terminals on the back of the receptacle are colored gold, silver, and green. Green is reserved for ground conductors. Since the green screw is always reserved, we shouldn't have to mention it further. Always attach your ground conductor to this screw. Use the gold terminal for “hot” wires and silver for a neutral. Two scenarios follow here. The first describes a 110 VAC example. On the back of the device, you generally find two brass screws and two silver screws. Notice that a jumper is tying the two screw bosses together. Attach your hot wire to the brass screw and the neutral to the silver screw. The next example is for 220 VAC. On a 220 VAC device, both sides have brass screws. Attach a hot wire to one side and the other hot wire to the other side. Hot wires are usually colored red, blue or black, while the neutral wires are whiteThis gives all available voltage to the receptacle.

NOTE: There are two important things to remember about voltage: (1) *never* apply a different voltage to the device than is indicated or designed and (2) do *not* attach a hot and neutral or two hot wires to the same side of the device. This results in a direct short.

Amperage rating

The maximum amperage rating of a receptacle should be clearly marked on the device along with voltage. Do *not* use a device that exceeds the maximum amount of amperes that a circuit is protected for or the maximum that a circuit can carry. If a circuit is forced to carry too much current, excessive heat buildup occurs and a fire or electrocution situation can develop. Ask a knowledgeable person for assistance if needed.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

403. Electrical wiring requirements

1. How is replacement wire type, size, and color selected for electrical equipment?

2. What effect does using the proper wire color have on electrical wiring procedures?

3. How would you identify a wires size?

4. When is stranded wire desired?

5. Why can a wire in free air safely carry more current than the same conductor installed along with other conductors in conduit or cable?

404. Wiring connections

1. When using a wire stripper, how can you prevent nicking the wire?

2. When removing the insulation from the end of a conducter, how far from the wire’s end should you cut through the insulation?

3. What tool can be used to make a loop in the end of the bare wire?

4. What could result from removing too much insulation from a wire?

5. How would you connect the *ground* conductor to the back of the receptacle?

6. How should the hot and neutral wires be connected to the back of the receptacle?

7. When connecting a 220 VAC plug, where should the hot wires be attached?

1–3. Wiring Diagrams

One of biggest hurdles for many HVAC/R technicians is wiring diagrams. These diagrams are the backbone of electrical troubleshooting. Some basic concepts such as symbols and types of diagrams are covered in this section. Also, the key skill of relating diagrams to the actual piece of equipment are taught. The section concludes by teaching you how to follow current flow by using a diagram. A strong understanding of this section will surely set you apart from other technicans in the field.

405. Wiring diagram concepts

Interpreting electrical diagrams is your starting point in any electrical troubleshooting job you encounter. Knowing how to read and interpret many different designs of diagrams is important. The following text can start you out on the right path.

Think of electrical diagrams as “road maps” for electrical circuits; in other words, graphic pictures of circuit operation. Each unit is represented by a symbol. Over the years, many designers have offered their individual ideas of what symbols or what types of diagrams to use to explain the circuit. So the term “electrical wiring diagram” has become a common name for all electrical drawings. Electrical drawings are the key to the electrical components in a system. Being able to find the circuit and determine the operation of components, as well as entire systems, can eliminate hit and miss guesswork and frustration.

Symbols

To interpret electrical diagrams, you must be familiar with electrical symbols. Knowing electrical symbols aids you in installing electrical circuits and, even more importantly, in locating electrical malfunctions. Symbols are a form of pictorial shorthand that shows the devices and conductors that create a complete circuit. To troubleshoot a piece of equipment, you must become familiar with the legends and symbols for that particular unit. For the most part, electrical symbols are standardized; however, you may encounter some unique symbols if you are stationed outside the United States. We show some examples of common electrical symbols in figures 1–25 and 1–26.

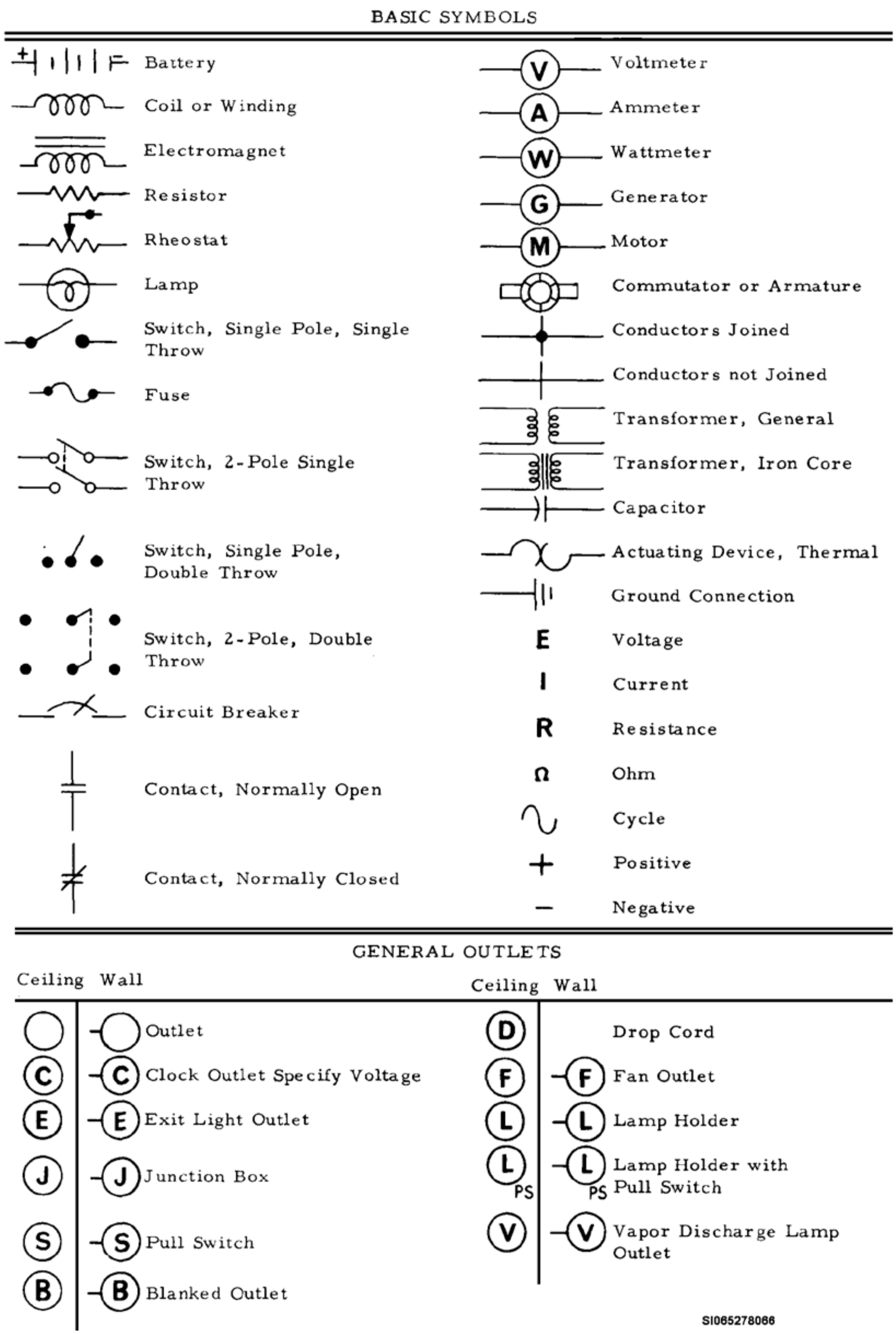


Figure 1–25. Basic electrical symbols.

The letters NO (normally open) and NC (normally closed) are used with electrical switching devices to tell you whether the switch is NO or NC. A normally open switch is one that normally has the circuit open and allows no current flow. Refer to figure 1–26 to the temperature-actuated switch, one type of NO switch (a thermostat) that closes the contacts with a rise in temperature.

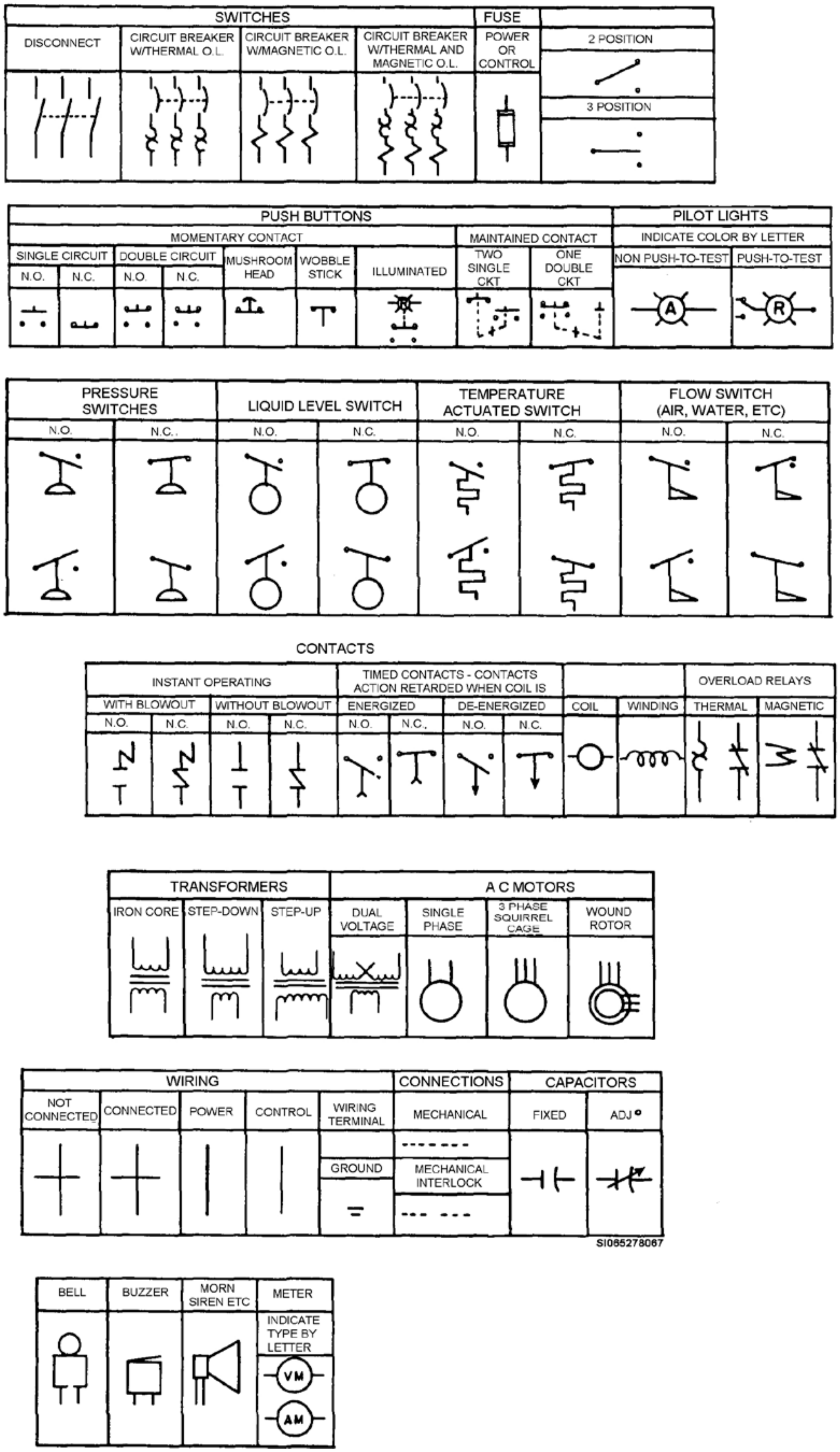


Figure 1–26. Electrical symbols.

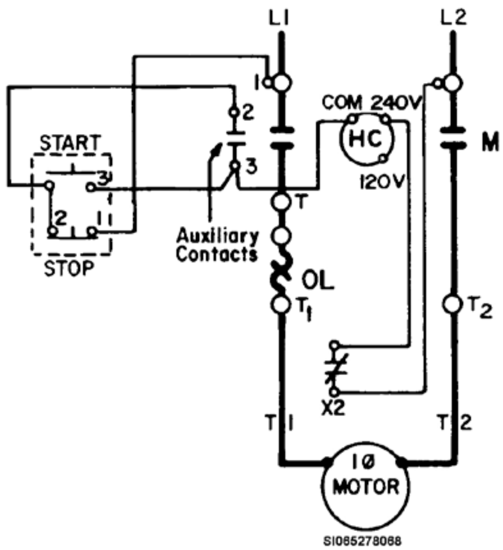


Figure 1–27. Wiring diagram of a motor starter.

For example, an air-conditioning unit comes on when the temperature rises. Another type of thermostat closes contacts with a decrease in temperature, such as in a heating system where the system comes on with a drop in temperature.

Electrical wiring diagrams

Figure 1–27 shows a wiring diagram of a motor starter. As you can see, this type of diagram is useful in wiring circuits because the connections can be made exactly as they appear on the diagram. Each line represents one piece of wire. We show four typesof wiring diagrams (block, wiring, connection, schematic) that you might see in figure 1–28. Notice the different names for the diagrams. Often in HVAC/R, these names are used interchangeably although technically incorrect. These diagrams have the necessary information such as the location of components, the actual wiring of a circuit and they provide a means of tracing the wires for troubleshooting.

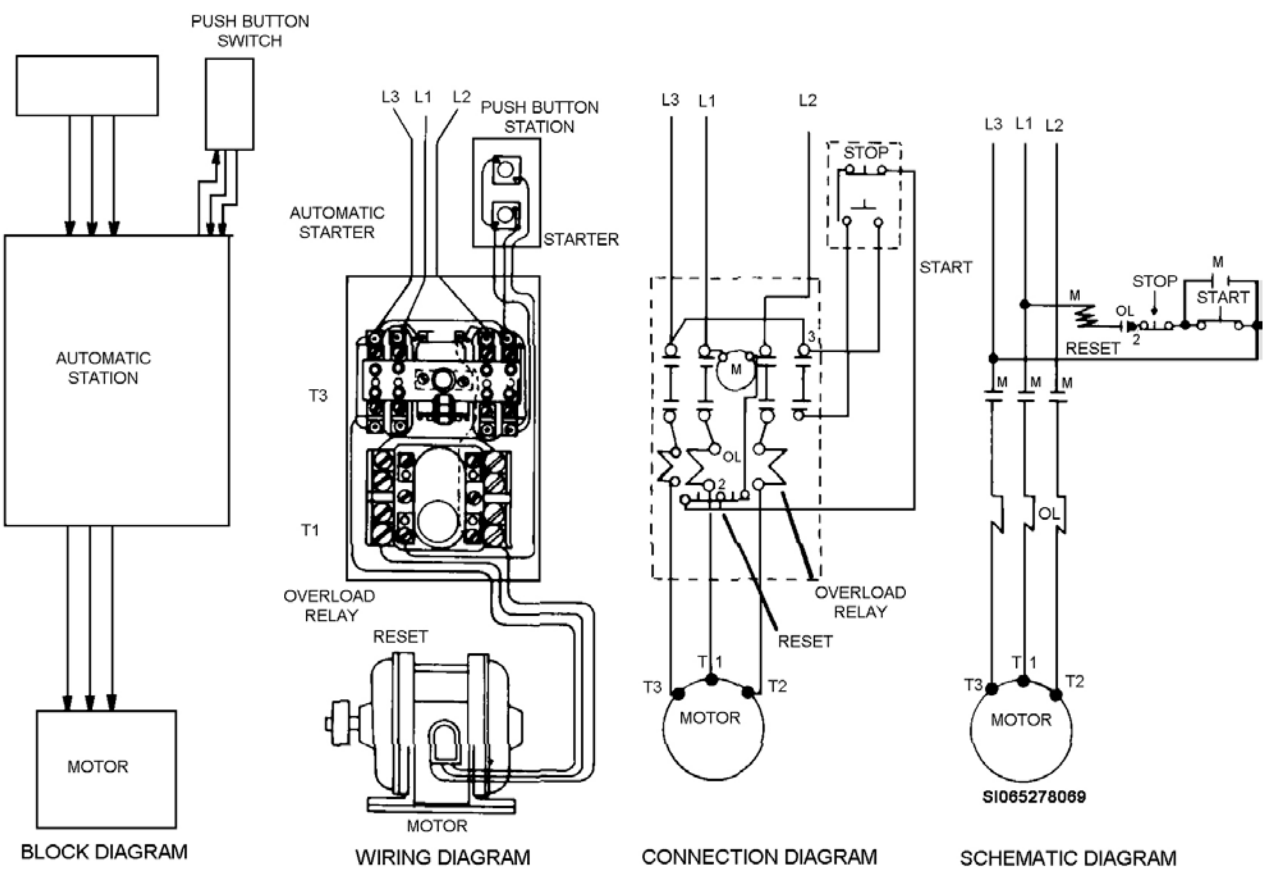


Figure 1–28. Types of wiring diagrams.

Electrical line diagrams

Line diagrams show all control devices between two vertical lines that represent the source of control power (fig. 1–29). These diagrams are also called *schematic* or *ladder* diagrams. As you can see from the figure, the circuits are shown connected from one source line horizontally through all devices to the other source line. With this type of diagram, you can trace the functions and sequence of operations of the devices and circuits easily. Line diagrams are valuable during troubleshooting. They show how the opening or closing of contacts affects other devices in the circuit.

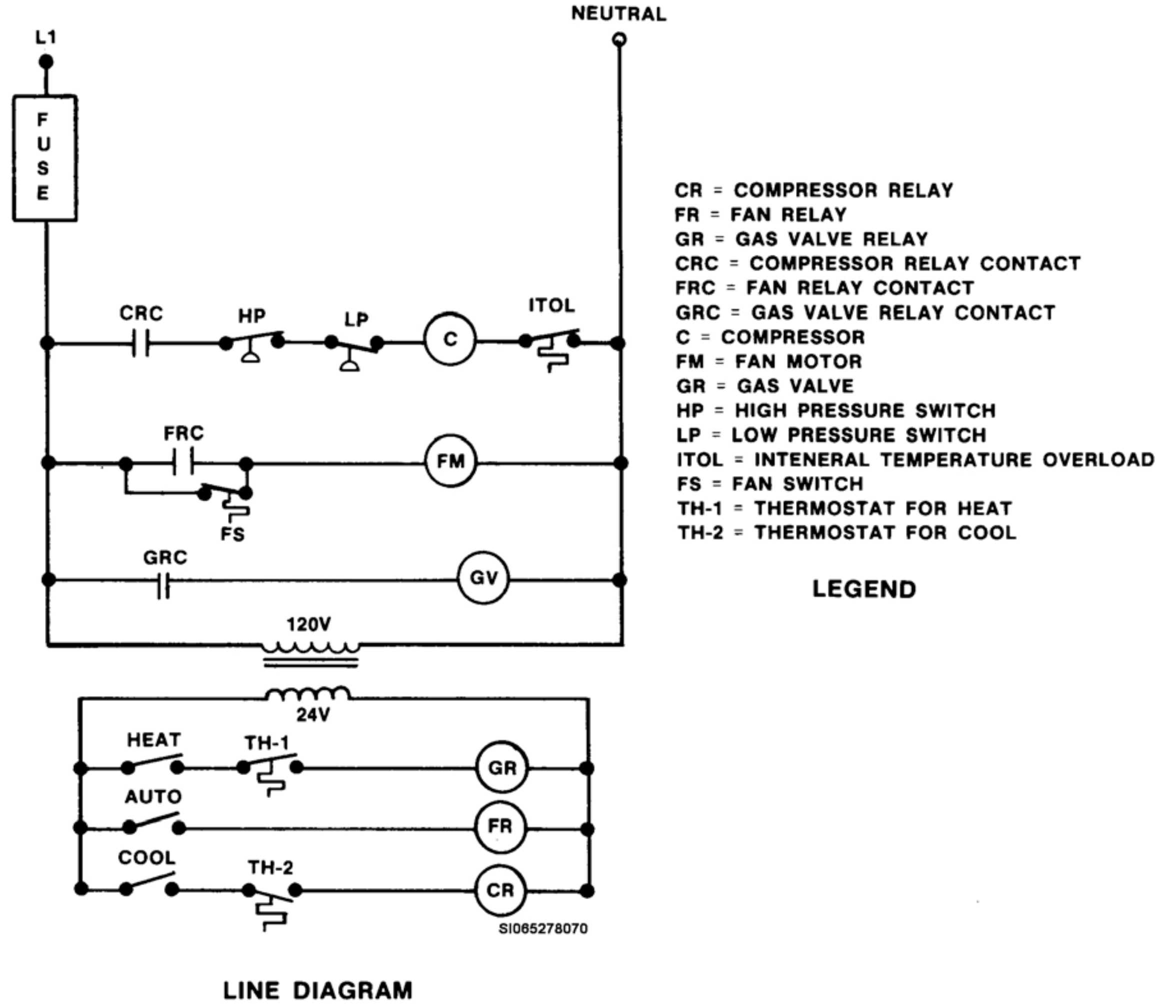


Figure 1–29. Basic electrical line diagram.

Let’s trace a wiring diagram (fig. 1–30) and see how easy it is to interpret an electrical circuit. Looking at figure 1–30, you can see we want to control a motor. When the temperature switch (TS) closes due to a rise in temperature, the coil, compressor relay (CR), is energized. This closes the NO contact, compressor relay contact (CRC), to complete the motor circuit. Did you notice that the contact is in a different location than the coil? This is something you’ll have to get used to. The separation of the different parts of the same component is common with schematics. Notice how the contact and the coil are ONE component but on the schematic they are in TWO different places. This is one of the most important concepts to grasp when it comes to reading schematics.

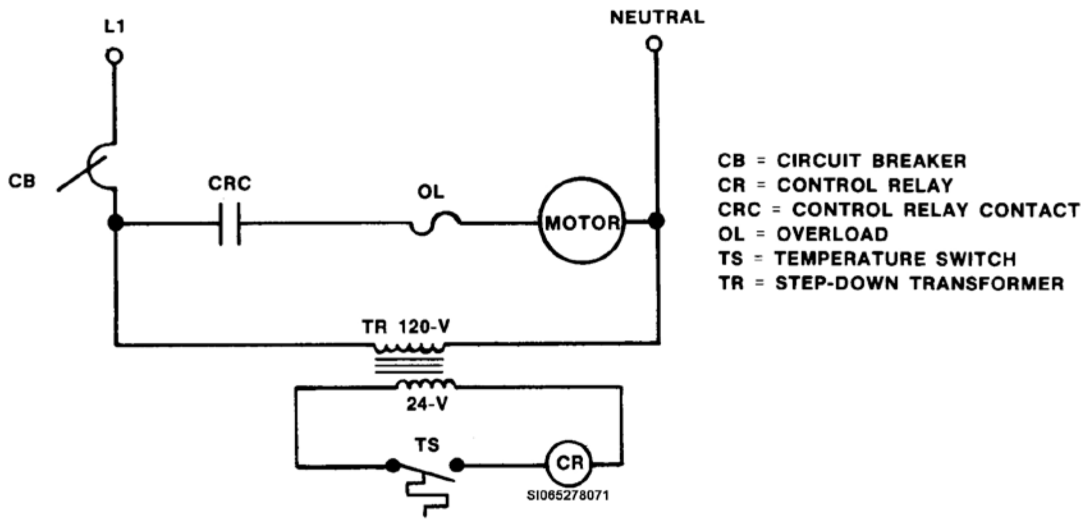


Figure 1–30. Basic motor control diagram.

Once you study the diagram, you can find the coil and the contact that it controls. The legend helps with this identification process. As you can see, the line diagram shown is an easy and simple explanation of how the electrical circuits work. Figure 1–31 shows both the wiring diagram and line diagram of a motor starter and the difference between the two. However, electrically they show the same operation.

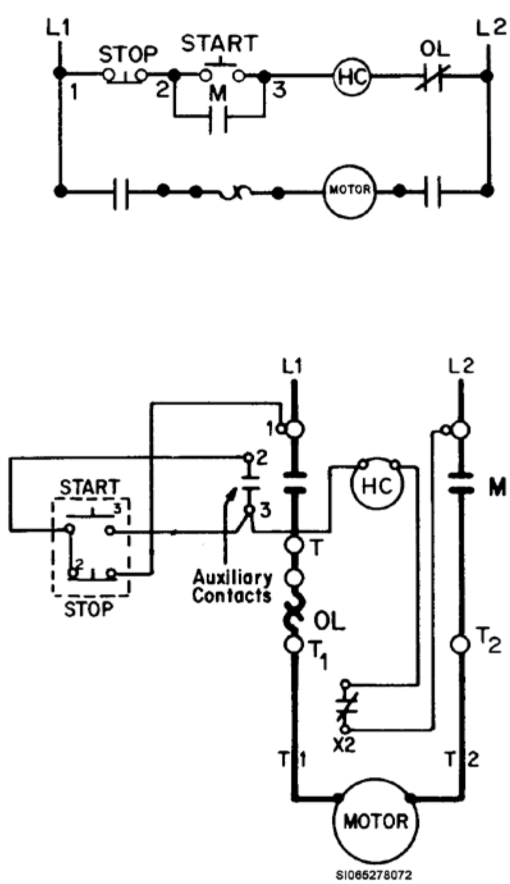


Figure 1–31. Wiring diagram and line drawing of a motor starter.

406. Current flow on diagrams

The ability to follow the path of current flow on a diagram is probably one of the most important skills you can have as an HVAC/R technician. This lesson uses the old Environmental Control Unit (ECU) to show you step-by-step how current flows. This diagram is simple and is great to teach the basics. When you work in the field, you will see more complex diagrams for equipment like furnaces, split-systems, boilers, and chillers.

Following current flow

In figure 1–32, the ECU schematic is shown. The ECU schematic is broken down into the VENTILATE and AUTO modes. Other modes are not covered.

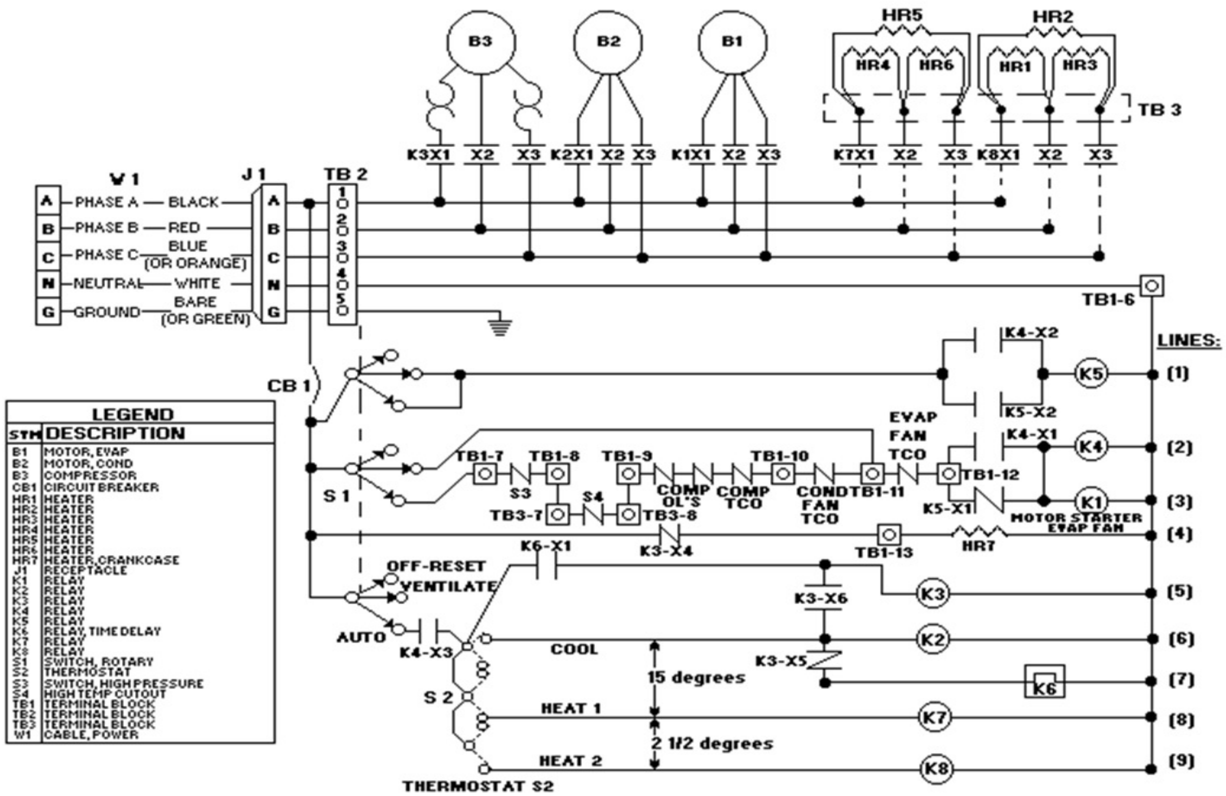


Figure 1–32. ECU Schematic.

With ladder diagrams, like this one, current flow is read from left to right. As you can see, there is a legend at the top left. This identifies the components. For example, if you want to know what B2 is, go to the legend, find B2, and you will see it is the MOTOR, COND. Some previous HVAC/R knowledge and a little common sense will need to be used to determine that MOTOR, COND means *condenser motor*.

VENTILATE mode

Let's go through a path in the system while it is in VENTILATE mode. Using figure 1–32, start on the left, just above the legend and see that there are three phases, A, B, and C. There is also a neutral wire that is white and a green ground wire. Start with Phase A (black) and follow it to J1 which is a receptacle. Continue from left to right to TB2 (terminal block 2). From TB2 the black wire splits off to a normally open contact K3–X1,X2, and X3. Current also passes to normally open contacts at K2X1, 2, 3, and K1X1, 2, and 3. Finally, power travels to the normally open contacts for the heater relays. The same sequence takes place for the B and C phase.

Notice CB1(circuit breaker) and S1, rotary switch. Also, notice the neutral line going to the far right to TB1–6. Notice the three positions for both CB1 and S1.

Now you can see the S1 switch goes left to right to TB1–11 through normally closed evaporator fan thermal cut out. If this set of contacts remains closed current will flow to TB1–12 and on to the K5-X1 normally closed contacts. If K5–X1 remains closed, then current will flow to the K1 relay coil and to the right neutral wire. Notice that the neutral ties back to the neutral terminal TB1–6; this completes the circuit. Once the K1 relay is energized the contacts that correspond to it will close. These contacts are located directly below B1, the evaporator fan motor. Following this sequence, you should be able to see that the K1 relay "controls" the evaporator fan motor. If this relay is not energized, the evaporator fan will not run.

Stay with this figure and look at the line below S1 and follow it to the right to K3–X4 which is normally closed. Current will then travel to TB1–13 to HR7 which is the crankcase heater. Since K3–X4 is normally closed, it will stay closed until its corresponding K3 coil is energized. Also, as long as the circuit breaker is closed power will travel to K3–X4.

Now in this figure, follow the current flow from immediately after the circuit breaker to the right until you reach normally open contacts K4-X2 and K5-X2. Notice K5 coil to the right of these contacts. This coil is not energized at this point.

We have the K4 –X1 N.O. along with the K4 coil. There is also a line added that starts just before the K1 coil and goes up to just before the K4 coil.

Start at S1 and notice the arrow pointing to the middle circle. This is the VENTILATE position. Current flows from S1to N.C. K5–X1 to energize the K1 coil. Remember that there is a line before K1 that goes up to K4 coil. This will energize K4 and close K4–X1 and K4–X2. Notice that these contacts are *not* on the same line as the K4 coil—K4–X1 *is* but K4–X2 is *not*. Even though a single component is physically together, it may be dispersed in various locations on the schematic.

Once K4–X2 closes, current flows to the K5 coil and energize it. This closes K5–X2 and opens K5–X1.

AUTO mode, cooling

Now we will turn the switch to AUTO mode. With S1 in the AUTO mode, operation of the air conditioner is controlled by the thermostat switch (S2). Operation in the AUTO mode with S2 in the high temperature stage (cooling) is as follows:

1. The evaporator fan starts up and operates differently in this mode. Current must flow from TB1–7 through the safeties all the way to TB1–12 and then on to K1 and K4.
2. Closed contacts K4–X3 send power to the thermostat S2 to turn on the condenser fan contactor K2. The contacts that correspond to K2, K2–X1, X2, X3 also close.
3. Going to the right from S2, closed contacts K3–X5 provide a circuit to time delay relay K6. K6 contacts K6–X1 close after a 1-minute time delay.
4. In contacts K6–X1 close, providing a circuit to turn on the compressor motor starter K3.
5. Since K3 is energized, contacts K3–X6 close, locking in the compressor starter. Contacts K3–X5 and K3–X4 open, taking the time delay relay out of the circuit. Contacts K6–X1 open.
6. Coil K2 and K3 are now energized and their corresponding contacts for close which energize B3 the compressor and B2 the condenser fan motor.
7. Once the conditioned space is satisfied, thermostat S2 breaks the circuit through K3–X6 to the compressor motor starter K3 and the condenser fan starter K2.

If any safety in between TB1–7 and TB–12 activates, then K4 de-energizes. Contacts K4–X1, K4–X2, and K4–X3 open. Relay K5 remains energized holding K5–X1 open. Thus, all electrical components are kept de-energized until the safety or overload resets and control switch S1 has been rotated momentarily to the OFF-RESET position.

The way this system is described above is how you need to follow current flow on schematics. As you follow each circuit, you should be describing in your head what is occurring with each component. If you pass over a component and don’t know what function it performs, you will not be able to troubleshoot or understand the system.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

405. Wiring diagram concepts

1. How should electrical diagrams be thought of?

2. How is each unit in a schematic represented?

3. On an electrical diagram, what does each line represent?

4. How are the different parts of the same components sometimes geographically located on a schematic?

406. Current flow on diagrams

1. According to the current flow diagram (fig. 1–32), what are the three phases in this circuit?

2. In figure 1–32, if the evaporator fan thermal cut out remains closed, where will current flow go to next.

3. Where does the neutral tie into to complete the circuit in figure 1–32?

4. In figure 1–32, what contact closes and allows current to flow to the K5 coil?

5. What contact in figure 1–32 closes and allows current to flow to the K3 motor starter?

1–4. Electrical Circuits and Troubleshooting

This section builds off of the previous wiring diagram section. Troubleshooting electrical circuits is crucial to any technician's toolbox of knowledge. First, the three electrical circuits: line, control, and load are taught. Series and parallel circuits are covered next. General troubleshooting procedures are extensively covered.

407. Electrical circuits

There are three circuits on every diagram: line, control, and load circuits. These circuits are configured in series or in parallel. You must be able to identify and understand the relationship of these circuits to each other and apply that knowledge to schematics and troubleshooting. The concepts discussed in this lesson are absolutely crucial to you understanding electrical systems and becoming a better troubleshooter.

Line circuit

The line circuit is sometime referred to as the *power* circuit. It represents the incoming power or line voltage. As a HVAC/R technician, the line circuit usually takes up the smallest portion of your schematics.

In figure 1–33, the ECU schematic, you can see the red rectangle showing the line circuit. This is the entire line circuit.

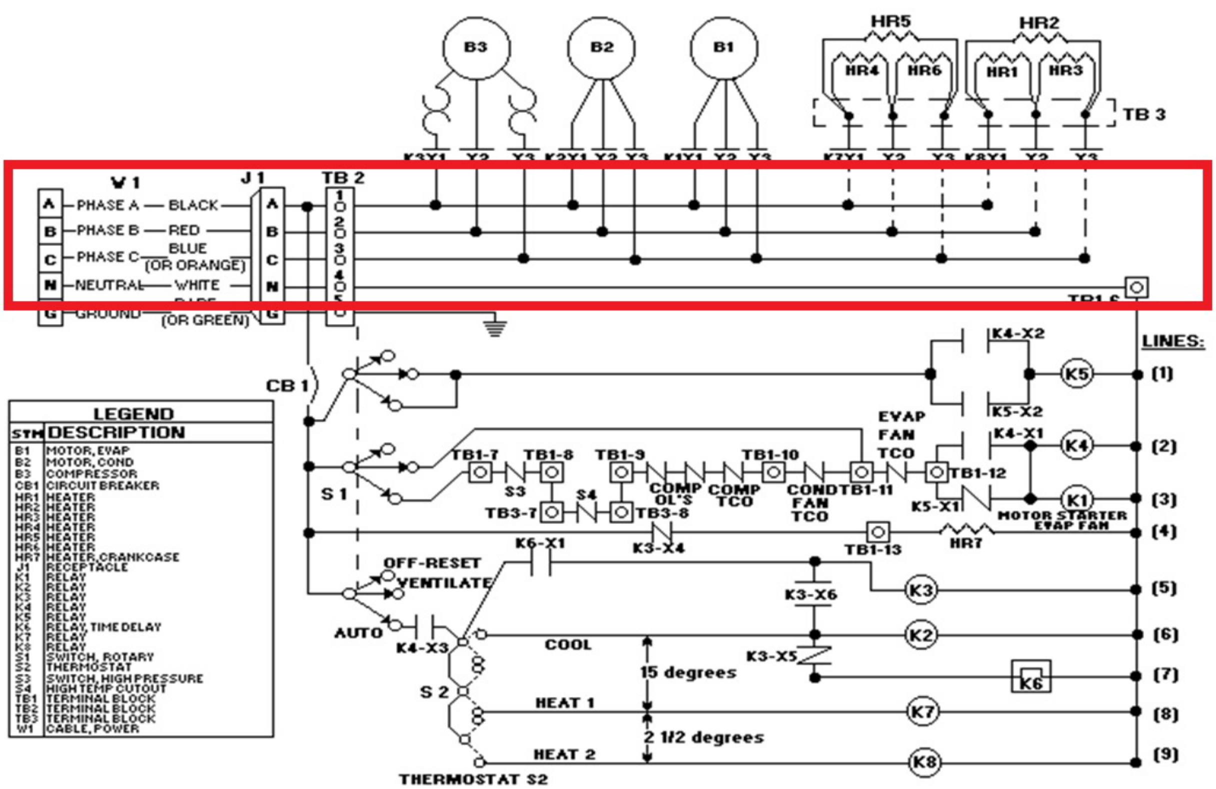


Figure 1–33. ECU line circuit.

Even though this circuit is small in size, it is very important to the rest of the system. If there is no line voltage, the system will not run. It will not do anything! This is where every good technician starts troubleshooting. Even if some components are running when you first arrive at the job site, you should check line voltage. Why would you check the line circuit if parts of the unit are already running? Because the incoming power may be the incorrect voltage. A simple check of the line circuit allows you to make sure the correct voltage is present and eliminate the line circuit as a potential problem.

Control circuit

What would be the problem if you took the line circuit and connected it directly to the compressor? The correct answer is that the compressor would run constantly unless something interrupted the line voltage. What can be installed to *control* when and how the voltage reaches the compressor or other load devices? A control circuit! The control circuit *controls* the load devices. In short, line voltage is supplied to a system and the control circuit determines when and how voltage is applied to the load devices.

On figure 1–34, the ECU schematic, you can see that the purple rectangle shows the control circuit. (**NOTE**: The control circuit is much larger than the other circuits. This is a recurring theme with HVAC/R schematics.)

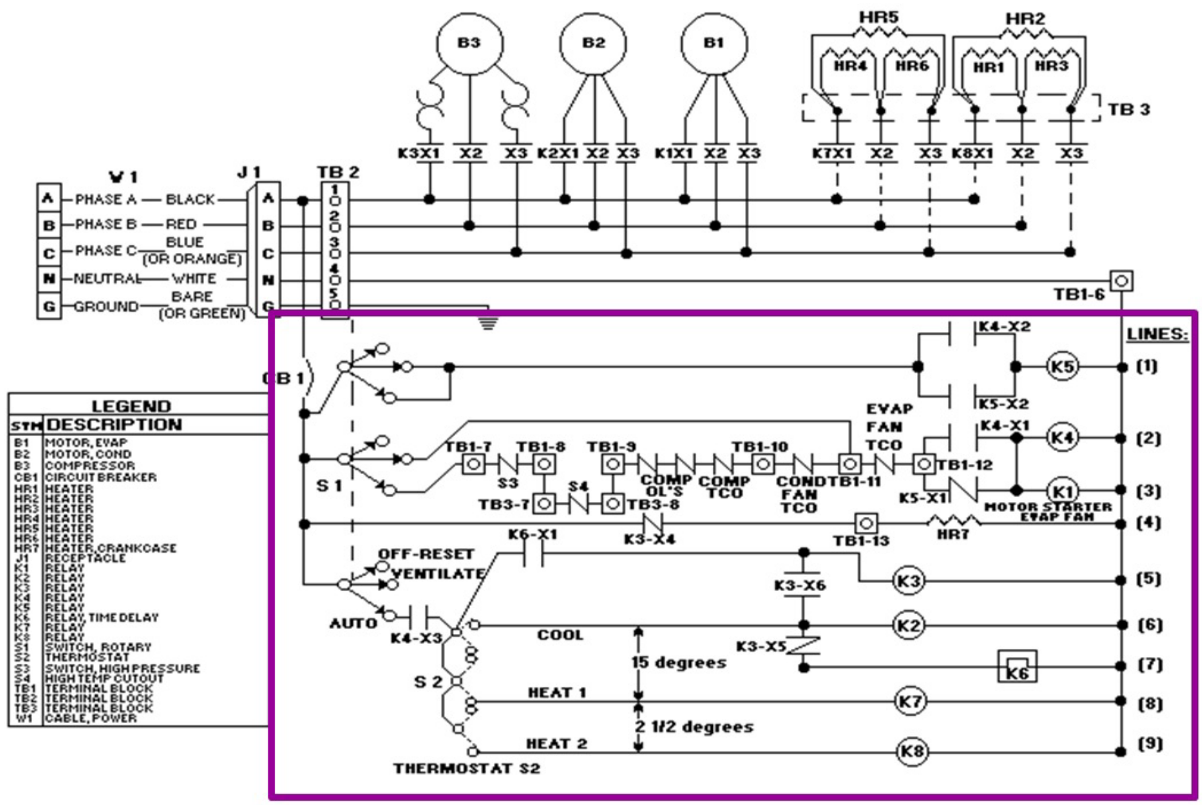


Figure 1–34. ECU control circuit.

Notice the coils that are in the control circuit, K1–K8, are all *loads,* but they are still a part of the *control* circuit. Let's look at a description of a load circuit.

Load circuit

The load circuit consists of the devices that are doing the work. Some examples of loads are compressors, motors, and heaters. This circuit doesn't usually take up much space on a schematic. Look at the blue rectangle in figure 1–35. This area is where the load devices are located. For example, B3 is the compressor. When the compressor is energized, it is pumping refrigerant; therefore, it is functioning properly.

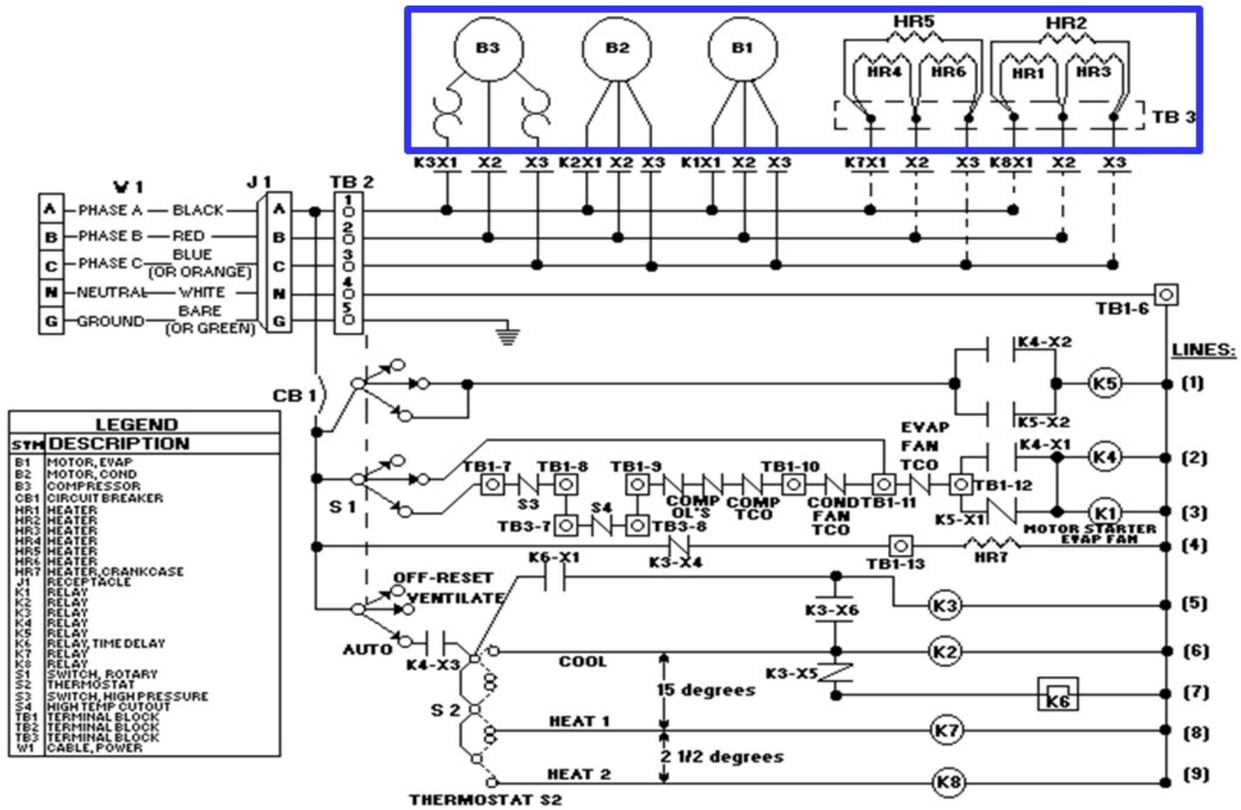


Figure 1–35. ECU load circuit.

Series and parallel circuits

The final aspects of circuits you must understand are series, parallel, and complex circuits. Almost all systems will be complex circuits, but you must understand series and parallel before you can understand complex circuits.

Series circuit

A series circuit has all of the components *in series* or directly after the other. Look at figure 1–36. You will see that each of these components are in series with each other. Why does this matter? If one part of the circuit opens, then the rest of the circuit will not get power. Look at figure 1–37. The red circle represents contacts K3–X4 being open. The red "X" means that no power is being passed to the rest of the circuit.

Figure 1–36. ECU series circuit.

Figure 1–37. ECU series circuit with an open.

Again, why does this matter? Well, look to the right of the "X" and you will see there is TB1–13 and HR7. HR7 is the crankcase heater. If you need power to HR7, then you need to figure out what is keeping K3-X4 in the *open* position.

Parallel circuit

A parallel circuit is different from the series circuit because it involves wires and components that are *in parallel* to each other. In figure 1–38, K5-X2 and K4-X2 are in parallel to each other. In a parallel circuit, if one of the circuits loose power the other circuit is not affected. In figure 1–39, this concept is identified. Notice that K4-X2 is open (annotated by the blue circle) but power is still passing through K5-X2 to the K5 relay.

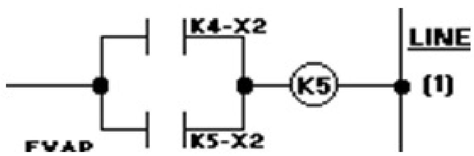


Figure 1–38. ECU parallel circuit.

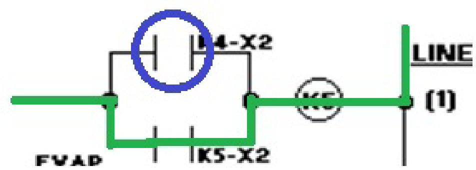


Figure 1–39. ECU parallel circuit with an open.

Complex circuit

A complex circuit is one that includes both series and parallel. Basically, this is *the* type of systems you will deal with. A key for you, as an HVAC/R technician, is to break down these complex circuits into smaller circuits and work through each in a logical manner.

408. Troubleshooting and correcting electrical circuits

Every topic covered in these CDC's is important, but troubleshooting and correcting electrical circuits are absolutely two of the most vital to you as an HVAC/R technician. Fist, we cover the use of electrical test equipment, schematic reading, and troubleshooting steps, and then we give a few common troubleshooting examples.

We cover general procedures for correcting electrical circuit malfunctions. This lesson is fairly long, but if you consider the importance of troubleshooting in this career field, then the length of the lesson makes sense. As stated earlier, the concepts and skills in this lesson are instrumental in your development as a highly skilled HVAC/R technician. Let's look at electrical test equipment.

Using electrical test equipment

There are many meters we use in troubleshooting electrical equipment. Among the more common are the multimeter, megohmmeter, and clamp-on meter. The purpose of a multimeter was covered in a previous volume. The focus in this lesson is on using a multimeter to check voltage and ohms. To troubleshoot ,you must know how to use a meter. Let's start with voltage.

Checking voltage with a multimeter

When you troubleshoot a circuit using voltage, you are checking for the potential difference between two points. Use meters to check AC or DC voltage. The reading on the display reflects the voltage difference across the unit being checked. There are three absolutely critical concepts you must understand and NEVER forget while troubleshooting voltage:

1. This is a LIVE circuit with current flowing. Do NOT touch the electrical components!
2. A voltage reading of zero does NOT mean what you are checking is bad. It just means there is no difference between the TWO points you are checking.
3. You have TWO leads; the meter's display shows the ***difference*** of voltages between the TWO places you place the TWO leads.

When checking voltage in a system, ensure your meter is on the proper setting. Most meters have a DC and AC setting. If you are checking DC, make sure it is set to DC, and if you are checking AC, make sure you set the meter to AC. Sound simple? It is except that many systems have both AC and DC circuits so you must stay focused on what part of the circuit you are working with.

Observe polarity when measuring DC voltage. Connect the plug [+] terminal of the voltmeter to the positive side of the electrical unit and the minus [–] terminal of the voltmeter to the negative side of the electrical unit. This is covered more indepth later in this lesson.

Disregard polarity when measuring AC voltage. Connect your voltmeter in parallel with the electrical unit to be tested.The steps below are very general procedures on how to check for AC voltage:

1. Select voltage setting.
2. Determine test points based off of the schematic.
3. Determine the proper voltage that should be displayed on the meter.
4. Place leads on test points.
5. Read the display.
6. Determine if there is a fault. If there is a fault then identify it.

Proper use of meters goes hand in hand with safety. Improper use of meters is a violation of safety precautions and may lead to serious harm to you or a fellow worker, or loss of equipment.

CAUTION: Remove all jewelry before you use a meter. *Never* connect your meter to a source of voltage that exceeds the selected calibrated scale. Where high voltage is present, connect your meter to the circuit *before* turning on the power. Do *not* touch your meter leads while power is on in the circuit being measured. If your voltmeter has a special ground clip, fasten it to the chassis ground *before* making voltage measurements.

Checking ohms with a multimeter

Now let's talk about checking for continuity or ohms. We use ohms to check the resistance of a unit or a circuit. Before you make a measurement or check for continuity with an ohmmeter, you must zero the meter by touching the leads together until it reads zero. It's very important to zero the meter each time you use it. Below are resistance checking steps:

1. Verify the circuit is dead by ensuring no voltage is present.
2. Select the resistance setting you need with a switch on your meter panel.
3. Read the schematic and determine your test points.
4. Isolate the part of the circuit that needs to be tested. This could be a load, switch, wire, or any unit of resistance. (Isolating the circuit means to **ELECTRICALLY** disconnect the part of the circuit being tested. You do NOT always have to physically remove the entire part from the system. You may have to break a soldered connection. This prevents current from the ohmmeter from finding an alternate path in which to flow. This would be a false reading and you would be misled.)
5. Check for resistance.
6. Determine if there is a fault. If there is a fault then identify it.

Be sure your meter leads make good contact with the part of the circuit that is being tested. Remove any dirt, grease, varnish, paint, or any other material that may prevent current flow.

NOTE: Keep your hands on the insulated portion of the meter leads. Body resistance can distort your ohmmeter reading if you touch the ends of the leads with your fingers. Figure 1–40 shows how to measure resistance properly.

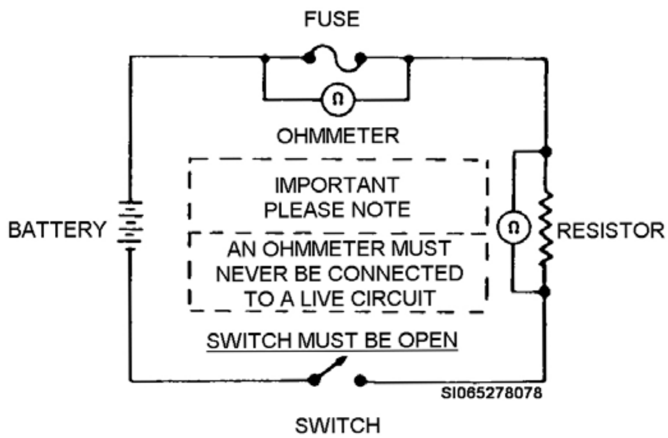


Figure 1–40. Method of connecting an ohmmeter in a circuit.

Safety is important in using ohmmeters. Improper use could lead to injury or damage to equipment. Always remember to remove all jewelry. (**NOTE**: Treat all circuits as energized circuits even if you personally have de-energized them.) Never connect your ohmmeter into an energized (live) circuit. This causes damage to the meter.

Megohmmeter

Sometimes a motor's windings or insulation becomes weak. If the motor windings become too weak, the motor could fail. If insulation becomes too weak, it presents a shock hazard. This is why the megohmmeter is important.

We use the megohmmeter for measuring the resistance of insulating material. This tool can also be called an *electrical insulation tester*. As its name indicates, the megohmmeter gives resistance readings directly in millions of ohms. One megohm equals 1 million ohms. We use the megohmmeter primarily to indicate the insulation resistance of cables, motor and generator windings, transformer windings, and circuits.

A megohmmeter supplies high voltage between 500 and 1000V of direct current. This is how it measures resistance. Since these voltages are high, only an experienced technician should use a megohmmeter. If this voltage is applied to a component for too long, it could damage windings or insulation.

The megohmmeter should read above 100M ohms to indicate good insulation. Below 100M ohms indicates there may be a problem with the insulation. In an air-conditioning or refrigeration compressor a low reading may indicate contaminated oil and refrigerant in the system because contaminated oil and refrigerant break down compressor winding insulation. Below are the steps for using a megohmmeter on a motor or compressor:

1. Disconnect power.
2. Isolate the compressor. Ensure you remove wires from all terminals. Wipe down terminals.
3. Connect a jumper between all terminals.
4. Connect the black lead to a bare metal ground.
5. Connect the red lead to a motor terminal.
6. Turn on the megohmmeter. Read the manufacturer's instructions to know how long to energize the megohmmeter.

Since a megohmmeter has its own power source, like an ohmmeter, *never* use it on a live circuit. To do so will more than likely ruin the meter.

Using a clamp-on meter to conduct an amperage draw

There are times when you must know the current flow in an AC circuit to get proper circuit functions or to prevent damage to equipment. There are several meters you can use to measure current flow, but the simplest and easiest one to use is the clamp-on meter. Most clamp-on meters are multimeters in that they measure either voltage or amperage. We won't consider the voltage aspect because we have discussed other meters for that function. We'll just deal with using this meter to measure current flow.

You use these meters to troubleshoot and analyze circuits and circuit parts. One use for this meter is to check the phases of a three-phase system. You can verify that each phase is supplying the same amount of power to the system. Should one phase reading be different from the other two, you then know that the system is out of balance and you've found a potential trouble.

Another purpose for the clamp-on is to check the amperage draw of a system, motor, or compressor. When you take current readings using the clamp-on meter, move the selector switch to check amperage. Squeeze the trigger assembly to open the clamping jaws. Place the open jaws around **one** of the circuit leads. Close the jaws. (**NOTE**: Check only one conductor at a time.) If your meter jaws encircle two phases, their magnetic fields cancel out and you won't get an accurate reading.). Two wires are inside the clamp and an inaccurate reading is displayed. If you make this mistake in the field, you could misdiagnose a system's fault.

Proper use of clamp-on meters helps to ensure safe operating conditions. Improper use of clamp-on meters is a violation of safety precautions and could lead to personal injury. Remove all jewelry. When you're taking measurements, DO NOT touch the jaws of the meter. Hold the meter by the hand grip only.

Relationships between schematics and the physical components

It is impossible to cover every type of schematic and electrical component in the HVAC/R industry, but the skill of relating electrical schematics to the actual component can be difficult to obtain. Many students of the HVAC/R craft have a strong ability to read schematics but can't find the component in the actual system or vice versa. You must be proficient at both to become a highly skilled technician.

General troubleshooting

Because many troubles with any HVAC/R system involve electrical problems, you need to be able to troubleshoot electrical circuits. We define electrical troubleshooting as a "systematic method of locating faults in an electrical circuit." Everyone has his or her own method of troubleshooting, but we all have the same goal—to repair the broken equipment and return it to operation.

Do a visual and operational check

First, make a visual inspection and don't overlook the obvious. Check to see if the unit is connected and turned on. Look for broken wires or terminals and loose connections. Quite often, a visual inspection will locate the trouble.If a wiring diagram or schematic is available, make use of it. Check to see where the circuit goes, where power is applied, and what units are connected. Make an operational check. See what parts of the system are functioning and what units are not operating. The parts of the circuit that fail to operate will be the trouble. Analyze the trouble by asking what allows these parts of the circuit to operate. A visual and operational check while studying the schematic will give you some ideas of where the trouble may be. Now select the meter you need to check the circuit. Sometimes, your selection may be a matter of personal preference while other times the nature of the trouble dictates the meter you must use.

Look for loose wire connections

The probable cause of most circuit troubles is loose connections. While checking a circuit, you may have to disconnect terminals at various points. Take extreme care to tighten the terminals when you reconnect the wires. When you replace terminals, be sure to clean them well and tighten them securely. Loose connections can cause arcing and can, in time, necessitate an assembly replacement.

Furthermore, loose connections can lead eventually to electrical shorts and grounds that may cause fires. Loose connections cause interference in electrical transmission and receiving equipment. Also, increased resistance resulting from a loose or poor connection increases the voltage drop in the circuit causing inefficient operation of the devices in the system. Always check a connection by (lightly) tugging on it. A secure connection creates no problems.

Check the type of wire

During your inspection, be sure to check the type of wire for the particular circuit. If the circuit is in a dangerous place, use only the wire approved for that location. Codes specifiy the type of wire that needs to be used. If the wiring is the wrong type, replace it.

Look for loose fittings

To avoid the possibility of short circuits, make periodic checks of the electrical fittings. These fittings include such items as conduit couplings, connectors, and box-entry devices. Check the fittings for looseness and separation, and tighten them or reclamp the conduit when necessary. Inspect and tighten conductor or conductor-enclosure supports, if necessary, to ensure a trouble-free operating system.

Troubleshooting open circuits

An open circuit is one that has a break somewhere. This break could be located in the wire, switch, fuse, or load device. If there is a break, there is no current flow, and the load device will not be operating (fig. 1–41).

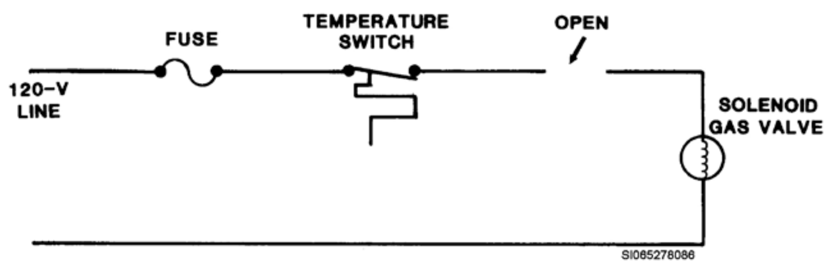


Figure 1–41. An open circuit.

Some examples of opens are a loose connection, a burned-out fuse, or a broken wire. Units of resistance such as a light bulb, solenoid coil, or a transformer can develop breaks, which are the same as opens. All of these examples of an open will give the same result—no current flow. When current cannot flow, circuits cannot operate. This is undesirable and must be corrected. Your job is to correct these circuit malfunctions and put them back in operation.

An open circuit simply means that the circuit is not complete. This may be intentional, as with a switch, or unintentional, as with a burned-out coil. In this discussion of troubleshooting electrical circuits, we deal with the unintentional open circuit. The normal indication that an open circuit exists is that the load device with the power on does not operate. For example, a coil for a gas valve does not energize and allow the valve to open. You can use almost any type of meter to locate an open circuit.

Using voltage to check continuity

If you don’t find the trouble by a visual check, use a multimeter set to read the voltage. One strategy you can use is to place one lead on a ground or neutral wire, and then move the other lead around to wherever you need it. You can find the trouble by checking the source of power and continuing on until you find the circuit trouble by getting a zero volt (0-volt) reading. When you determine that power is being sent to a load, you must turn power off, disconnect the load, and ohm it out. You won’t read voltage after a load because the load consumes the voltage. In figure 1–42, the load is the gas valve. As you can see, 120V is being read across the gas valve; this means voltage is being applied to the valve. As long as 120V is being applied to the gas valve, it will read 120V ***regardless, whether it is a good or bad gas valve.*** This is why you must ohm out the gas valve to determine whether it is bad.

Assuming that everything is all right at the main panel, let's examine a single 120-volt circuit. Illustrations help explain the procedure for locating an open in a circuit. Figure 1–43 shows a circuit with a solenoid gas valve in series with a temperature switch (thermostat) and fuse, and the normal voltage readings at the various points of the circuit. If the gas valve fails to energize, check the circuit in progressive steps from the last point where you know voltage is present, through the circuit and gas valve. In figure 1–43, we have voltage at one connection of the fuse and no voltage at the other. Since the fuse is a power ***passer***, normally the same voltage reading should occur between both sides of the fuse and the ground. The only conclusion in this case, then, is that the fuse is open.

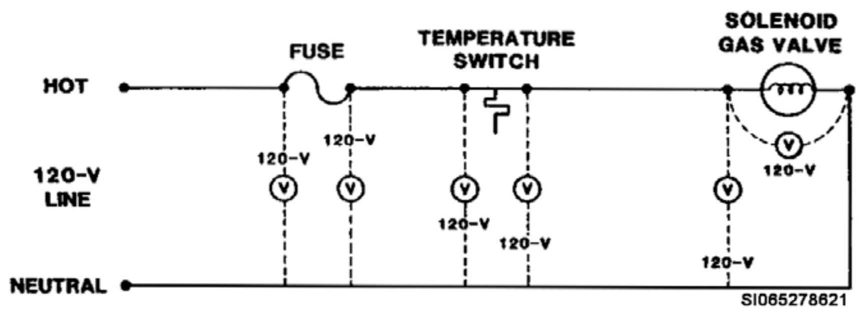


Figure 1–42. Normal voltage reading of a circuit.

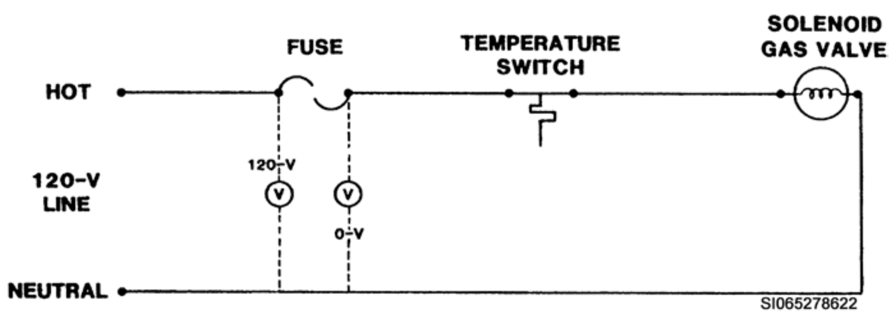


Figure 1–43. Circuit with a blown fuse.

Figure 1–44 shows that there is a voltage reading when the voltmeter is connected across the gas valve. If there is power present *going to* the gas valve, then there will always be a voltage reading across it. To be sure the consumer is inoperative, you must check it with an ohmmeter. You must use the ohmmeter because if you use voltage, the gas valve will read 120V across it whether it is bad or good.

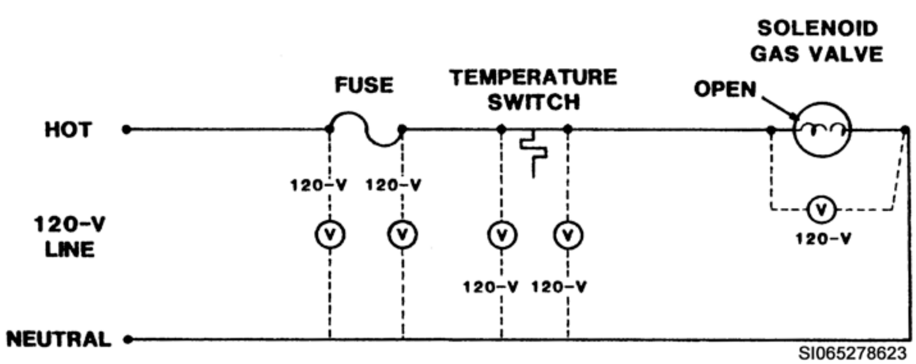


Figure 1–44. Circuit with a burned out gas valve.

In figure 1–45, you find two lamps wired in parallel and controlled by a double-throw switch. With the switch in the OFF (center) position, there is no complete circuit. When the switch is in the BRIGHT position, a circuit is completed through the switch and through the lamps. With the switch in this position, the only resistance in the circuit is the resistance of the lamps. When the switch is in the DIM position, the circuit is completed through the lamps as before, but this circuit has an additional resistor in series with the lamps. This added resistance causes a decrease in current flow, so the lamps glow with less intensity than before.

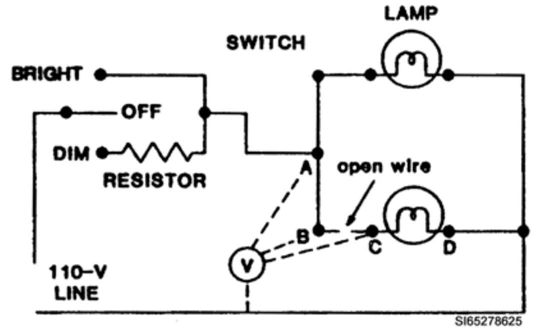


Figure 1–45. Shorted control service.

If one of the lamps lights and the other one does not, check the complete circuit to find the open. The part of the circuit up to point A is common to both lamps, and that much of the circuit must be completed for even one lamp to light. The place to begin checking the circuit is after point A in the affected part of the circuit. In a circuit, such as the one shown in figure 1–45, it is best to use a voltmeter to locate the trouble.

If you connect the negative lead of the voltmeter to the ground and the positive lead to point A, you will get a reading on the meter, because point A is connected through the switch to the positive line wire. If you move the positive lead of the voltmeter in succession from A to B to C, you are able to check the continuity of wires AB and BC. If the check at point C reveals no voltage, this indicates that wire BC is open.

Using an ohmmeter

Many times you can determine the approximate location of an open by simply studying the circuit diagram before doing any actual circuit testing. For example, suppose both lamps in figure 1–45 light when the circuit switch is placed in the BRIGHT position, but neither lamp lights when the switch is placed in the DIM position. Because the lamps light when the switch is in one position, you can assume that all wires and lamps are good. The only units that could be faulty are the resistor half of the switch or the wires that connect the switch and the resistor. By using the ohmmeter as you did before, you can check continuity of these parts.

CAUTION: When you use an ohmmeter, be sure that the circuit is de-energized and is isolated to prevent reading resistance from other portions of the circuit.

Shorts

A shorted circuit occurs when an accidental low resistance connection between two conductors of different potential bypasses the load device of an electric circuit. This type of trouble is commonly known as a *direct short*. It can cause damage to an electrical circuit if proper overload protectors are not used. These overload protectors are fuses and circuit breakers. A fuse may blow and a circuit breaker may trip, either causes the circuit to open. This stops current from flowing and protects the circuit. An example of this trouble is where a hot conductor comes in contact with a neutral conductor and bypasses the load (fig. 1–46). The meter setting used to find shorts will be ohms.

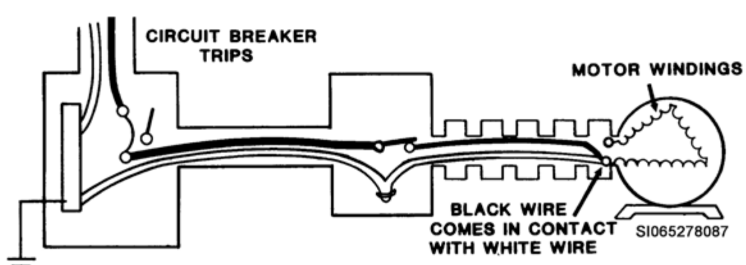


Figure 1–46. Direct short.

Before using a meter, remove the power from the circuit and isolate the circuit from the system to prevent damage to the meter.

REMEMBER! To isolate the circuit means to isolate it *electrically*. This means to disconnect the wires from the component.

Your first step in troubleshooting a direct short is to shut off power. In most cases, the short circuit will have done this already by tripping the circuit breakers or burning out the fuses. In any event, you must shut off the power. Talk to the people who were present when the unit malfunctioned. Did they notice sparks arcing? Did they smell insulation burning? If the circuit is fused, check the fuse condition. Check the wiring diagram and then do a visual inspection. Use your senses of sight, smell, and touch. A blackened spot on the unit or conduit may locate the short. The smell of hot insulation can give you the location. A hot spot on the unit can help you find the shorted area.

If you do not find the trouble with a visual inspection, you must isolate it step by step. First, reset the breakers or replace the fuse. Switch the circuit “ON” and see if you can get a usable reading. Compare the reading against the load device data plate for accuracy. If the fuse does not blow or the breaker does not trip immediately, then you may not find the trouble in the load device or breaker; it just might have been a weak circuit protection device. STQ20 But, if a short does trip the breaker or the fuse burns out again, then the trouble most likely is in the wiring or controls or possibly the load device (fig. 1–47, A).

To find the direct short, you first disconnect the wires at both ends of the circuit and test either end with an ohmmeter. A normal reading between circuits would be infinity. The infinity symbol looks like this, ∞. If a short exists in the circuit, you get a zero (0) reading (fig. 1–47, B). Remember you do NOT want continuity (0) between these two lines. Often time’s technicians get confused on what the meter is supposed to be reading. Know what the meter should read before you place the leads on the device.

Now go back and place all controls in an open position. Then go to the first control and check between the circuits in both directions (fig. 1–47, C). One direction shows clear of trouble by reading infinity. The other shows the circuit still shorted (zero ohms). Move down the shorted circuit to the next control or junction box and repeat the process until you isolate the short to a single wiring section (fig. 1–47, D). Once the circuit is isolated, you can then replace the wire.

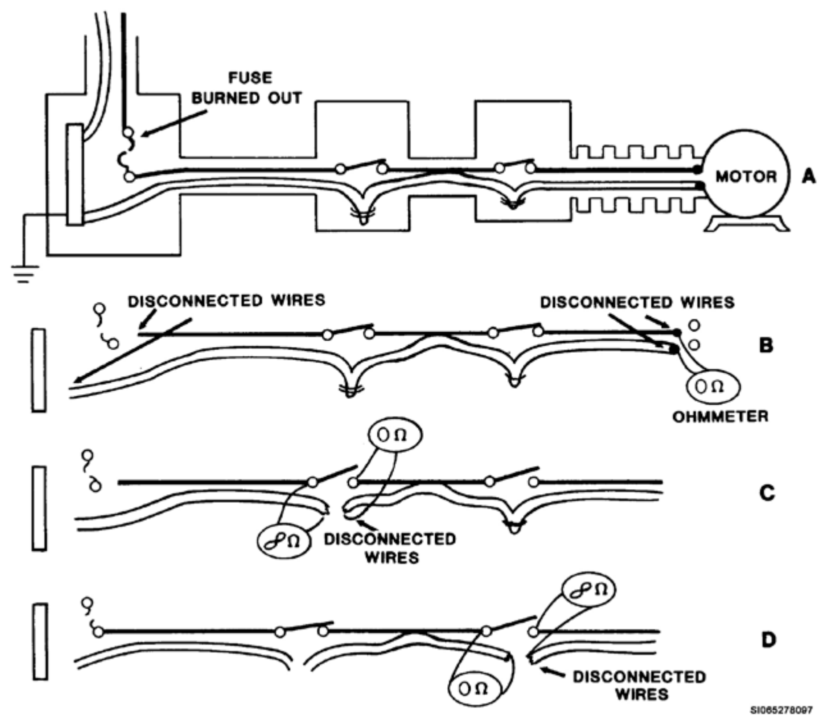


Figure 1–47. Troubleshooting direct shorts.

NOTE: Some controls may automatically open when the circuit is in the off position. If this is the case, work systematically from one control to the next to find out where the short is.

Shorted control devices

A shorted control device is one type of a shorted circuit. If all the wire circuits show a normal reading, then your trouble is in a control. Thermostats, relay coils, and fan switches are all examples of units that can become shorted. When testing control devices, isolate the device by disconnecting the wires and take readings with the control open and then closed. A control in an open position would read infinity, which indicates that there is no physical contact within the control, hence no short. A continuity reading across an open switch would indicate a short (fig. 1–48). In almost all cases, you must replace a shorted control device. Very seldom can you repair one successfully.

WARNING: Always turn off power and isolate the circuit when using an ohmmeter!

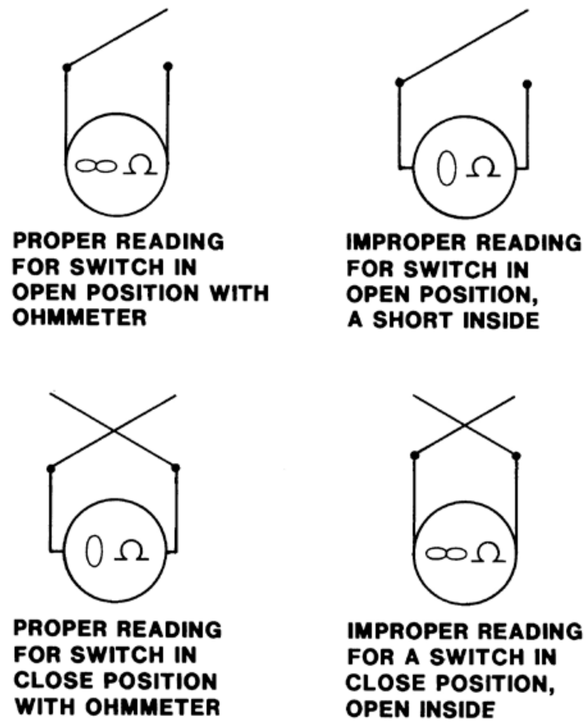


Figure 1–48. Shorted control device.

Grounds

Figure 1–49 shows a short-to-ground condition, which occurs when a conductor comes in contact with the metal structure of the load device. An electric motor or other piece of equipment becomes grounded when the insulation breaks down and some part of the wiring comes in contact with the frame of the equipment. Also, a conductor in conduit is grounded if an un-insulated portion of it accidentally comes in contact with the conduit (fig. 1–50). This type of electric trouble is very dangerous. Many deaths and injuries from electrical equipment are caused by accidental grounds. While a direct short shuts the current off by the overload, this type of trouble may not. That is why all electrical equipment has to be grounded according to the NEC.

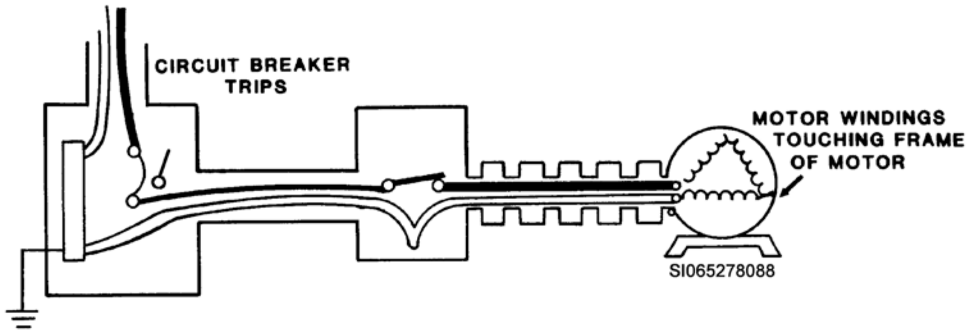


Figure 1–49. Grounded short to a motor.

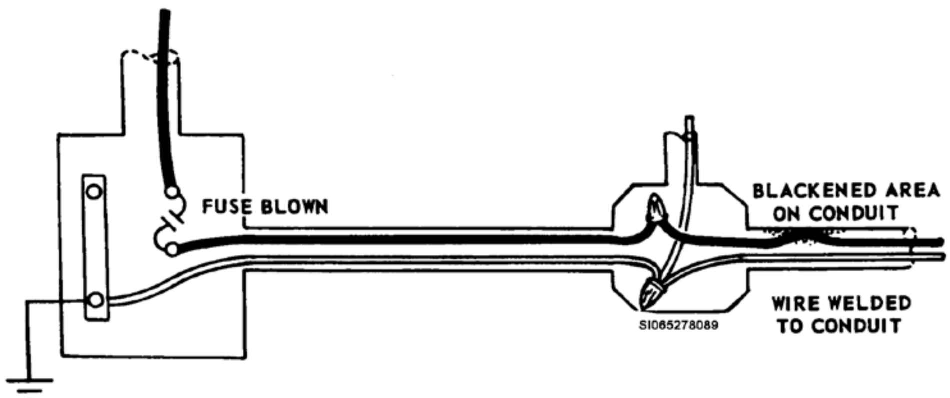


Figure 1–50. Grounded short in conduit.

Remember, a grounded circuit is one in which a phase wire is making physical contact with the equipment or with the conduit. If the phase wire is contacting a grounded conductor (green or bare wire, chassis, or conduit system), you must take your ohm readings between the affected phase wire and the grounded conductor. This can require a check between the isolated (open) phase wire and each of the grounded conductors. To do this, open the neutral at the power panel and check from the phase conductor to the neutral. A zero (0) reading indicates a direct short. Infinity or O.L. indicates that the two conductors are not in physical contact and therefore not shorted. If the neutral is clear of shorts, then check the equipment ground (green) conductor in the same manner. If the equipment ground is clear, then check from the phase wire to the conduit. Somewhere, the phase wire is making physical contact with the conduit. Refer again to figures 1–48, 1–49, or 1–50 for a visual display of this situation.

Troubleshooting tips

Experience will help you develop troubleshooting skills. It takes time, so be patient. Spend time with the equipment and with the manuals that explain how to operate the equipment. Your shop has these manuals. If for some reason, there are no manuals available, try to get one from the manufacturer of the equipment.

Don’t be too proud. When you get stuck, ask for help. Experienced coworkers can share a wealth of information with you. Do the things you know to do while troubleshooting; then, if necessary, save yourself some grief by calling on the old-timers in your organization. For a lot of individuals, one of the greatest compliments you can offer is to ask them for help.

CAUTION: Know what you are looking for! Do *not* place your leads on any device unless you know what you should be reading on your meter. If you do otherwise, you are just guessing.

Line, control, load

Line, control, load, or LCL, is a troubleshooting strategy you can use to work through the systematically through an electrical circuit. It is not the only strategy but it is a common one. The concept is based off of the direction the current flows. The line voltage comes into the unit, the controls *control the function of the unit* and determine when each load device operates.

Where did you lose power?

If you can determine where power is lost, you will have an advantage and more than likely find the problem. Look at figure 1–51. Let’s use an example to explain this concept. We are only concerned with the path to the pumpdown solenoid which is circled in red; assume everything is working as it is designed. This is a 120V, single-phase circuit. Follow these procedures to find out where you lost power:

- Set the meter to check for volts.
- Place one lead on a neutral and do not move it.
- Move the other lead around from test point to test point.

The concept works like this: there should be power at every point along the path to the pump down solenoid. If you look at the schematic, you can see there are numerous points where power should be—2 on the copper strip, 4 after the cooling contacts, both sides of the thermostatic motor control (TMC), and entering the solenoid.

This technique is extremely simple. Take the meter lead that is *not* on the neutral and place it at 2. You should read 120V because the meter reads the difference of potential between the 120V at 2 and the 0V on the neutral. See formula below:

Meter Lead 1 – Meter Lead 2 = Meter display

120V – 0V = Meter displays 120V

NOTE: This concept is a little more complicated for 240/480V.

Continue down the path and place the “moving” meter lead to point 4 after the cooling contacts. Move on to one side of the TMC and then to the other. Finally, check the pump down solenoid to make sure you have 120V. You have 120V going to the solenoid coil, but it is not opening. If we are *only speaking electrically*, then this tells you that the solenoid coil is open which means that it needs to be replaced. Double check by ohming the coil out. If it is good, it will read ohms; if it bad, it will read O.L.

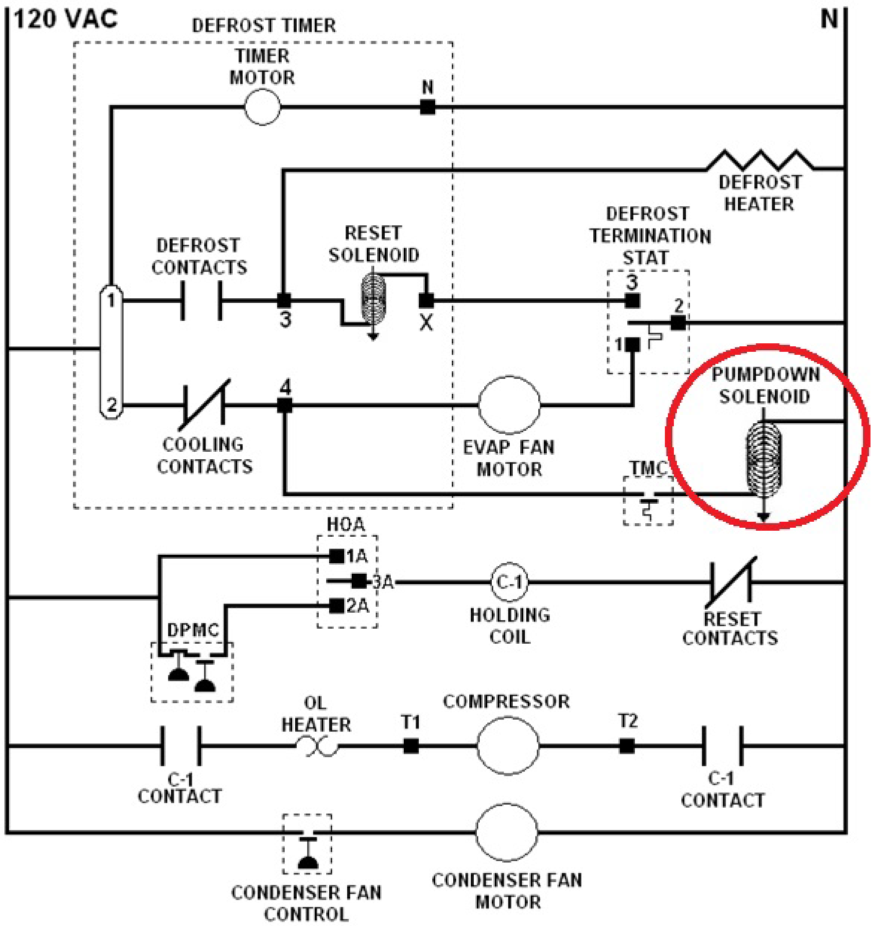


Figure 1–51. Losing power.

But what if there isn't 120V at every point? Place the "moving" meter lead on point 2. The meter reads 120V; this is good. Now, place a meter lead on point 4 and leave the other lead on the neutral; you read 0V. What does this mean? It means that power is not traveling from point 2 to point 4. This means that cooling contacts are open! Think about it, you had power at 2 but not at 4. What is the only thing in between these points? The answer is the cooling contacts. Now you must discover why the cooling contacts are open, but for this example, we will not go any further.

Backtrack

Another strategy is to backtrack through the system. Let's say your compressor is not running in figure 1–52. You know K3 is the coil that closes the contacts that allows line voltage to reach the compressor. You may want to start at the coil and ohm it out to see whether it is good. Generally it is not a good idea to start at the load because it is not good to just assume that parts are bad but let's say you are completely lost and need to do this. (Or you are really experienced) Assume that the coil is good. If you move backward through the schematic, you see that N.O. contact K3-X6 is nearby. This contact closes when K3 is energized and you know K3 is de-energized so it is supposed to be open. No problem here.

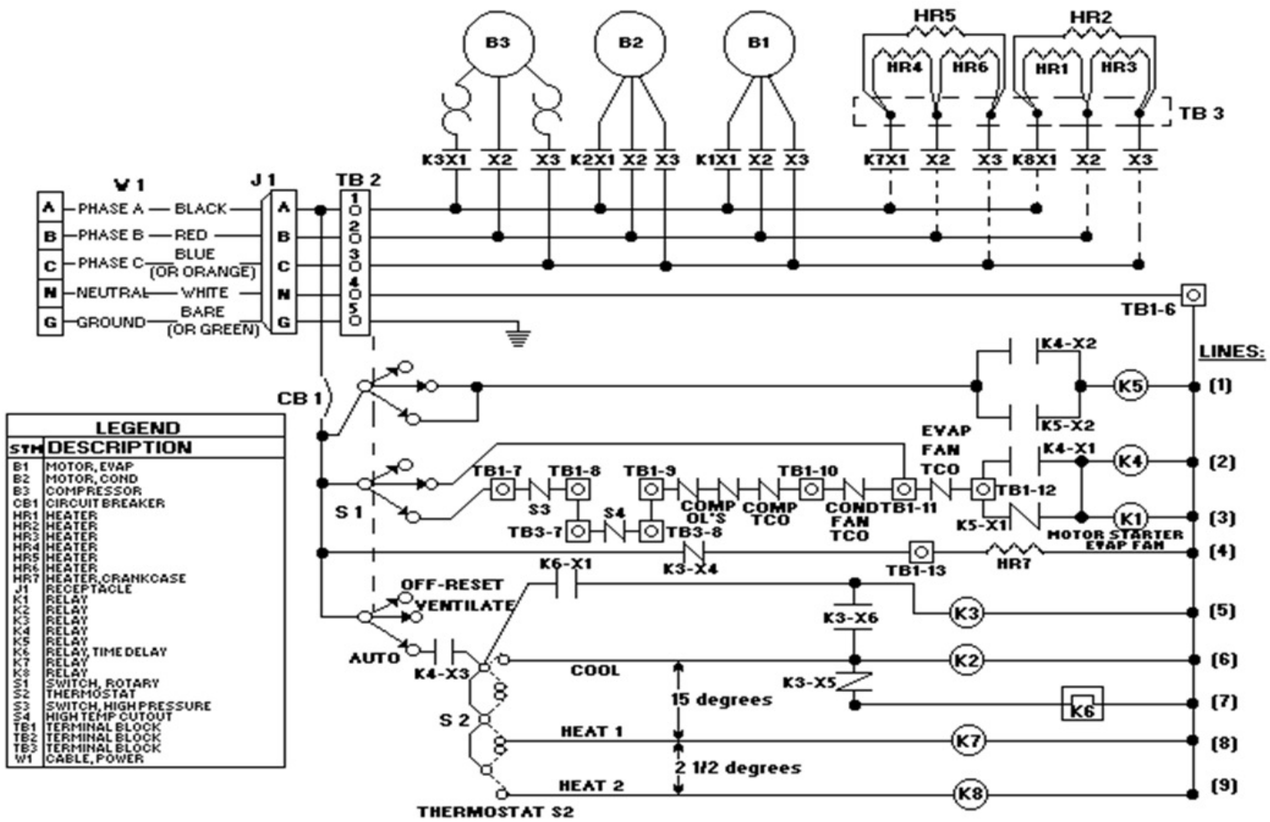


Figure 1–52. Backtracking.

Continue to go back to K6–X1. You check and realize that K6–X1 is open. This is supposed to be closed because K6 is time delay and should have closed these contacts by now. You ohm out the K6 time delay relay and find that it is bad. You have successfully backtracked and found the issue.

This should not be your primary troubleshooting strategy because it is not the *most* systematic approach. This strategy can be used when you are in bind and other approaches are not working for you.

Common line voltage problems

We have covered many different electrical problems so far but now we will cover some specific examples of common line voltage electrical problems you will encounter. This section can serve as reference for you whenever you get stuck in the field or if you are struggling to remember certain line voltage concepts. Controls and protective devices will be covered later.

Missing a phase

Let's troubleshoot an open circuit with voltage. Check each incoming phase by connecting one lead of the meter to the neutral, and the other lead to each phase, one at a time.

On a 208-volt, three-phase service, you should get 120V on each phase to ground. More than a 10 percent differential from 120V on one phase means that the phase is open and you are getting feedback from equipment connected to the load side of the panel. Sometimes there is a slight variation of normal voltage from different phases.

To determine whether one phase is dead, check between the phases. To do this test, place one lead of the voltmeter on phase A, the second lead on phase B, and then read the voltage. It should read 208V. After you take this reading, move the second lead to phase C and take the reading. After this reading, move the first lead to phase B and take the reading. You have now read between all phases, A to B, A to C, and B to C.

Which phase is dead? Assume that phase B has a blown fuse. When you take your reading between phases A and B (fig. 1–53) you get a low-voltage reading. Your next reading, between phases A and C, is normal, but the next reading, between phases B and C, again is a low reading. Each time you read to phase B, you get low voltage. This is a good indication that phase B is open.

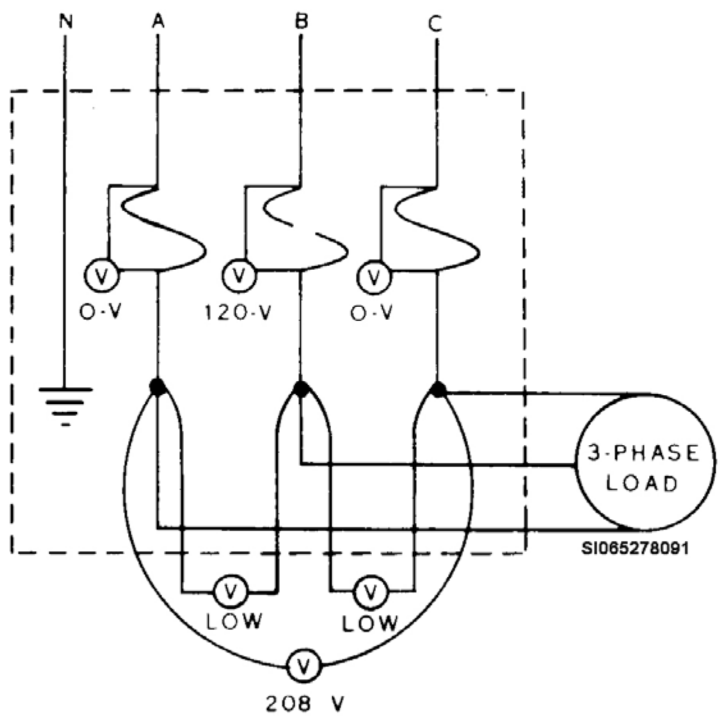


Figure 1–53. Checking fuses for 3 phase circuits.

CAUTION: Should the amperage be too high for the meter, it could blow up.

If you choose to use this method, disconnect some part of the circuit so the units of resistance will not operate.

Improper power

Improper power is another form of trouble. Improper power simply means that the circuit is not receiving the correct voltage and current that it needs to function correctly. This may be caused by aging in the circuit or equipment, corrosion of connections, wire too small for the length of the circuit, the circuit connected to the wrong voltage, or an increase in circuit resistance caused by loose or aging connections. Below are some indications of improper power:

- Unusually slow or sluggish operation of equipment.
- Heating of conductors or equipment.
- Incorrect operation of equipment.

If you note these conditions, you need a voltmeter or an ammeter. Check the source voltage at the panel and also at the equipment. Check the data plate on the equipment to assure that it is rated for the applied voltage. If the voltage at the equipment is different from the applied voltage by more than five percent, it usually requires a replacement of the existing circuit with a circuit of larger wire. Corrosion maintenance can be required on contacts and connections. An excessive voltage input can cause incorrect operation of equipment. In some cases, an excessive voltage can cause equipment damage.

Missing power

Would it not be a shame if you search through the entire schematic and spent hours troubleshooting only to find out the problem was no power? It would. This is why when you are troubleshooting, you should always ensure you start by checking to see if you have power.

Correcting the malfunction

Once you find the trouble, you must fix the equipment. Sometimes a repair or cleaning is all that is required. Other times a part may be needed. The thing to keep in mind is to get a replacement that works without any modification to install it. This doesn't mean that you always have to get original equipment. In a lot of cases, generic parts work. Be aware though, some manufactuers require or recommend that you use their parts.

To aid in obtaining the correct replacement, take down all the information that is on the part. It is a good idea to take down information about the unit on which the part is installed. It is better to have too much information than not enough. This will save on trips back to the unit to obtain needed information. Some parts may not have very much information to begin with. Sometimes you have to remove the part so the parts store can match the part. This is especially true with older equipment. Should you remove any parts, label the wiring and make a drawing to help with installing the replacement part.

It may be a while until you can get back to finish the job, and it is possible that you may not be the one to finish, so be sure there is enough information available that someone else can finish the job.

After the part has been replaced, then run an operational test to ensure everything was wired properly and the system is running. Do *not* just replace the part, turn the system on, and leave the job site. Ensure you perform an operational test!

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

407. Electrical circuits

1. What circuit *usually* takes up the *smallest* portion of HVAC/R schematics?

2. What effect will *no* line voltage have on a system?

3. Why would you check the line circuit if parts of the unit are already running?

4. What is unique about the control circuit compared to the line and load circuits?

5. What effect does one circuit in a parallel circuit have on the other crcuit if it loses power?

6. How should an HVAC/R technician work complex circuits?

408. Troubleshooting and correcting electrical malfunctions

1. While checking between two points, what does a voltage reading of zero indicate?

2. In general, what will a meter read when checking between two points?

3. When checking DC voltage, how do you connect the terminals to the electrical unit?

4. What is the second step in checking for AC voltage with a multimeter?

5. When checking for AC voltage with a multimeter, what is the next step after you have chosen the test points?

6. What is the *first* step in checking for ohms with a multimeter?

7. What effect can body resistance have on an ohm reading if you touch the ends of the leads with your fingers?

8. When will the megohmmeter *primarily* be used?

9. When connecting a megohmmeter to a motor or compressor, where is the *black* lead connected?

10. When connecting a megohmmeter to a motor or compressor, where is the *red* lead connected?

11. When conducting an amperage draw on a three-phase system, what is caused if one phase reading is different from the other two?

12. When conducting an amperage draw on a three-phase system, what effect will having the jaws of the clamp-on meter encircle two phases?

13. What effect will having two phases inside the jaws of the clamp-on meter when you are troubleshooting a three-phase system?

14. In general troubleshooting, how often will a visual inspection locate the trouble?

15. If your personal preference cannot dictate the meter selection to use to troubleshoot a system, what will?

16. What can loose connections eventually lead to in a circuit?

17. What effect does a loose connection have on voltage in a circuit?

18. What effect does making periodic checks on electrical fittings have?

19. When does a shorted circuit occur?

20. What could it mean if the fuse does *not* blow or the breaker does *not* trip immediately after you reset the breaker?

21. When does an electrical motor become grounded?

22. What steps can be taken to gain troubleshooting experience?

23. Why should you *not* place your leads on any device unless you know what you should be reading on your meter?

24. How should you double check a solenoid coil to ensure it is bad?

25. On a 208-volt service, what does a 10 percent differential from 120V on one phase mean?

26. If you check phase by placing one voltmeter lead on the top of the fuse and the other lead on the bottom of the same fuse, what must you do to the circuit *first*?

Answers to Self-Test Questions

401

1. Acid reacting with the molecules of metals.
2. Some molecules in the acid and metal solution have an extra electron (negative ion), and others are short an electron (positive ion).
3. When we attach conductors and a unit of resistance from the negative terminal to the positive terminal, the electrons that gathered at the negative terminal pass to the positive terminal.
4. It operates on the principle that voltage is produced by heating the junction of two dissimilar metals.
5. Because the metals are dissimilar and respond to heat differently.
6. Because of the way the two different metals react to heat.
7. Relative motion causes the conductors to cut through the magnetic field resulting in voltage.
8. A voltmeter.
9. Because they have so much resistance to electric current.
10. Because of its light weight.
11. For added strength.
12. It is mixed with other metals to form a copper alloy.
13. Larger wire.
14. The resistance goes up.
15. Voltage supplies the force.
16. With a clamp-on meter.
17. Because the current changes its direction of flow.
18. The circuit could become overheated and eventually cause a fire.
19. The material of the conductor and the amount of current flow.
20. The voltage polarity changing at regular intervals.
21. The speed of rotation of the rotor and the number of pairs of poles.
22. AC current flow through the wire.
23. It lessens the effect of the applied voltage.
24. (1) The number of turns of wire in the coil, (2) cross-sectional area of the coil, and (3) material in the center of the coil or the core.
25. The *NEC* book for the formulas.
26. By applying a greater voltage.
27. The capacitor discharges in the original current direction to continue the flow until it discharges.

402

1. As if they are *live*.
2. By using insulating material, such as a shirt or piece of dry rope, as a loop to pull a person from a live circuit.
3. Immediately flush the affected part of your body with water.

4. Open the switch.
5. Remove the fuses and attach a warning sign to the switch.

403

1. It should be the same as the original wiring on the equipment.
2. It helps to standardize wiring procedures and also aids in identifying and tracing wires.
3. By using the AWG number assigned to represent wire sizes.
4. When you need flexibility.
5. It can dissipate the heat faster.

404

1. By using the cutting notch that matches the wire size.
2. 1.25 to 1.5 inches.
3. Longnose or needle nose pliers.
4. The bare wire is exposed and might come in contact with the box or another conductor and cause a ground or short.
5. To the green terminal.
6. The hot goes to the gold terminal and the neutral goes to the silver terminal.
7. Attach a hot wire to one side and the other hot wire to the other side.

405

1. As road maps for the electrical circuit.
2. By a symbol.
3. One piece of wire.
4. Sometimes they are separated on schematics.

406

1. A, B, and C.
2. Current will flow to TB1–12 and on to the K5-X1 normally closed contacts.
3. The neutral ties back to the neutral terminal TB1–6
4. K4–X2.
5. K6–X1.

407

1. The line circuit.
2. It will not run.
3. Because the incoming power may be the incorrect voltage.
4. The control circuit is much larger than the other circuits.
5. The other circuit is not affected.
6. By breaking down these complex circuits into smaller circuits and working through each in a logical manner.

408

1. It means there is no difference between the TWO points you are checking.
2. The meter's display will show the *difference* of voltages between the TWO places you place the TWO leads.
3. Connect the plug [+] terminal of the voltmeter to the positive side of the electrical unit and the minus [–] terminal of the voltmeter to the negative side of the electrical unit.
4. Determine test points based off of the schematic.
5. Determine the proper voltage that should be displayed on the meter.
6. Verify the circuit is dead by ensuring no voltage is present.

7. Body resistance can distort your ohmmeter reading.
8. To indicate the insulation resistance of cables, motor and generator windings, transformer windings, and circuits.
9. Connect the black lead to a bare metal ground.
10. Connect the red lead to a motor terminal.
11. You then know that the system is out of balance and you've found a potential trouble.
12. Their magnetic fields cancel out and you won't get an accurate reading.
13. If you make this mistake in the field you could misdiagnose a trouble.
14. Quite often.
15. Nature of the trouble.
16. Electrical shorts and grounds that may cause fires.
17. Increases the voltage drop in the circuit causing inefficient operation of the devices in the system.
18. Helps to avoid the possibility of short circuits.
19. When an accidental low resistance connection between two conductors of different potential bypasses the load device of an electric circuit.
20. You may not find the trouble in the load device or breaker; it just might have been a weak circuit protection device.
21. When the insulation breaks down and some part of the wiring comes in contact with the frame of the equipment.
22. Spend time with the equipment and with the manuals that explain how to operate the equipment.
23. It indicates that you are guessing.
24. Ohm the coil out.
25. The phase is open and you are getting feedback from equipment connected to the load side of the panel.
26. Disconnect some part of the circuit so the units of resistance will not operate.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (401) What relationship between magnetic field and conductors is required to generate voltage mechanically?
   a. No relationship exists between the two.
   b. Relative motion between to the two.
   c. A direct temperature relationship.
   d. Conductors must be solid copper.

2. (401) Nickel and chromium alloys are used in heater elements because they
   a. have a very low resistance to current.
   b. make it possible to operate the elements at high pressures without melting.
   c. make it possible to operate the elements at high temperatures without melting.
   d. make it possible to operate the elements at low temperatures without melting.

3. (401) What effect does the length of a wire have on the amount of pressure needed to force the electrons to the load device?
   a. The long wire decreases need for voltage.
   b. No pressure will be needed.
   c. More pressure will be needed.
   d. Less pressure is needed.

4. (401) Resistance should *not* be considered a *bad* thing because
   a. even conductors offer resistance to flow.
   b. a circuit reading O.L. will still allow flow.
   c. voltage will always flow, no matter the resistance.
   d. an open circuit will allow flow.

5. (401) *All* forms of opposition to current flow are measured in
   a. amperes.
   b. ohms.
   c. volts.
   d. watts.

6. (401) How is direct current produced?
   a. By a battery or a thermocouple.
   b. Through a rotating magnetic field.
   c. Through relative motion.
   d. By an alternating current generator.

7. (401) The sine wave gets its name because the alternator output voltage at any one point on the wave is the product of the sine of the
   a. product of the sine of the stator angle and the peak voltage.
   b. rotor angle and the frequency.
   c. rotor angle and the zero voltage.
   d. rotor angle and the peak voltage.

8. (401) What can you do to greatly increase the inductance of a coil?
   a. Insert any non-magnetic substance.
   b. Remove the magnetic core.
   c. Add a core of magnetic material.
   d. Add a core of balsa wood.

9. (401) Current lags the voltage in a purely inductive circuit because of the
   a. resistance of the circuit.
   b. opposition by DC voltage.
   c. opposition by impedance.
   d. opposition by inductive reactance.

10. (402) When working with electrical equipment, how should you treat all electrical circuits as being
    a. dead.
    b. live.
    c. safe.
    d. grounded.

11. (402) How can you prevent anyone from *accidentally* closing the breaker to a circuit that is under repair?
    a. Lock the breaker in the ON position so other people know it is on.
    b. Lock the breaker in the OFF position and tell other technicians you plan on tagging it.
    c. De-energize the circuit by closing the switch and post a warning sign outside of the breaker box to let other technicians know you are working there.
    d. Lock the breaker in the OFF position and tag it to indicate that the system is being repaired.

12. (403) If using an aluminum-clad wire in place of a copper wire, how many sizes larger must the wire be to carry the same current safely?
    a. One.
    b. Two.
    c. Three.
    d. Four.

13. (403) The type of insulation for a conductor is *primarily* based on
    a. insulation is the same for all conductors.
    b. where it is going to be used.
    c. the load device.
    d. the line voltage.

14. (403) What, if anything, does the location of a conductor affect?
    a. Nothing, because it is insulated.
    b. The device it is connected to.
    c. Whether it is stranded or not.
    d. Its current-carrying capacity.

15. (404) How is a solderless pigtail splice finished?
    a. When applying the solder to the joint.
    b. By twisting the wire into three wires.
    c. With a wire nut.
    d. By stripping the insulation.

16. (404) When making a terminal loop, what will happen if the loop is *not* placed in a clockwise direction?
    a. It will never connect.
    b. The screw will keep the loop tight.
    c. The screw tends to spread the loop as you tighten it.
    d. It will be looser than if you turn it counterclockwise.

17. (404) How is a stranded wire pushed into a push in connection?
    a. Insert a small screwdriver into the slot.
    b. Insert a large screwdriver into the slot.
    c. Pull the wire through with wire strippers.
    d. Pull the wire through with needle nose pliers.

18. (404) How do you ensure the wire is placed tightly into a push-in connection?
    a. By pulling slightly on it.
    b. By pushing it out of the connector.
    c. By pulling hard with a needle nose plier.
    d. By pulling hard with a wire stripper.

19. (404) When checking voltage rating, what will result if you place two hot wires to the same side of a device?
    a. Proper system operation.
    b. Device will explode.
    c. A short to ground.
    d. A direct short.

20. (404) What could result if a circuit is forced to carry too much current?
    a. Circuit will run properly.
    b. A fire or electrocution.
    c. A more efficient circuit.
    d. Circuit will exceed expectations.

21. (405) What is a common theme amongst schematics?
    a. Different parts of the same component being separated.
    b. Line circuit being the biggest portion of the diagram.
    c. Load circuit being the biggest portion of the diagram.
    d. Control circuit being the smallest portion of the diagram.

22. (406) On the Environmental Control Unit (ECU), what component should come on after the compressor relay is energized?
    a. Evaporator fan.
    b. Condenser fan.
    c. Compressor.
    d. Lockout relay.

23. (406) What should you be doing as you follow each circuit on a schematic?
    a. Guessing the potential solution.
    b. Jumping around the schematic.
    c. Simply moving your finger left to right over the diagram.
    d. Describing in your head what is occurring with each component.

24. (407) What is the key to understanding *complex* circuits?
    a. Breaking down the line circuits into smaller circuits.
    b. Keeping the complex circuits as large circuits and working through each in a logical manner.
    c. Breaking down the complex circuits into smaller circuits and skipping circuits you don't understand.
    d. Breaking down the complex circuits into smaller circuits and working through each in a logical manner.

25. (408) What are you checking for when you troubleshoot a circuit using voltage?
    a. Proper resistance at one point.
    b. The amperage between two points.
    c. The potential difference between three points.
    d. The potential difference between two points.

26. (408) How should you connect a voltage meter when checking AC voltage?
    a. In parallel.
    b. In series.
    c. With one lead connected to the circuit.
    d. In a way that recognizes the polarity.

27. (408) When testing equipment for high voltage, when should you connect your meter?
    a. While the compressor is running.
    b. After selecting the voltage setting.
    c. Before turning on power.
    d. After turning on power.

28. (408) What should you do to the multimeter before checking for ohms?
    a. Turn it off and on.
    b. Insert thermistor attachment.
    c. Remove battery because it creates voltage.
    d. Zero it out by touching the leads together.

29. (408) What does it mean to isolate the part of the circuit you are testing?
    a. Check it with a meter.
    b. Physically remove the entire component.
    c. Remove the components electrical and non-electrical hardware.
    d. Electrically disconnect the part being tested.

30. (408) What tool should you use to test insulating material?
    a. A megohmmeter.
    b. A meter set to volts.
    c. Clamp-on ammeter.
    d. A regular meter set to ohms.

31. (408) When taking current readings using the clamp-on ammeter, you squeeze the trigger assembly to
    a. close the clamping jaws and place the open jaws around one of the circuit leads.
    b. open the clamping jaws and place the open jaws around one of the circuit leads.
    c. close the clamping jaws and place the jaws around two of the circuit leads.
    d. to open the clamping jaws and place the open jaws around two of the circuit leads.

32. (408) What effect does an open circuit have on the load device? The load device will
    a. run intermittently.
    b. run more efficiently.
    c. *not* operate.
    d. operate continuously.

33. (408) What should you do if you are having problems troubleshooting?
    a. Ask for help.
    b. Stress out.
    c. Close out the job and return to the shop.
    d. Stay on job site for hours even if you get nowhere.

34. (408) What is the next step after a part has been replaced?
    a. Close out the job.
    b. Run an operational check.
    c. Disconnect electrical circuit.
    d. Tell your supervisor the job is complete.

Student Notes

Please read the unit menu for unit 2 and continue ➔

Unit 2. Electrical Devices

THIS UNIT WILL cover numerous electrical devices. Our discussion starts with protective and control devices. These devices are important to protecting other electrical components in our HVAC/R systems. They consist of distribution panels, fuses, circuit breakers, and electromagnetic devices.

Next, motors will be covered. Motors are extremely important in HVAC/R systems. They drive compressors, fans and pumps. The motor lesson is very comprehensive and starts off with an introduction to motor concepts and controllers. Afterwards, you will learn how to operate, service and troubleshoot a motor. Considering how important motors are, operating, servicing and troubleshooting motors are extremely vital concepts to learn. Finally, you will read about correcting motor malfunctions, replacing motors and connecting the wires required for a motor to run.

2–1 Protective and Control Devices

As the name says, protective and control devices protect and control our HVAC/R systems. Distribution panels, fuses and circuit breakers, control devices, and electromagnetic devices are covered in this section.

409. Distribution panels, fuses, and circuit breakers

There are many problems that can occur in an electrical circuit. Some of these problems can cause damage to expensive equipment such as motors and compressors. Protective devices are required to preserve valuable and critical HVAC/R equipment. The fact that these devices are protecting equipment from being damaged is the most important concept to retain in this lesson. These devices are not placed in a system to annoy the technician during troubleshooting. They exist to notify the worker that a negative electrical condition has occurred and the electrical system needs to be thoroughly evaluated. The three type of devices discussed in this lesson are distribution panels, fuses and circuit breakers.

Distribution panels

There are many different styles of distribution panels that you will encounter. These panels allow a single point to locate overload protection devices for many individual circuits. There may be more than one distribution panel in a single facility. Each individual circuit should be marked on the panel. The markings should tell you what a circuit goes to and the maximum load designed. Two types of distribution panels that you commonly see are permanent or temporary.

CAUTION: *Never* use a protective device that is too big for the circuit, and *never* bypass the overload device.

Permanent distribution panel

A permanent panel is mounted into a wall or other frame structure in a facility or home. These panels have a power source coming into them that branches off into individual circuits. There may be two or three phases of power available to you to use through common busses. A busbar, bus for short, is a metal strip or bar that conducts electricity with the panel. There should also be a neutral and ground circuit as well. The circuit protection devices attach to the busses. A conductive clip attaches directly to the energized bus and the non-conductive back clips to the frame of the panel. When the protective device is in place, a circuit terminal is exposed to which you can attach the conductor. Torque the terminal screw carefully. It must be tight enough not to cause resistance or let the conductor slip out. Over tightening could cause cracking of the device body.

Temporary distribution panel

A temporary panel can be found at construction sites or at deployed locations. This panel is mounted on a post or similar support structure. The panel you find at your deployment has a stand attached to it. Regardless of the application, a temporary panel must be high enough off of the ground to keep it out of the water. It should be water resistant or sheltered. For this reason, the case may appear a little different or may have a roof and sides constructed around it for safety. The interior of a temporary panel remains essentially the same as a permanent distribution panel.

Safety

When you first open a distribution panel, it may look a little intimidating. It probably looks like a complete mess of wiring and you don't know where the many wires lead. Study the labeling on the front of the panel cover or facility schematics or prints. Another resort may be to try and trace the circuits. In any case, make sure you know on which circuit you are working. Many technicians have been shocked thinking a control or load device is "dead" when it really is not. Use your meters, tools, and other experienced technicians to help you if you have doubts about what you are doing.

Fuses

A fuse contains a metal alloy wire or ribbon that has a low melting point. One effect of current flow is heat. If current flow increases, heat increases proportionally. If the heat generated by the current flow reaches a predetermined temperature, the alloy melts and opens the circuit.The fuse can carry its rated amperage indefinitely but melts or "blows" if its rated current is exceeded.

The most important fuse characteristic is its current-versus-time or "blowing" ability. There are three time ranges, or existence of overloads, that we broadly define below:

1. FAST from 5 microseconds to ½ second.
2. MEDIUM from ½ to 5 seconds.
3. DELAYED from 5 to 25 seconds.

Fuses are connected in series with the load device in the circuit so that all current flows through them. Fuses are rated in both voltage and amperage. When a fuse blows, replace it with another of the same rated voltage and current capacity, including the same current-versus-time characteristic. Let's take a look at some fuse designs.

Fuse design

You will work with plug and cartridge-type fuses. Fuses are designed so that they are not all interchangeable. For instance, there are rejection and non-rejection type fuses. Rejection type fuses will not allow a smaller current or voltage rated fuse to be placed inside the fuse holder.This is a safety requirement so technicians can't install an inadequate fuse and damage equipment or create a safety situation. Let's look at the two designs further.

Plug fuses

Plug fuses of the Edison-base type, shown in figure 2–1, screw into sockets similar to an ordinary light socket. Plug fuses are used in low-capacity branch circuits only. A branch circuit is a circuit that *branches* off from a main circuit. They range in size from 0.5 to 30 amperes (amp) at a maximum of 150V. Plug fuses have a clear glass or mica window directly over the fuse element. This window provides a means for determining visually whether the fuse is good or blown. There are also rejection-base type plug fuses that have porcelain threads. The Edison-base type and Rejection-base type are NOT interchangeable. There are two categories of plug fuses: medium duty (TL or SL) and heavy duty (T or S).

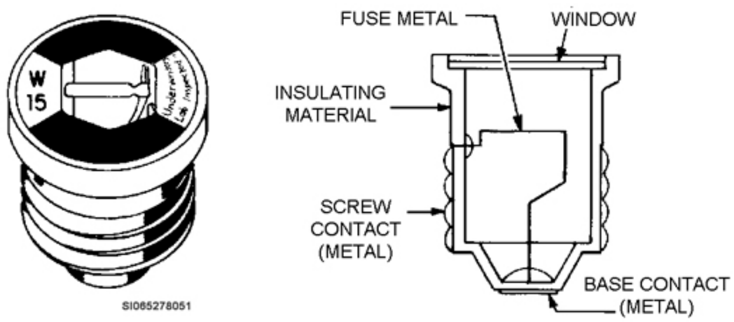


Figure 2–1. Plug fuse, Edison type.

Medium duty

Fuses rated from 0.5 to 15 amps have a hexagonal window, while those rated from 16 to 30 amps have a round window (fig. 2–2). You must screw plug fuses in firmly for good contact, but not tight enough to make them difficult to remove. Use Edison-base fuses only for replacements in existing installations.

Heavy duty

Plug fuse panels to be used in new work must be modified so that you can use the type S fuse. Type S plug fuses, as shown in figure 2–3, require an adapter. The adapter is designed so that once it is screwed into place, it cannot be removed. Type S fuses and adapters come in three capacity ranges:

1. 0.5 to 15 amps.
2. 16 to 20 amps.
3. 21 to 30 amps.

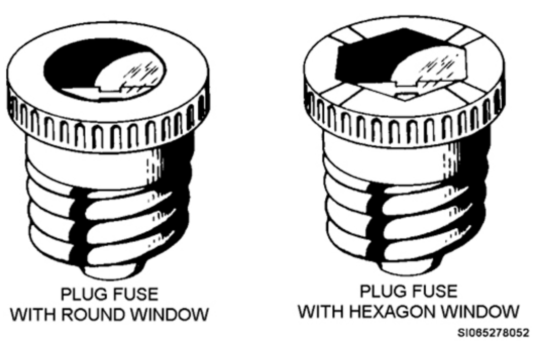


Figure 2–2. Plug fuse.

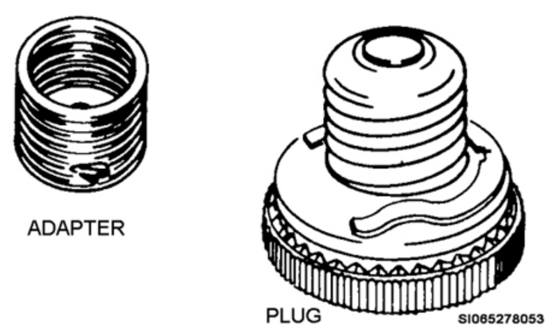


Figure 2–3. S-type plug adapter.

The advantage to this system is that fuses of a larger ampere capacity range cannot fit into an adapter of a lower ampere capacity range. In addition, this prevents objects such as pennies and wire from being inserted into the socket to override the protection.

Cartridge fuses

Cartridge fuses are of two types—ferrule and knife-blade (fig. 2–4). Both types are available with replaceable or nonreplicable fuse links. The miniature ferrule or glass-tube ferrule is commonly used

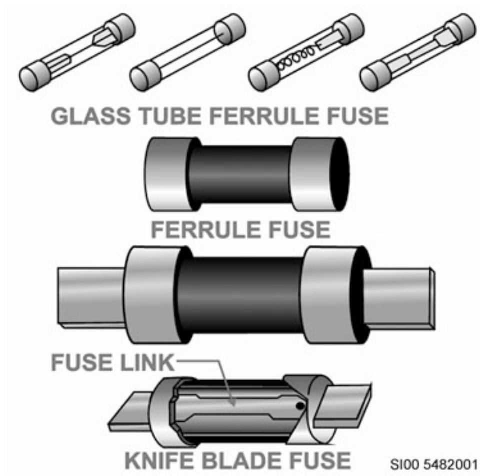


Figure 2–4. Cartridge fuses.

to protect control circuits, alarm systems, and electronic circuitry. Miniature ferrule fuses are rated at a maximum of 250 volts and low amperage. Ferrule-type fuses are available in ampere ratings from 0.5 through 60. Fuse panels that use ferrule-type fuses have specially designed fuse clips in which only ferrule types fit. Fuse diameter and length increase as amperage and voltage increase. Ferrule-type fuses are found in commercial and industrial systems. These fuses are common in supplying power to boilers and chillers and other HVAC/R equipment.

Fuse panels that provide distribution for high-capacity circuits use knife-blade fuses for protection. The fuse clips are especially designed to receive knife-blade fuses *only*. Knife-blade fuses are available in ampere ratings of 61 through 6,000. The maximum voltage rating for the knife-blade fuse is 600 volts.

You must consider two factors when selecting fuses for circuit protection: the total current flow and the voltage of the circuit in which the fuse is to be installed. Since the purpose of the fuse is to protect the circuit, it must be the weakest point in the circuit. Thus, the fuse used must be rated no higher than the lowest rated component to be protected.

Another point to remember is that some equipment, such as an electric motor, requires more current during starting than for normal running. Thus, a fast-time or medium-time fuse rating that gives running protection might blow during the initial period when high starting current is required. Delayed-action fuses are used to handle these situations.

Fuse technical specifications

There are many technical specifications of fuses that must be taken into account when working with them. While troubleshooting you may run into a fuse of the wrong size. Also, you may have to order a replacement so the specifications are crucial. As you read the list below, realize the importance of each element of a fuse. Some of the various technical specifications are as follows:

- Amperage.
- Element.
- Voltage rating.
- Speed (Example: Time delay).
- Interrupt rating.
- Class (Example: CC or K5).
- Body style.
- Rejection/Non-rejection.

Categories of fuses

There are four categories of fuses commonly used in this career field. They are mentioned in the following paragraphs.

Fast-acting

A fast-acting fuse blows as soon as an over current condition occurs. These are not used with devices that have a high starting current because the fuse would blow as soon as the high current condition existed.

Time-delay

A time-delay fuse functions differently than a fast-acting fuse. If there is an overcurrent condition that lasts for a specific period of time the fuse will blow. As opposed to the fast-acting fuse, these fuses can be used with equipment that has a high starting torque. An example would be a compressor with high starting current. You would not want the fuse to blow as soon as the current was high because the compressor would never be allowed to start.

Multipurpose

A multipurpose fuse uses the concepts from the fast-acting and time-delay fuses. This fuse is fast-acting when the current is above 500 percent of the maximum current rating but also has a time-delay feature that opens the circuit if the current stays above the current rating for a specified period of time. So if a motor has high starting amperage the fast-acting capability of the fuse will NOT open the circuit. For example, a fuse is rated at 1 amp and a current condition of 2 amps exist at start-up. The fuse will not blow because 2 amps is not 500 percent of the maximum current rating and the time-delay feature has not opened the circuit. If a current of 6 amps occurs at start up then the fast-acting feature of the fuse will open the circuit to protect it. And finally, if a high current condition continues after start-up then the time delay feature will open the circuit.

Current-limiting

This fuse will blow when the current rating is exceeded and temperature resistors in the fuse exceed their designed temperature. These resistors will close once the temperature falls.

Fuse block

A fuse block is a component that holds the fuse or fuses securely in place. It consists of a plastic block and a metal fuse holder. The block should be secure and not loose. Technicians may bend the fuse holder to make the wrong size fuse fit into the holder. This weakens the metal and is not a safe technique. Also, this can cause the holder to become loose and create a safety issue. Therefore, ensure the fuse holder is intact and has no bent or broken metal. If the fuse holder is loose the fuse could fall out or cause arcing which is very dangerous. Before installing a fuse in a panel, check the condition of the fuse holder or clips. They must be clean and should hold the fuse firmly.

Where are fuses found?

It is useless to know about fuses if you don't know where to find them. Fuses are used in various locations to protect different types of devices. It is vital to know the whereabouts of fuses so you can find them and troubleshoot them.

Line voltage

These fuses are located where the incoming power is located. This location is commonly a distribution panel. This will vary for every system.

Electronic circuits

Fuses are used on printed circuit boards also. These fuses are held in place by fuse clips. You must be careful not to break the fuse clips or holders while removing fuses. It would not be good if you were unable to put a fuse back on a circuit board because you broke the clip or holder. The unit would probably not run because of your carelessness and poor workmanship.

Capacitors

Capacitor fuses are used to isolate a shorted capacitor. A shorted capacitor can create excessive heat and explode or rupture. This problem is resolved with a fuse. If excessive heat occurs the capacitor fuse will blow and isolate the capacitor. Take note that not all capacitors require fuses.

Blown fuses

A blown fuse is a fuse that will no longer pass power. It creates an open in the electrical circuit. The technician should verify with a meter that the fuse is open. If the technician uses the ohm setting on the meter and receives a display of O.L. it means the fuse is bad and needs to be replaced.

A blown fuse indicates that something is wrong and you must correct the cause. You should not just replace the fuse and walk away. You must discover the reason the fuse is blown. There could be a short in the system so do a very thorough visual inspection.

The proper initial selection of fuses can become complicated and might demand the attention of an electrician. If the blown fuse is the right size and type, then replace it with an identical fuse. Be cautious though, even if you replace a blown fuse with an identical one the original fuse could be the wrong size. If it is rated to small then it will continue to blow. If it is rated too high, then there is a risk of damaging the electrical devices.

Circuit breakers

The circuit breaker is another type of protective device. It is used more often than fuses because of the way it reacts to an overloaded circuit (fig. 2–5). In the figure, you can see three different designs: single -, double-, and three-pole circuit breakers. A circuit breaker trips when an overloaded condition exists, but it can be reset to complete the circuit again without having to remove or replace it. Circuit breakers are classed according to their operating principle. The classes are thermal, magnetic, or combination thermal-magnetic. A shortened version of circuit breakers is “breaker”.

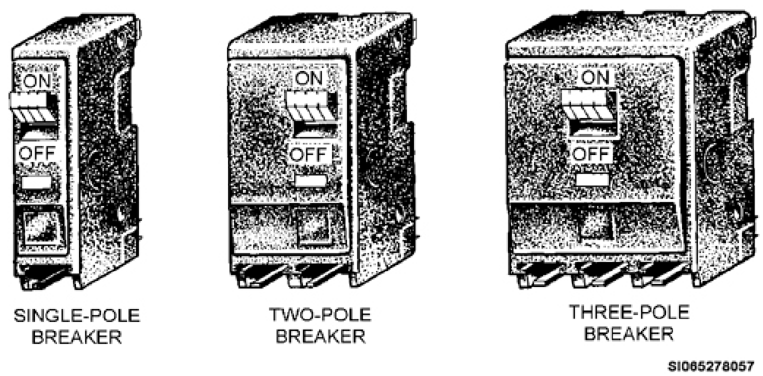


Figure 2–5. Typical circuit breakers.

Thermal-type

A thermal-type circuit breaker has a bimetallic element within the breaker that responds to temperature changes. The bimetallic element is made by fusing together two strips of dissimilar metals. Each strip has a different expansion rate when heated. Current flowing through the breaker generates heat, which increases as the current flow increases. The heat causes the bimetallic element to bend and act against a latch. The breaker mechanism is adjusted so that, when the current flow reaches a set level, the element bends enough to trip the latch. This action opens a set of contacts to break the circuit (fig. 2–6). The thermal-type circuit breaker is commonly called a time lag breaker because the breaker does not open immediately when an overload occurs. The bimetallic element requires a short time (the length of time depends on the size of the overload) to respond to the heat generated by the overload current.

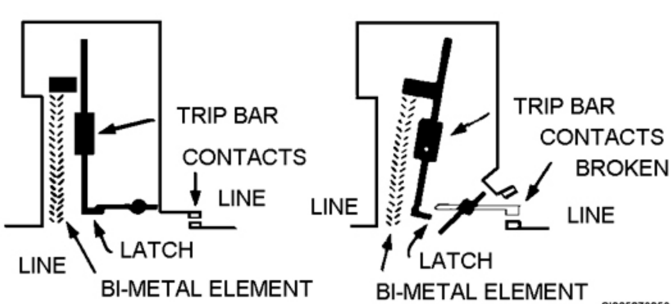


Figure 2–6. Thermal circuit breaker.

Magnetic-type

A magnetic-type circuit breaker responds instantaneously when an excess of current flows through the breaker. The instant response is an advantage over the thermal type circuit breaker. A small electromagnet actuates the breaker mechanism. Whenever a predetermined amount of current flows through the electromagnet, enough magnetic flux is created to attract a small armature. As the armature moves, the breaker mechanism trips and opens the circuit (fig. 2–7).

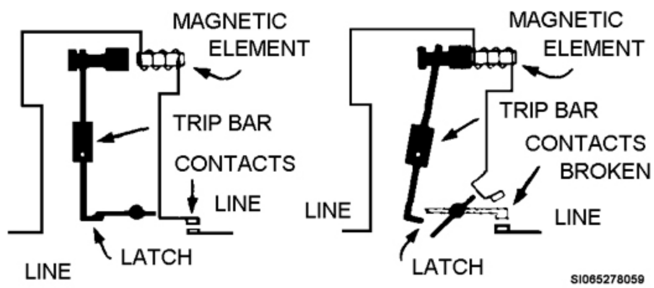


Figure 2–7. Magnetic-trip circuit breaker.

Thermal-magnetic type

The thermal-magnetic circuit breaker, as the name implies, combines the features of both the thermal and the magnetic types (fig. 2–8). Of the three, the thermal-magnetic circuit breaker is preferred for general use. A small overload actuates the bimetallic strip to open the circuit on a time delay, while a large overload or short circuit actuates the magnetic strip to open the circuit instantaneously. Circuit breakers are rated in amperes and volts the same as fuses; you select them on the same basis. Circuit breakers are sealed units; never attempt to adjust their ampere capacity or to repair them.

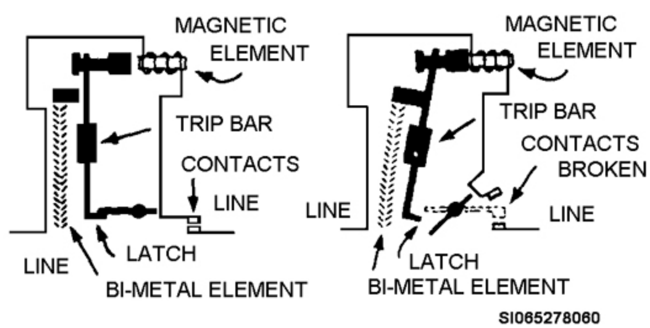


Figure 2–8. Thermal magnetic circuit breaker.

Ground fault circuit interrupter

Circuit breakers that are to be used in circuits that may pose an added hazard to you are made with an extra safety feature. This breaker is called a ground fault circuit interrupter (GFCI). It is a thermal-magnetic breaker with an additional internal circuit which detects a current leak from the hot wire to ground and opens the breaker if that current reaches a set amount, thereby providing a time delay. This leakage cannot be more than 5 (±1) milliamperes (thousandths of an ampere) to ground. Most of these breakers have a test button that you can use to check the GFCI to see if it will trip when there is a fault.

You find the circuit hot wire connected to the GFCI breaker the same as you do on a standard breaker. The circuit neutral is connected to another terminal on the GFCI instead of to the neutral bar in the panel. The GFCI comes with an attached white neutral wire that you will find connected to the neutral bar. Refer circuit breakers to the electrical shop when you know one is inoperative. Some circuit breakers are attached to our HVAC/R equipment; these breakers can be worked on by the technician.

Circuit breaker technical specifications

There are many technical specifications of circuit breakers that must be taken into account when working with them. While troubleshooting you may run into a circuit breaker of the wrong size. Also, you may have to order one so knowing the specifications are crucial. Below are various technical specifications:

- AC/DC voltage rating.
- Type (example: high interrupting capacity).
- Amps.
- Length, width and depth.
- Maximum wire size.
- Minimum wires size.
- Number of poles.
- Designated purpose.
- Type of terminal connection.

As you can see from the list above there are many specifications that apply to breakers. Since a breaker is a protective device it is absolutely critical the proper one is used for the application. You will probably not be required to initially select a breaker but you will be working with them so you should know as much as possible about them.

Where are circuit breakers found?

Circuit breakers can be found on equipment or virtually anywhere in a facility. On the inside of the breaker panel door, there is a place for descriptions of each piece of equipment and its designated circuit breaker.

The action of turning a breaker ON or OFF is often called “flipping the breaker”. If a unit is OFF and someone tells you to “flip the breaker”, they are asking you to turn it on. If a unit is ON and they tell you to “flip the breaker”, they are asking you to turn it OFF. Another term that is used is checking to see if the unit is “dead”. This means, “is there voltage present?” After a breaker is flipped OFF, someone may tell you to check to see if the circuit is “dead”. Yet another term that is used is “kill it”. This simply means to turn the breaker to the OFF position. If you are told to “kill it”, then you need to turn the breaker OFF.

CAUTION: When working on equipment, ALWAYS ensure you turn off the *correct* breaker. Even if you are 100 percent sure you “flipped” the correct breaker, verify with a meter that voltage is *not* present.

The safety ramifications of not turning off the correct breaker and verifying the circuit has no power could mean the death of you or another Air Force team member. Do not overlook the importance of this. Consider that each Air Force member has family and friends that care for them. It would be an absolute shame if they got hurt or passed away because of your lazy mistake. It is very easy to intend to turn off the breaker but actually turn off the wrong breaker. This mistake would be found if you verify with your meter that the circuit is indeed dead.

410. Control devices

In this lesson switches and timers are covered. A switch is a device that passes power to other parts of the circuit and a timer will dictate the time that electricity is passed to the other parts of the system. A few types of switches will be covered and timers and their applications will also be discussed.

Switches

We can describe a switch as a device used in an electrical circuit for making, breaking, or changing connections under conditions for which the switch is rated. Switches are rated in amperes and volts.

The rating refers to the maximum voltage and current of the circuit in which the switch is to be used. Because it is placed in series with what it controls, all the circuit current passes through the switch. Because it opens the circuit, the applied voltage appears across the switch in the open circuit position. Open and close switch contacts to minimize arcing; switches normally use a snap action. We cover the types of switches most commonly used in the next few paragraphs.

Toggle switches

Toggle switches are designated by the number of poles, throws, and positions they have. The number of poles is equal to the number of circuits that can be completed through the switch at any one time. (Example: Single pole can complete one circuit, double pole can complete two circuits, and so on.) The number of positions a switch has is the number of places at which the operating device (toggle, plunger, etc.) comes to rest and, at the same time, opens or closes a circuit. The number of throws signifies the number of times you can move the toggle or plunger of the switch in one direction. (Example: A single-throw switch has two positions but makes only one movement; a double throw switch has three positions and can be moved in one of two directions.) See figure 2–9 for a view of toggle-type switches.

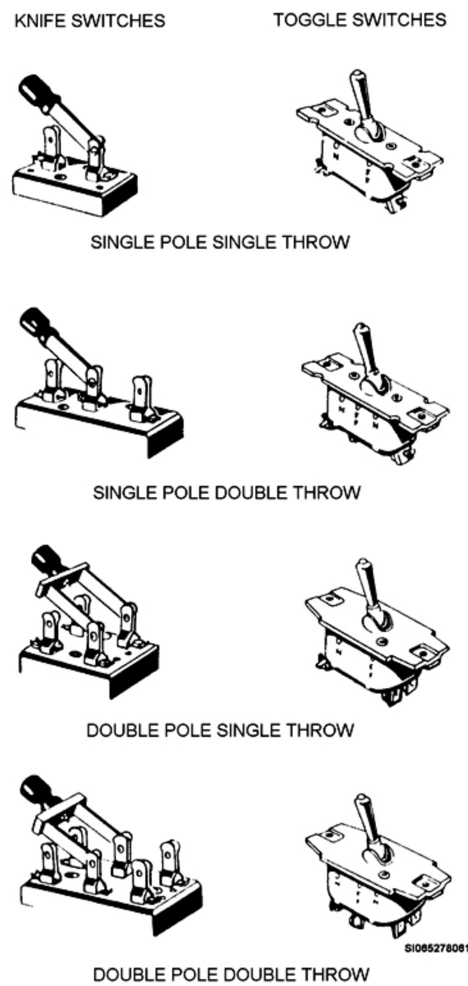


Figure 2–9. Toggle switches.

Push-button switches

Push-button switches have one or more stationary contacts and one or more movable contacts. The movable contacts are attached to the push-button by an insulator. This switch is usually spring loaded and is of the momentary contact type. Usually, these switches have two push-buttons to operate the movable contact, but some switches have only one.

When push-button switches are designed with two push buttons, one is used to put the switch in the ON position, and the other to put it in the OFF position. Both push buttons are insulated from the movable contact to avoid injury to you from electrical shock. Push-button switches are used to operate electric motors, valves, and other similar equipment.

Snap-action switches

Snap-action switches vary in their designs. Figure 2–10 shows two different snap-action switches. The first one shown on the left of the figure has a permanent magnet installed. The permanent magnet helps keep the contacts firmly closed. The other snap-action switch shown on the right in figure 2–10 has an over-center spring arrangement that causes the movement of the actuating lever to engage the spring and causes the switch to move with snap action. The contacts of both must open or close quickly to avoid excessive arcing across the points. Arcing burns the contacting surfaces and can eventually cause switch failure.

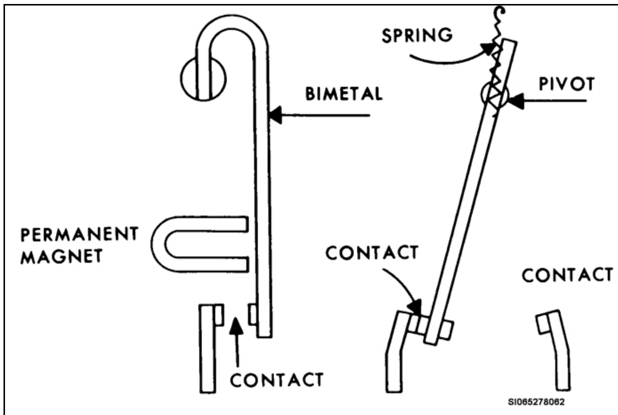


Figure 2–10. Snap-action switches.

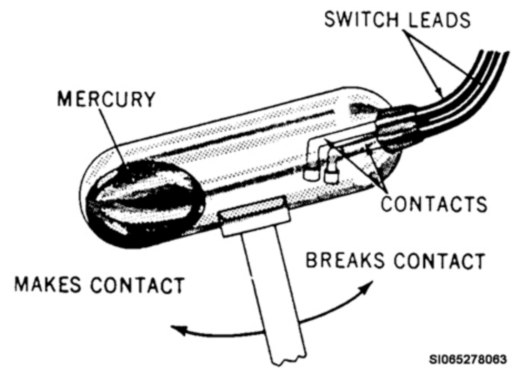


Figure 2–11. Mercury switch.

Mercury switches

A mercury switch is one that has the electrical contacts and a small amount of mercury in a hermetically sealed short glass tube, such as that shown in figure 2–11. Tilting the switch causes the mercury inside the tube to cover or uncover the contacts. The contacts are covered to complete the circuit through the mercury.

Microswitches

Microswitches are small switches with very small movement of the tripping device (1/16 inch or less), hence, the name “micro,” which means “small.” To see how these switches operate, notice the normally closed switch shown in figure 2–12. When the plunger is pushed in, the spring is pushed down. The movable contact, which is attached to the spring, is separated from the fixed contact. The normally closed (NC) circuit opens.

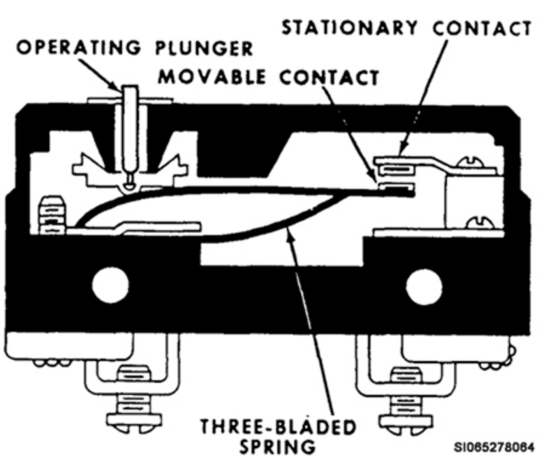


Figure 2–12. Microswitch.

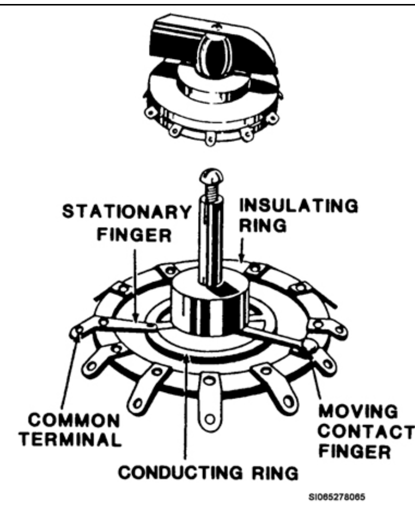


Figure 2–13. Rotary switch.

Rotary switch

The rotary selector switch takes the place of several switches. When you turn the knob of a rotary switch, the switch opens one circuit and closes another. Some rotary switches may open and close a number of circuits. The selector switch, shown in figure 2–13, is a typical example of the switch.

Switch selections

You must consider several factors when selecting a switch to control a circuit. Voltage, current, circuit operation, and time involved are all factors in the selection of switches.As you have seen, there are several types of switches from which you can choose. It will be up to you, or engineers, to decide what type of switch to use when original replacement switches can no longer be ordered. Although the type of switch may be changed, the switch specifications cannot, for they have already been determined by the circuit in which the switch is to be used.

Timers

The two major types of timers you come across are electronic and mechanical. We discuss the major differences in the following paragraphs. Timers are used to create a controlled switching action (delay) to turn a control circuit on or off, depending on the effect needed. Timing is sometimes adjustable or fixed. A fixed timer is a programmed response according to the manufacturer and cannot be adjusted. These timers are specific in time of action and contact construction. Adjustable timers are more generic so we discuss them a little more in depth.

Principle of operation

Timers consist of two sections, timing mechanism and switch. For our purposes, these are separate circuits. The timing mechanism controls the switches.Timing is started when power is applied. Time elapses until the first programmed time is complete. The first time completion triggers a switch to change positions. If the switch started normally open (NO), it is now closed. If the switch was NC, it is now open. This action effectively controls another circuit to turn it on or off after a period of time.

Electronic timers

Electronic timers are very versatile and reliable. The solid-state circuitry is usually enclosed in a water-resistant case. The timing mechanism can be a low voltage (5 to 12 volts direct current (VDC) or VAC) or higher voltage (110 VAC or 220 VAC). The timer may have a small adjustment knob or screw on it that you can adjust. The switches on electronic timers are usually solid-state. Timers of this type cannot tolerate large current draws through them. Look at the current specifications on the manufacturer’s data sheet for the timer before using them on a control circuit. You might use a control relay after the timer to make your system work.

Mechanical timers

Mechanical timers are resistant to physical shock and outside electrical influences. This makes them reliable and practical. They typically use AC voltage for the timing mechanism and the contacts can normally carry more current that an electronic timer. Mechanical timers use a clock motor and cams or pins to form an “on-off” program. The cams may be able to turn on their shaft or you may have to screw out the pins and place them in other areas.

411. Electromagnetic devices

All transformers, relays, solenoids and contactors rely on the same magnetic principles. An energized coil of wire provides a magnetic field. Transformers are electrical components with no moving parts but are capable of performing a major electrical function. It is through the use of transformers that we are able to provide a circuit with specified amounts of voltage that is different from the incoming or supplied amounts. Relays and contactors take control voltage and change the position of contacts to pass power to load devices. Most of the solenoids you encounter as a HVAC/R mechanic are electrical devices that usually consist of a movable mechanical portion that opens and closes valves. Some special applications you might see are solenoids used to open and close switches. This lesson discusses various applications for the use of each of these devices.

Transformers

Transformers change voltage; they either step-up or step-down voltage. Examples are 10,000-volt step-up transformers used for igniting an oil-fired furnace and 24-volt step-down transformers used for control voltage with most residential thermostats. Regardless of the type, every transformer consists of three basic parts: a primary coil, a secondary coil, and an iron core (fig, 2–14).

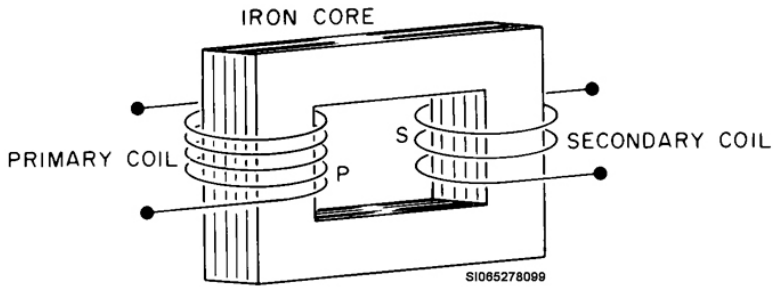


Figure 2–14. Transformer components.

Figure 2–15 illustrates how transformers work. The primary coil (A) must always be connected to the power source. The secondary coil (B) is always connected to the circuit requiring the changed voltage.

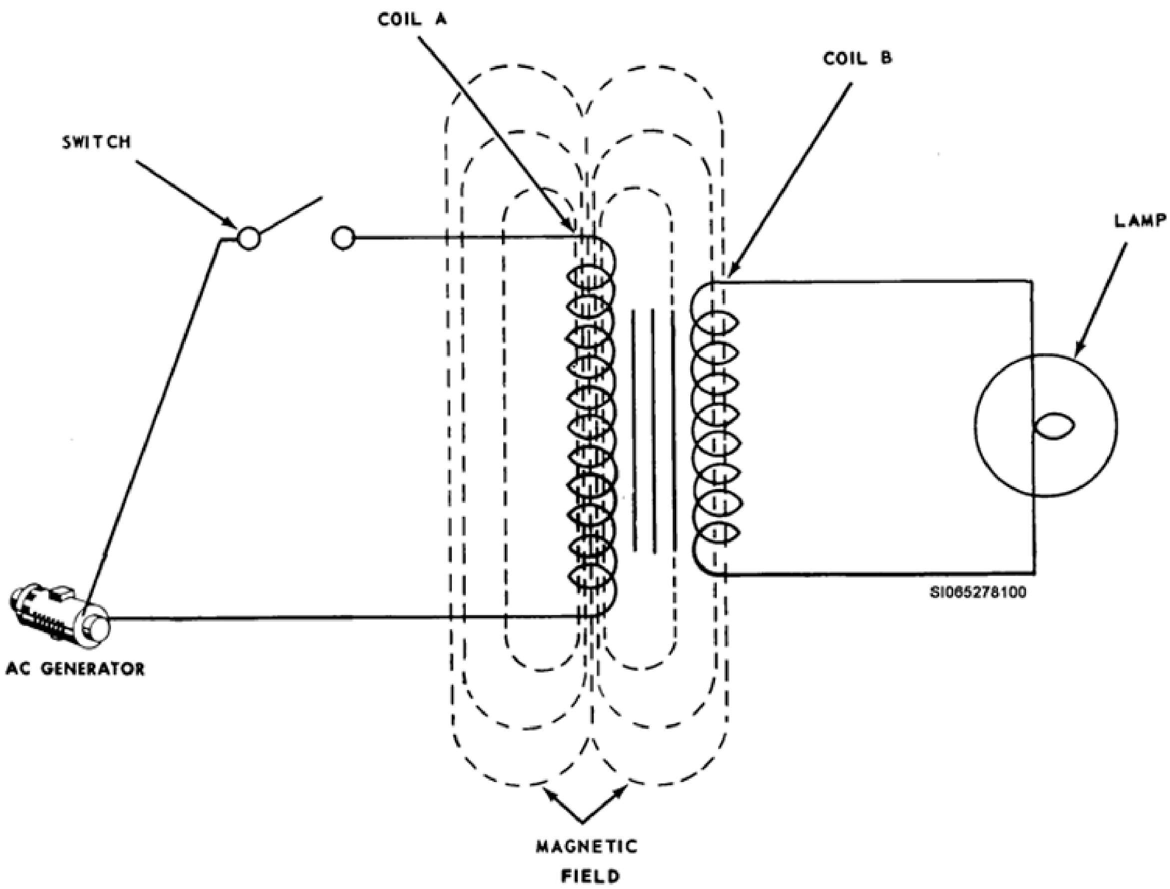


Figure 2–15. Transformer action.

Transformer operational theory

When AC flows through a coil, an alternating magnetic field is generated around the coil. This alternating magnetic field expands outward from the center of the coil and collapses into the coil as the AC flows through the coil. Since the AC magnetic field must cut through the turns of the coil, a voltage is induced within the coil itself (self-induction) which opposes a change to current flow. If the alternating magnetic field generated by one coil cuts through the turns of a second coil, a voltage is induced in this second coil (*mutual induction*). The voltage generated in the second coil is the EMF of mutual induction. In transformer action, a voltage transfers from one coil to another by a varying magnetic field. This transfer of a magnetic field from one coil to another we call *magnetic induction.*

Transformer construction

A simple transformer has two coils placed close together and electrically insulated from each other. The coil hooked to the power supply is the primary coil. It generates a magnetic field that cuts through the turns of the other coil, called the *secondary* coil. The secondary side of the transformer connects to the load. The ratio of turns or loops in the primary and secondary coils determines if the transformer output voltage is "stepped up" or "stepped down." You see in figure 2–16 that a transformer having fewer turns in the secondary steps down voltage and a higher number of turns in the secondary steps up voltage.

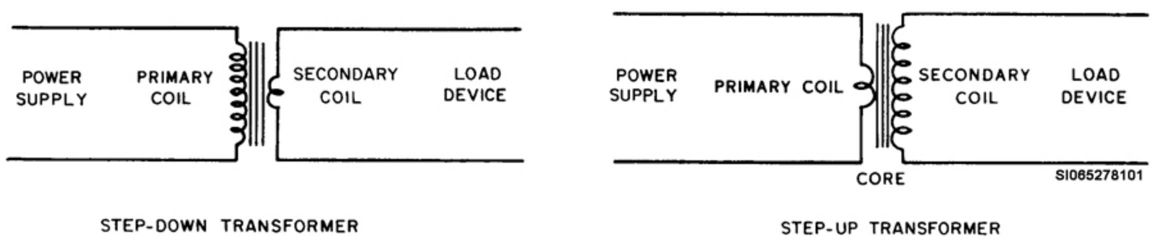


Figure 2–16. Transformer turns.

Because the primary and secondary coils are not very efficient by themselves, you must have some part that positions the coils in place and provides a path for magnetic flux lines. A transformer has a laminated silicon steel core to provide the path for magnetic lines of flux and positioning of the coils. Iron is usually the metal of choice. Iron has little resistance to magnetic lines and allows nearly all of the magnetic field of the primary to flow through the iron core and cut the secondary. The iron core increases the efficiency of the transformer to 98 or 99 percent. The two types of transformers that are common in the HVAC/R career field are the low-voltage control transformers and the high-voltage ignition transformers.

There are many technical specifications of transformers that you must take into account when working with them. While troubleshooting, you may run into a transformer of the wrong size. Also, you may have to order one so knowing the specifications are crucial. Some of the technical specifications are as follows:

- Volt-amp rating (VA)
- Input voltage
- Output voltage
- Phase (single- or three-phase)
- Height, depth and width.
- Hertz.
- Mounting setup.

Low-voltage control transformers

Low-voltage control transformers step-down voltage to approximately 24 volts. The output of this type transformer produces a power source for low-voltage control circuits (under 50 VAC). In figure 2–17, there is a low-voltage control transformer requiring 120 VAC and 60 Hz. To install, you connect the black and white primary leads to the power supply, and the blue and yellow leads to the secondary side for 24 VAC. See figure 2–17.

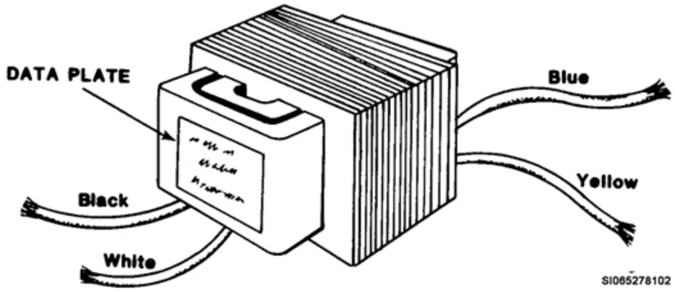


Figure 2–17. Low voltage control transformer.

High-voltage ignition transformers

High-voltage ignition transformers step up voltage to about 10,000 volts. The output of this type transformer ignites fuel by producing an electrical arc. You see in figure 2–18 a transformer that is used on oil burners.

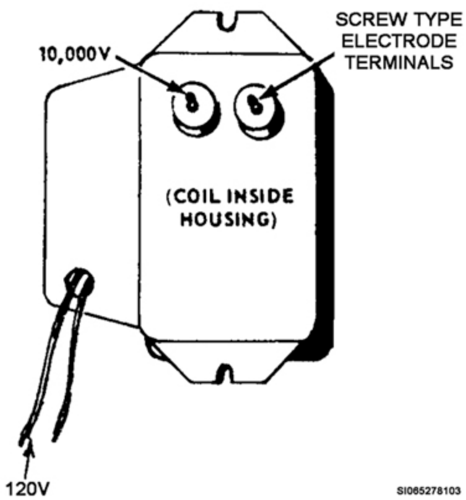


Figure 2–18. High voltage ignition transformer.

Bad transformers

There are a few ways to check a transformer's performance. First, ensure the transformer is the proper size for the unit. Then ensure the transformer is wired properly. Next, verify there is proper voltage supplied to the transformer. If the transformer is 120 volts, then it needs to get that voltage. After you verify the incoming voltage, determine if voltage is leaving the secondary side of the transformer. If voltage is leaving the secondary side, then the transformer is good. If it is not, then the transformer is bad. To check if the primary or secondary side of the transformer is bad, ohm out each side.

Let's use an actual transformer and the information on its data sticker as an example. There are wiring diagrams or schematics available for transformers, but in this example, we will just be using the information on the transformer to troubleshoot. In this example, we will assume an incoming voltage of 120 volts. Also, we will assume that required output voltage is 24 volts.

- Look at the data to see if the voltages fall in the range of our requirements. The primary side can be wired for 120 volts and the secondary side is designed to produce 24 volts.
- Check to see if it is wired properly. The black wire on the primary side should be connected to power and the white wire to a common.

- Ensure incoming voltage is correct/exist. Set the meter to check voltage and place meter leads on the black and white wires. The meter should read 120 volts. If it doesn't then STOP! This means you don't have voltage going to the transformer, so you must find out why.
- Check the secondary side if supple voltage is present at the transformer. Place meter leads on yellow and blue wires. Twenty-four volts means the transformer is good. If the meter reads zero, then you have just diagnosed a bad transformer.
- Ohm out the primary black and white wires and the secondary blue and yellow to be thorough. The meter will read "O.L." on the side of the transformer that is bad.

Remember that two parts of the transformer are two separate coils. Each of these coils could go bad. It is important to determine which side is bad because if you replace the transformer and the new transformer goes bad quickly, you may have another electrical issue that is causing the transformer to fail.

Relays

We use a relay to control motors or other items. Quite often you need to control an operation from a point other than its actual location. System design pattern, space limitations, toxic or hazardous locations, or many other conditions may cause this situation. Control of motors, fans, or pumps located in remote areas, fuel valves located in toxic atmospheres, or refrigeration system valves located in enclosed areas are examples of this situation.

For remote control, use one of the most common types of electromagnetic devices, a relay. A relay is nothing more than a switching device. It uses either a solid-state electromagnet or a solenoid in its operation. We use these relays to open and close the electrical contacts. A relay is controlled manually or automatically.

Most of the common relays have an insulated wire wrapped around an iron core (fig. 2–19). When current passes through the relay coil, a magnetic field builds up around the coil to make the fixed iron core an electromagnetic. The switch end of the relay is a piece of soft iron attached to some non-conducting material. This is hinged at one end of the relay frame and extends over the top of the relay coil. The instant that current flows through the relay coil, the iron core pulls down on the free end of the armature, while the other end swivels on its hinge. At the free end of the armature, you find one or more contact points which are made of copper, silver, or platinum.

The idea behind the relay is to create a switch by connecting one part of a circuit (or circuits) to these swinging contact points, then continue the circuit from one or more stationary contact points located somewhere in the downward path of the moving (armature) points. When these sets of contact points come into contact with each other, the once-open circuit becomes a closed circuit. The relay remains energized until someone or something shuts off the current flowing to the coil.

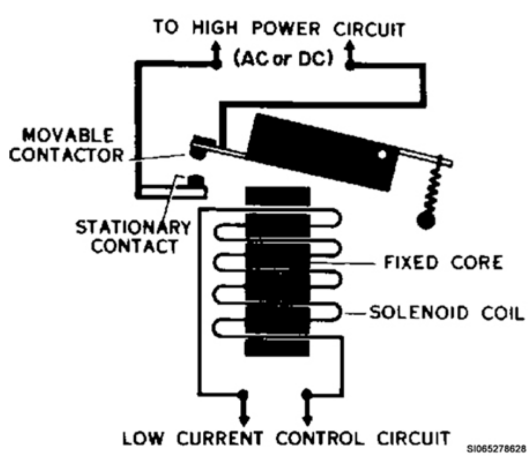


Figure 2–19. Common relay.

As we stated earlier, a relay is an electromagnetic switch that can be made to control many other relays. In electronic controls, you can use a master relay to make other relays automatically open or close their respective circuits when a certain event takes place.

Look at figure 2–20 for an example of a relay. Only one side of the coil is shown for simplicity. There are terminals 3, 6, and 9. For this relay, power enters on terminal 9 and travels to the back of terminal 3. Voltage “sits” here until the coil is energized. Once the coil is energized, the position of the contacts change and voltage passes to terminal 6 and travels to the rest of the circuit.

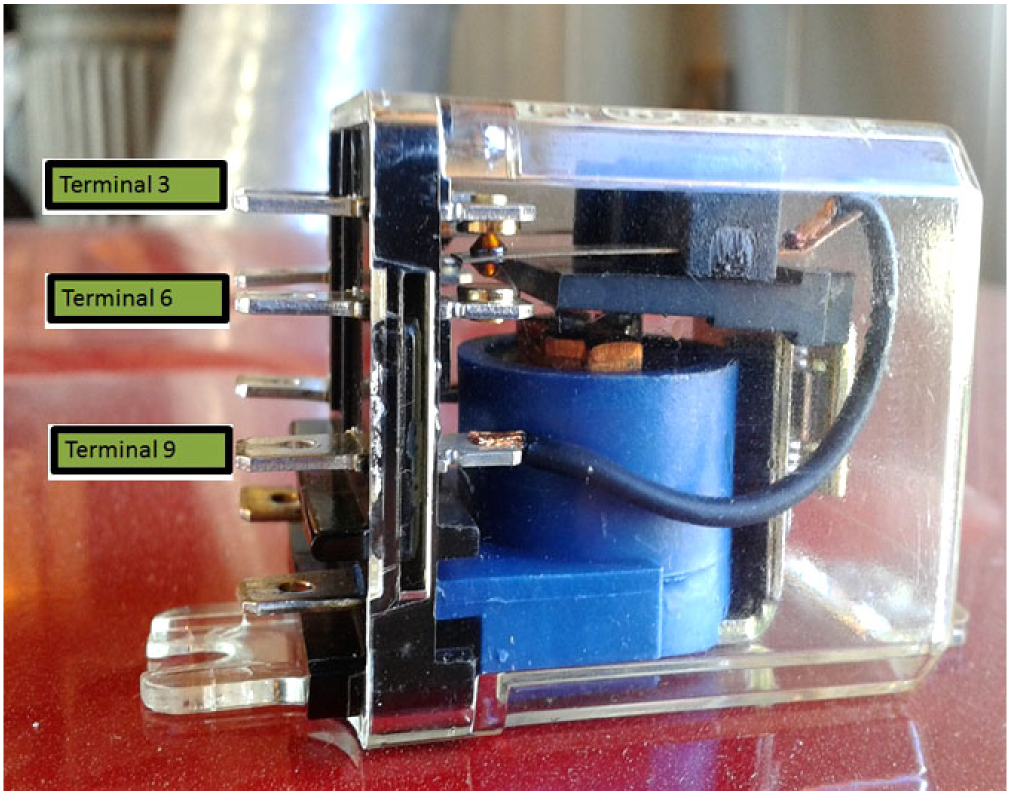


Figure 2–20. Cube relay.

Figure 2–21 gives a close-up shot of the contacts.

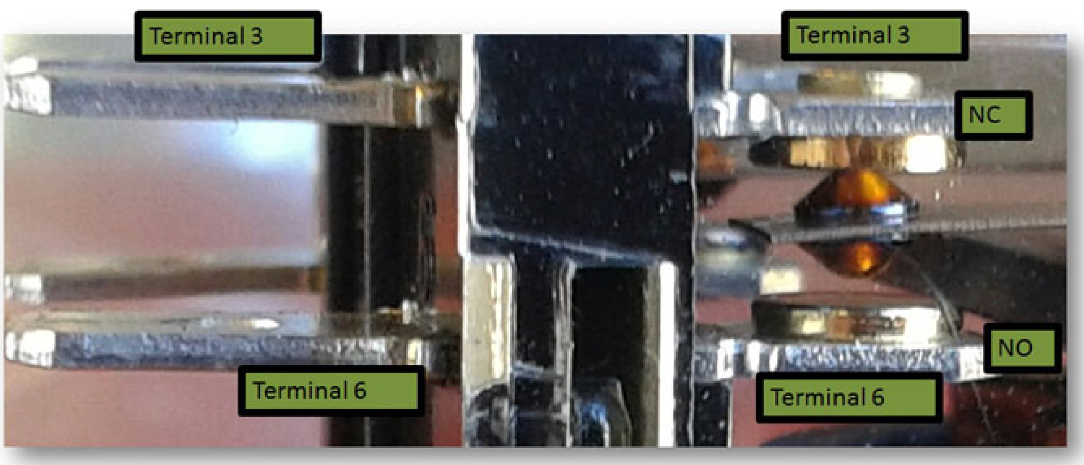


Figure 2–21. Relay contacts.

Troubleshooting relays

Figure 2–22 shows the bottom of the relay. Notice there the numbers 1 - 9. Now, notice the bottom terminals are not labeled. These terminals connect to the coil. If you suspect the coil is bad, isolate the relay from the system, set the meter to ohms, and place the leads on each coil terminal. If it is good, it should be close to its designed ohms, but if it is bad, it will read O.L. This tells you the coil is open and needs to be replaced.

Figure 2–22. Contact terminals.

"Brown" relay

Let's look at a commonly used electrical relay (fig. 2–23). It is often referred to as a "brown" relay. This relay uses to 24 volts to energize its coil. The rest of the coil passes 120 volts from one part of the system to another. This is a classic example of "using low voltage to control a higher voltage".

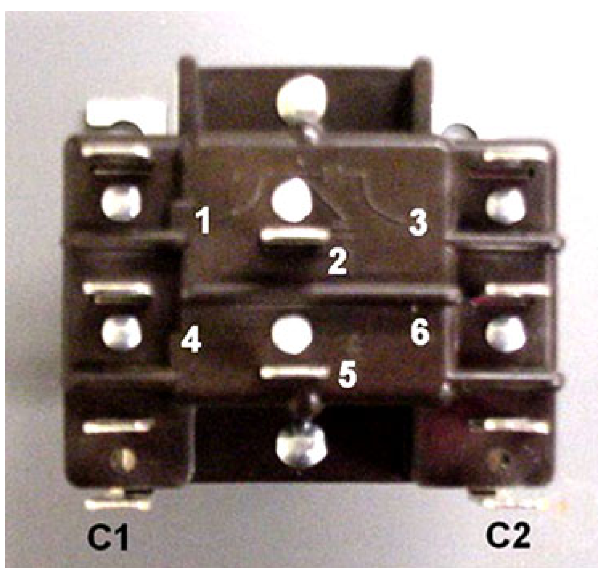


Figure 2–23. Brown relay.

Coil

The coil is behind the contacts. Terminals C1 and C2 are connected to the coil and are used to energize/de-energize the coil and to check whether the coil is good or bad.The C terminals are where the 24 volts AC enters. It doesn't matter at which terminal the power enters, it can be C1 or C2. If power comes in at C1, then the C2 will be the neutral.

Contacts

The brown relay has terminals 1 through 6 which are points for checking whether the contacts are closed or not. As the contacts change positions from opened to closed, power is sent to separate devices. For example, when terminal 4 and 6 are closed, it may pass power to a contactor; however, when 4 and 5 are closed, power is passed to a circuit board or other device. It all depends on the systems operation and design.

Making the connection between coil and contacts

In normal operation, the only way the contacts change position is by the coil energizing or de-energizing. Once the coil has 24 volts applied the contacts change position.

NOTE: Do *not* assume that when the coil energizes the contacts *close.* This is a common mistake. Below is the proper statement:

"When a coil energizes, it changes the position of its corresponding contacts".

This means if the contacts were OPEN, they will now CLOSE. If they were CLOSED, then they will now OPEN.

Below are the NORMAL positions of the contacts. Normal means their position with NO POWER applied to the coil. In other words, when there is **NOT** 24 volts applied to C1 or C2.

- Term 1 and 2 are NC.
- Term 1 and 3 are NO.
- Term 4 and 5 are NC.
- Term 4 and 6 are NO.

Once power is applied to C1, all of the contacts will change positions and will be as follows:

- Term 1 and 2 are Open.
- Term 1 and 3 are Closed.
- Term 4 and 5 are Open.
- Term 4 and 6 are Closed.

Let's troubleshoot. You know you are supposed to have 120 volts leaving terminal 3, so you check terminal 3 to neutral (or ground). You read 0 volts. What does this display mean? Since there is 0 volts on the neutral (ground) and the meter reads difference in potential, there must be 0 volts at terminal 3.

0 volts (terminal 3) – 0 volts (neutral) = A display of 0 volts

There is supposed to be 120 volts on terminal 3, but there isn't. This means contacts 1 and 3 are open when they are supposed to be closed. Ask yourself, what changes the positions of the contacts? The coil! Check the voltage going to the coil by placing the meter leads on C1 and C2. A meter reading of 24 volts means there is voltage being applied. A meter reading of 0 volts means the coil is not getting voltage. If the coil is getting 24 volts, then the next step is to ohm the coil out. An ohm reading of resistance (or ohms) generally means the coil is good. If the meter reads O.L. then the coil is bad.

Relay replacement

There are too many relays to discuss specific replacement. Let's jump into it! The steps listed below are general:

- Step1 – Turn off the power to the system and then verify the system is dead.
- Step 2 – Label the wires you are removing to match the terminal you took them from. If you take a wire off of terminal X, place a marker on the wire that shows where you took it from. (This is important because you may not be the technician who installs the new component.)
- Step 3 – Remove the bad relay and replace with the proper new one.
- Step 4 – Connect all wires and ensure the component is secure and will not move around.
- Step 5 – Turn the system on and ensure it operates correctly.

Solenoids

Instead of electromagnets, heavier duty relays use a solenoid in their operation. The one main construction difference is that the solenoid moves an internal iron core instead of an attracting armature to close a set of contact points. In figure 2–24, you see two parts of a circuit attached to two fixed (stationary) contact points mounted in line with each other but separated by airspace. When current passes through the coil, the magnetic field developed around the coil pulls the movable iron core down into the coil. When the core comes to rest on the fixed contact points, the core's metal T-head forms a bridge to complete the main circuit. Because of its heavy-duty construction, the solenoid relay can handle much higher main-circuit currents than a common relay.

Notice that the circuit that controls the magnetic field (feeds the coil) is separated from the circuit that controls the electrical load (figs. 2–24 and 2–25). Normally the load circuit is made up of a larger conductor and is shorter in length than the control circuit.

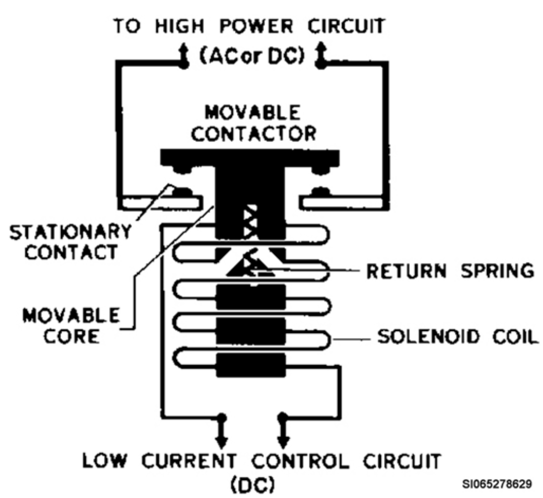


Figure 2–24. Solenoid open.

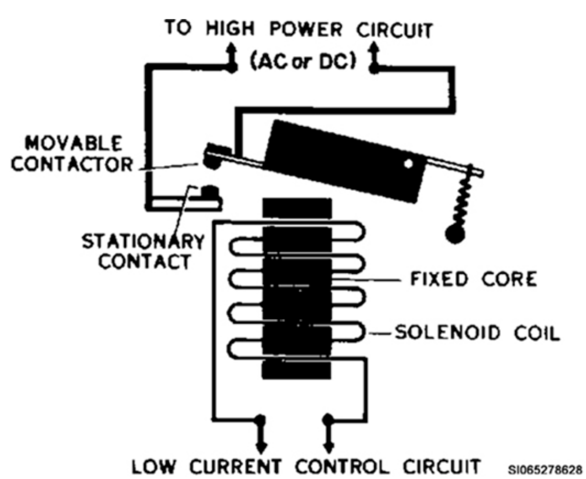


Figure 2–25. Solenoid.

Relays are represented on drawings in various ways. One problem that sometimes arises in circuit tracing and identification of components is that the operating coil for a relay is separated from its contacts on the drawing. In some cases, the operating coil may control several sets of contacts. Some sets of contacts may be closed when the coil is energized, while other sets of contacts may be opened.

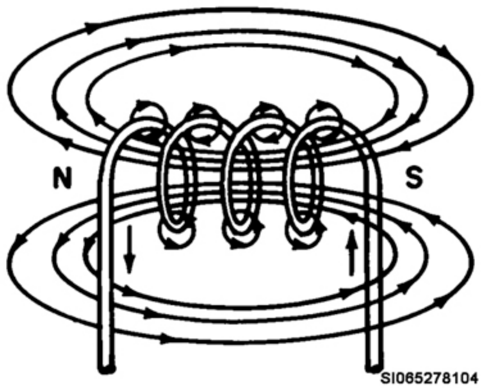


Figure 2–26. Magnetic field produced by a coil.

Solenoid valves

A solenoid is a coil of wire that acts like a bar magnet when current is flowing through it (fig. 2–26). You can use this magnetism to do mechanical operations such as opening and closing valves and actuating switches (relays and motor starters).

Figure 2–27 illustrates the basic operating principle of solenoids used in a *solenoid valve.* A solenoid valve joins two units: an assembly of the solenoid and plunger and a valve that opens or closes by the movement of a magnetic plunger (fig. 2–27). Looking at figure 2–28, view A, you can see two lines coming from the right side of the image; these represent wires. There is a switch on the bottom wire that is closed. This means current is being sent to the coil to energize it.

You can see that, when the coil energizes, the plunger moves off the valve seat into the solenoid and opens the valve. The valve stays open as long as the circuit remains completed and the current flow energizes the coil. In figure 2–28, view B, when the circuit opens, the solenoid de-energizes and the valve returns automatically to the seat and closes the valve. These solenoid valves control the flow of liquids and gases.

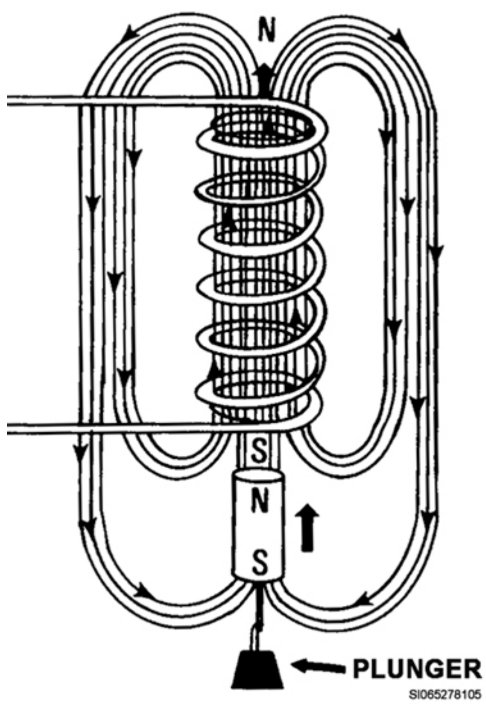


Figure 2–27. Basic solenoid operation principles.

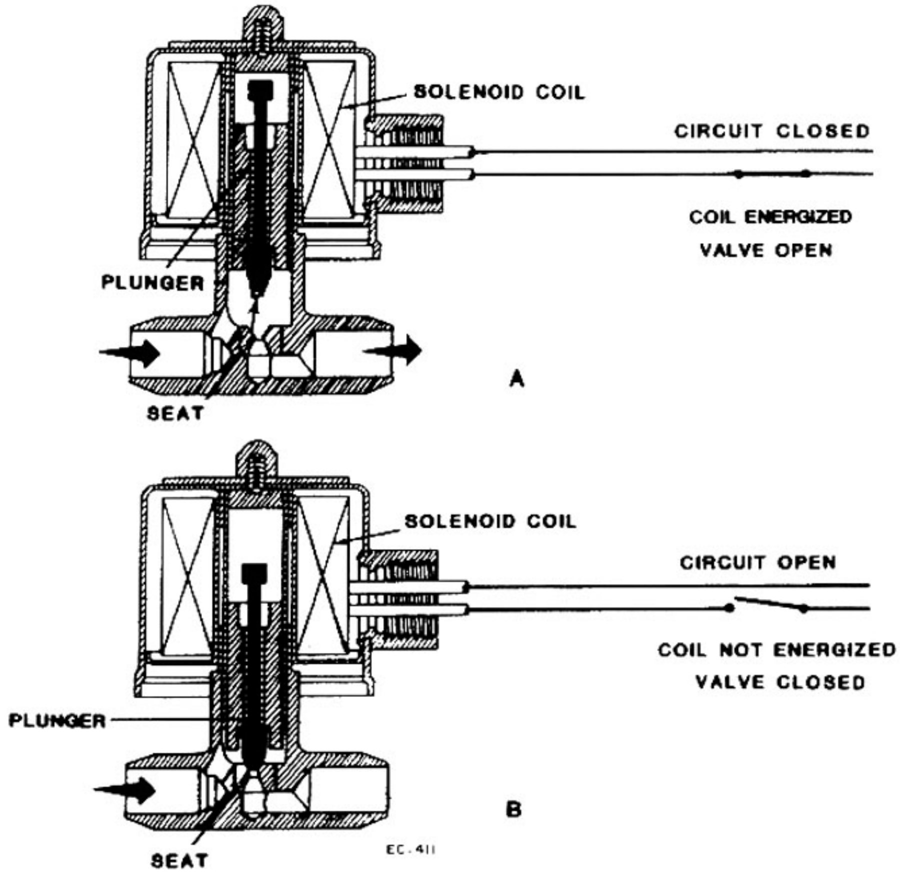


Figure 2–28. Solenoid valve in OPEN and CLOSED positions.

There are several different types of solenoid coils available from a variety of manufacturers. The type you select depends on the specific application. One type of moisture-resistant coil used for normal control of gas or fluid flow handles temperatures up to 175°F. Special applications include those with extremely high air and internal-fluid temperatures, high voltage, or high steam pressure. Another situation may require the use of a solenoid coil in high moisture or water applications. Under these circumstances, use a coil that is both waterproof and fungus proof.

A principal cause of coil malfunction is excessive heat. When a valve is exposed to extreme temperatures above its rating, the coil will probably fail. A missing part, a damaged plunger tube or tube sleeve, or improper assembly may also cause coil failure. The applied voltage must be at the coil's rated frequency and voltage.

Troubleshooting solenoids

When a particular type of solenoid is energized, it opens the valve and allows refrigerant to flow. Now look at the schematic in figure 2–29. On the right-hand side you will see an object that looks like a coiled labeled "pumpdown solenoid". Remember, it is very important to be able to find a component on a schematic and then find it on the unit. See the path that current must take to energize the solenoid. Current must pass through the wires, the cooling contacts and the thermostatic motor control before it can get to the solenoid coil and energize it.

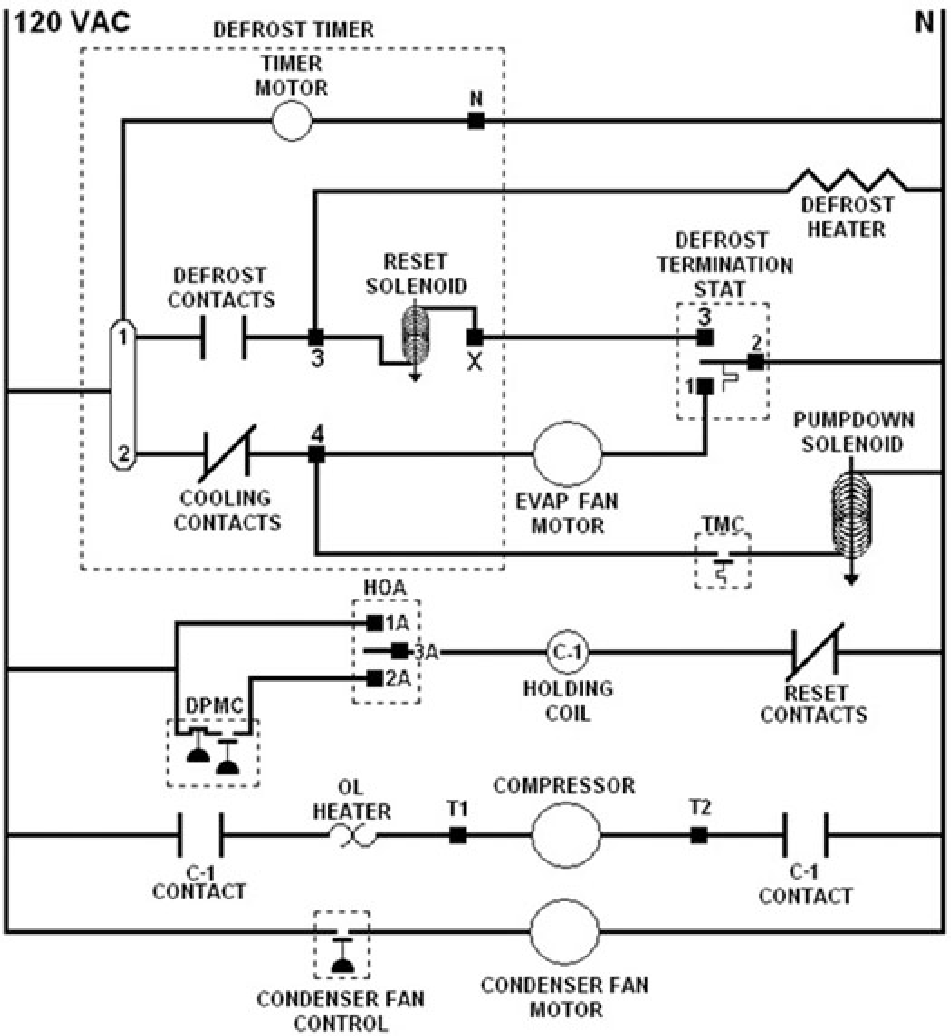


Figure 2–29. Commercial refrigeration schematic.

Once it has been determined there is current getting to the solenoid and it is still not energizing then it needs to be "ohmed out". First shut off the power and determine there is no voltage present. Then set the meter to ohms and place both leads on each side of the coil. The meter will read designed ohms if it is good and O.L. if it is bad.

Solenoid replacement

Turn off the electrical power to the solenoid valve before replacing the coil. Once you secure the power, you can disconnect the electrical leads safely. This coil can be removed without having to open the refrigerant lines. Put the new coil of the proper voltage and amperage back onto the valve then wire it in. Turn the system ON and observe the system to ensure it runs properly. There could be a mechanical issue with the valve components, but we will not cover this in this electrical lesson.

Contactors

A contactor is similar to a relay but has higher current ratings. It is usually controlled by a circuit with a lower voltage, often called *control voltage.* For example, the coil of contactor may have 24 volts applied to it, but when the contacts close, they pass 120 volts.

Coil and contacts

Coil and contacts are basically the same concept as a relay. A coil energizes and changes the position of the contacts. The contacts have a line side and a load side. Look at figure 2–30 to see that line voltage comes into one side of the contactor, and it leaves to the load side. The line voltage enters on one side of the contactor and stays there until the coil is energized. Once the coil is energized, the contacts close and pass power to the load device.

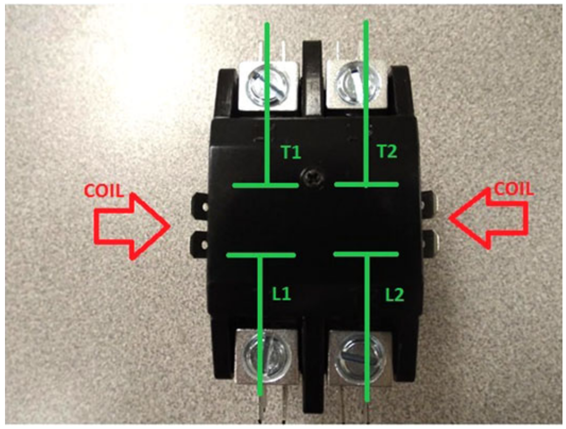


Figure 2–30. Contactor.

Troubleshooting contactors

Troubleshooting contactors is not a difficult task. First, verify power. Line voltage is needed entering the contactor and control voltage needs to be present at the coil. Once the coil is energized, there should be power passing out the other side of the contactor. Let's finish up this lesson with an example demonstrating contactor troubleshooting:

> Airman Messineo is on a trouble call and thinks the contactor is the issue. He is trying to remember how a contactor works; therefore, he draws a simple sketch to jog his memory. He remembers that C1 has incoming power that should pass through the coil and be consumed, then current will travel out to C2. He then remembers that once the coil is energized, it should change the position of the contacts. There are two contacts on this unit and they should be closed when the coil is energized.
>
> With his Arc flash gear already donned, he grabs his meter and sets it to voltage. Before he places his meter anywhere, he determines the readings he should get at certain points. He jots down some notes to ensure he is taking his time and being systematic. He takes the readings and writes them down also.
>
> He was supposed to read 240 volts between T1 and T2, but he did not. This means the contacts did not close. He already knows that the contacts change position when the coil energizes; therefore, he suspects the coil is either not getting power or it has an open. Airman Messineo's crew lead, TSgt Standards, advises him to check for voltage going to the coil before turnign the power off. Being a humble troubleshooter, Airman Messineo checks for 24 volts at the coil. He checks both sides of the coil and the meter reads 24 volts. This means voltage is being applied to motor; therefore, a logical explanation for this trouble is the coil has an open.
>
> Airman Messineo disconnects the power, removes the wires from the coil, sets the meter to ohms, and places the meter leads on both sides of the coil. It reads O.L. The coil is bad. He snaps a picture of the data sticker and texts it to the parts noncommissioned officer (NCO) in the shop. The parts NCO finds an exact replacement in the shop and sends Airman Soandso to the job site. Airman Soandso arrives and delivers the part to Airman Messineo. Airman Messineo disconnects power, ohms out the new part to ensure it is good, and successfully replaces the part. TSgt Standards advises the Airmen that the system should be ran and checked for proper operation. The system works perfectly.

In the example, you see that knowing how the system works, using teamwork, being humble, working systematically, and not rushing led to a successful job well-done. This is the way you should do your job every day at work.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

409. Distribution panels, fuses and circuit breakers

1. Where could many overload circuits devices be located?

2. When can a protective device that is too big be used?

3. Where could you find temporary distribution panels?

4. How long can a fuse hold its rated voltage?

5. How are fuses rated?

6. What will happen if you tried to place a smaller than design sized rejection type fuse into a fuse holder?

7. Where are plug fuses used?

8. What size window is used with plug fuses rated between 16 through 30 amperes?

9. When is the miniature ferrule or glass-tube fuse commonly used?

10. Why must the fuse be the *weakest* link in a circuit?

11. How must the fuse be rated compared to the *lowest* rated component?

12. Why are fuse specifications crucial?

13. Why are fast-acting fuses not used with devices that have a high starting current?

14. Which fuse should be selected for systems with high starting torque?

15. When does a multipurpose fuse become fast acting?

16. What effect does bending a fuse holder have on the metal?

17. Why must fuses be carefully removed from a circuit board?

18. What are the effects of a shorted capacitor?

19. What should be done if the selection of fuses becomes too complicated?

20. Why should you be cautious if you replace a fuse with an identical one?

21. What is the difference between a fuse and a circuit breaker tripping?

22. Why is the thermal-type circuit breaker *commonly* called a time lag breaker?

23. How is the length of time for a thermal-type breaker to respond to the heat generated by the overload current determined?

24. Why should you *never* attempt to adjust the ampere capacity of circuit breakers or repair them?

25. How is the circuit neutral connected in a GFCI?

26. Where would you find descriptions of each piece of equipment and its designated breaker?

27. What term is used to describe turning a breaker ON or OFF?

410. Control devices

1. How are switches rated?

2. What voltage appears across the switch in an open circuit position?

3. What does the number of poles determine in a toggle switch?

4. What does the number of throws signify?

5. How are the movable contacts attached to the push button switch?

6. In a snap acting switch, how are the contacts kept firmly closed?

7. What can arcing in switches cause?

8. Why are contacts in a mercury switch covered or uncovered with mercury?

9. How is solid state circuitry usually enclosed?

411. Electromagnetic devices

1. Where is the secondary coil of a transformer *always* connected?

2. How is a voltage induced in a coil?

3. How would you know if a transformer output voltage is stepped down or stepped up?

4. How does iron allow nearly all of the magnetic field of the primary to flow through the iron core and cut the secondary?

5. When checking a transformer's performance, what should be determined after incoming voltage is verified?

6. How is the primary or secondary side of the transformer checked?

7. If you are troubleshooting and you don't have 120 volts going to the transformer, what should be your next step?

8. What will the meter read if you ohm out a bad transformer?

9. How is a relay used to open and close electrical contacts controlled?

10. What will cause the relay to de-energize?

11. On many relays, what two terminals are used to check whether the coil is bad or good?

12. What is the proper way to describe the cause and effect of a coil energizing?

13. If contacts were open and its corresponding coil now energizes, what is the new position of the contacts?

14. On a 24-volt coil, if you read 24 volts across the coil terminals, what does this tell you?

15. On a 24-volt coil, if you read 0 volts across the coil terminals, what does this tell you?

16. What is the *first* step in relay replacement?

17. During a relay replacement, what is the next step *after* turning off the power?

18. What is the *last* step in relay replacement?

19. In a solenoid, how is the movable iron core pulled down into a coil?

20. If a situation requires the use of a solenoid coil in high moisture or water applications, what type of coil should be used?

21. What is the *last* step in solenoid replacement?

22. What is the *first* step in troubleshooting a contactor?

2–2 Motors

Motors are one of the most important items in the HVAC/R career field. A solid understanding of motors will make you a quality and reliable technician. A poor understanding of motors will create more trouble and time for you to complete work orders.

In our world of automation, we take for granted one of the most efficient devices ever invented—the electric motor. It is estimated that 90 percent of industry uses electric motors. Without motors, the wheels of industry would come to a halt and thousands of labor-saving devices would become useless. HVAC/R systems use various types of electric motors to operate compressors, dampers, fans, pumps, and valves. You, as an HVAC/R mechanic, must understand the principle of operation and construction features of electric motors and motor controls to troubleshoot and balance systems.

412. Motor concepts

The electric motor is the rotating machine that converts electrical energy into mechanical energy. Practically, all motors are designed to meet the requirements of a specific function. The two types of motors you must know are single-phase (1ø) and three-phase (3ø) motors. Let’s consider the 1ø motor first.

Single-phase motors

One of the major differences between a 1ø and a 3ø motor is that the 1ø motor requires some means to start it, whereas the 3ø motor does not. Single-phase motors range from a fraction of a horsepower (hp) up to 10 hp. They are often 120V, 208V or 240V.

Split-phase motors

Split-phase motors are usually fractional hp motors. Basically a split-phase motor is built the same as a 3ø motor. It has a stator, a squirrel-cage rotor, and two endbells. The windings, however, are different from those in a 3ø motor. The split-phase motor has two windings. One winding is of heavily insulated copper wire, which is generally located at the bottom of slots in the stator, and is called the *run* or *main* winding. The other winding is called the *start* winding and generally is located in the stator and laid on top of the run winding. The start and run windings are connected to power until the motor reaches 75 percent of its maximum revolutions per minute (rpm). A centrifugal switch or electronic relay has been added to the motor. A rotating part of the centrifugal switch is on the rotor, and a stationary part (containing a set of contacts) is in the endbell. This is shown in figure 2–31.

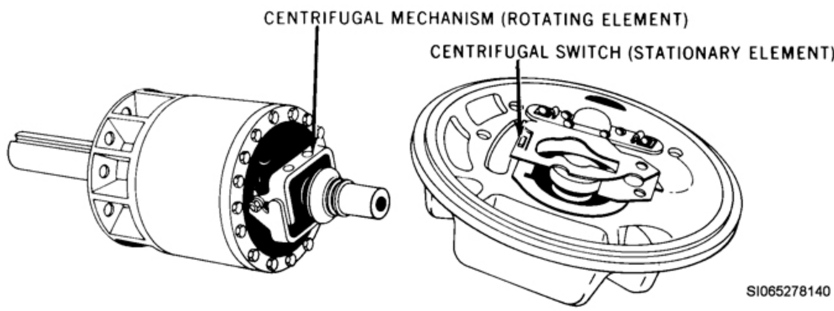


Figure 2–31. Components of a centrifugal switch.

The rotating part of a centrifugal switch is a mechanism that relies on motion and flyweights to operate. As the rotor turns, the flyweights are pulled out by centrifugal force. This applies pressure to the closed contacts of the switch and causes them to open. These contacts are in series with the start winding. When the contacts open, the start winding de-energizes.

Figure 2–32 is a schematic wiring diagram of a split-phase motor. The centrifugal switch, then, disconnects the start winding from the power. The run (main) winding is made up of many turns of heavy copper wire; the start winding is made up of fewer turns of smaller wire. If the start winding is not disconnected after a short period of time, it will burn up.

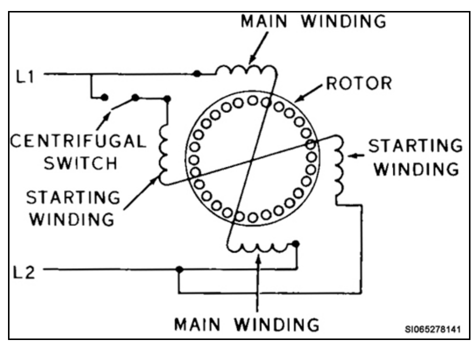


Figure 2–32. Split phase motor schematic.

When voltage is applied to both the start winding and run winding, the current in the run winding lags the voltage more than the current in the start winding. This creates a rotating magnetic field inside the stator. The rotating magnetic field induces a current in the rotor which sets up a magnetic field. The magnetic fields combine in such a manner as to cause rotation of the rotor. The start winding is used only for starting the motor. After the rotor reaches a certain rpm, the start winding is disconnected by the centrifugal switch or electronic relay. The electronic relay is a solid state device that opens the start winding after the designed speed is achieved. After the start winding is cut out, the motor operates on the rotating magnetic field produced by the run winding and the rotor.

Capacitor-start, induction-run motors

A capacitor-start motor (schematic diagram in fig. 2–33) is an improved version of the basic split-phase-type motor. An intermittent type of capacitor is connected in series with the start winding. When the motor reaches 75 percent of full speed, the centrifugal switch or a relay cuts out the start windings and the capacitor. The capacitor, along with the start windings, gives the motor a greater starting torque than a basic split-phase motor. To create a starting torque in a capacitor motor, a stronger rotating magnetic field has to be established in the motor. The

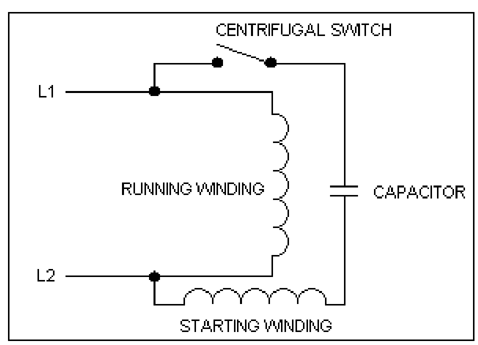


Figure 2–33. Capacitor-start motor.

start winding is out of phase with the run windings by approximately 90 degrees. A capacitor causes the current in the start winding to reach its maximum value before the current in the run winding becomes maximum. Actually the capacitor causes the current in the start winding to lead the current in the run winding. This causes a revolving magnetic field in the stator, which induces a current in the rotor and causes it to rotate. Remember, when the motor stops, the centrifugal switch contacts close so the motor can be started again. Capacitor-start motors are usually furnished in ratings from 1/6 to 10 hp and are used on compressors, pumps, and fans.

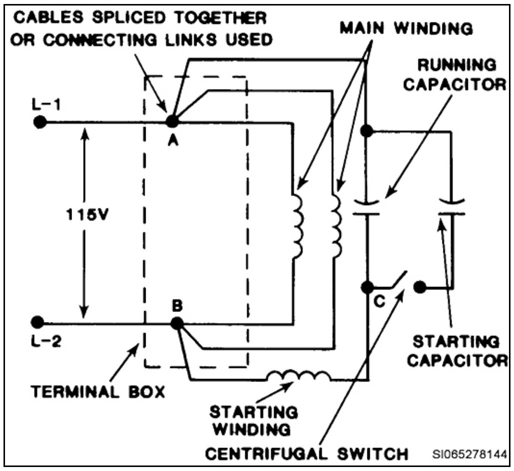


Figure 2–34. Capacitor start, capacitor-run motor schematic.

Capacitor-start, capacitor-run motors

We commonly refer to the capacitor-start, capacitor-run motor as the capacitor-run motor. Both the run windings and start windings stay in the circuit at all times. This motor has two capacitors connected in parallel with each other and in series with the start winding. One capacitor is continuously rated and stays in the circuit. The other is intermittently rated and is used in the start circuit. The start capacitor is removed from the circuit by the centrifugal switch when the motor reaches a certain rpm. This actually uses both capacitors in the circuit for both starting and running torque. This motor has high starting torque and good running characteristics. Figure 2–34 shows a schematic of a capacitor-run motor.

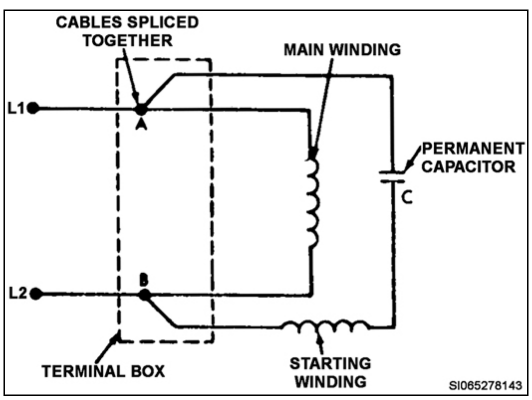


Figure 2–35. Permanent-split capacitor motor schematic.

Permanent-split capacitor motors

The permanent-split capacitor motor consists of a standard split-phase stator, a squirrel-cage rotor, a capacitor, and endbells. This is another version of the basic split-phase motor. A permanent-type capacitor is connected in series with the start windings and is left in the circuit at all times (fig. 2–35). The start windings in this motor are not high-resistance windings and have the same number of turns and wire size as the run windings. The capacitor, instead of resistance, is used to give the split-phase effect. This eliminates the need for a centrifugal switch in the motor. The capacitor is continuously rated and is selected to give the best operation at full speed while sacrificing starting torque. The permanent-split capacitor motor has the operating characteristics of poor starting torque with a high-current draw. However, it runs with a good torque under load conditions and at a constant speed.

Shaded-pole motors

The shaded-pole motor is a single-phase induction motor that uses a different method to produce starting torque. Instead of a separate winding like the split-phase and capacitor motors, the shaded-pole motor’s start winding consists of a copper band placed across one tip of each stator pole (fig. 2–36). This copper band has the characteristic of delaying the magnetic field through that portion of the pole. When AC power is applied, the main pole reaches its polarity before the shaded portion of the pole. This causes the shaded poles to be out of phase with the main poles, and produces a weak rotating magnetic field. Due to the low starting torque, it is not feasible to build motors of this type that are larger than 1/20 hp.

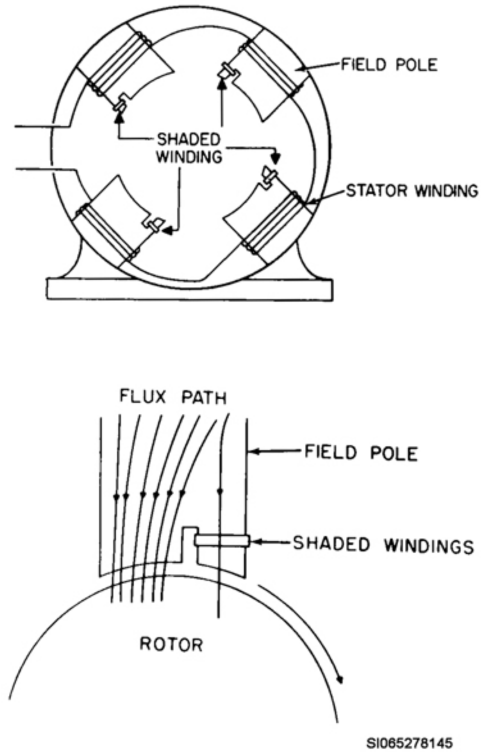


Figure 2–36. Shaded-pole stator.

Three-phase motor concepts

The two general types of 3ø motors are induction and synchronous. Both AC motors depend on the existence of a rotating magnetic field for their operation. We discuss only the induction type. Of all AC motors, the induction motor is the most widely used. Its design is simple and sturdy. Three-phase motors are also referred to as *polyphase* motors and can be broken into three basic parts: stator, rotor, and endbells.

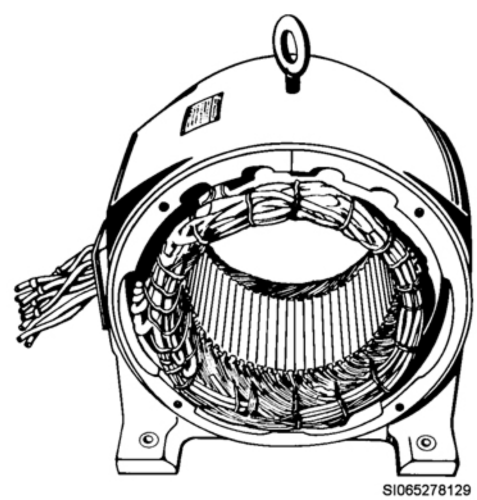


Figure 2–37. Three phase wound motor.

Stator

The stator, or frame (fig. 2–37), houses the stator windings and provides an attachment point for the voltage supply. The stator is made of cast iron or cast steel and has a laminated silicon steel core pressed inside. The steel core is laminated to reduce eddy currents, which is a loss due to stray currents. This steel core is constructed with semi-closed slots that hold the field windings. The field windings are made of a number of varnished insulated coils, which are 120 degrees (electrical) apart. These coils are insulated from the core with treated paper called fish paper. The coils are connected to form three separate windings. These windings are connected in either a wye or delta arrangement, which we discuss later. The field windings and the steel core together make up the stator or stationary part of the motor.

Rotor

The two types of 3ø induction motors are the squirrel-cage and the wire-wound rotor, also called an *armature*. These two types of AC motors vary only in the construction of the rotor. The rotor is the rotating part of the motor. The rotor provides a point to convert electrical energy to mechanical energy and to attach the motor to the load. Rotors may be either the wound or the squirrel-cage type, depending on the manufacturing and motor requirements. Squirrel-cage rotors are cheaper to build and require less maintenance than the wound rotor.

Squirrel-cage rotor

The squirrel-cage rotor consists of a laminated silicon steel core, rotor bars, and end rings, mounted on a shaft (fig. 2–38). On the most recent types, the rotor bars are cast into place on an angle called a *skew*. The skew effect increases the torque of the motor. The end rings short circuit or connect the rotor bars and end rings together. When one rotor bar is energized, all of them are energized. The rotor bars and end rings together make up a squirrel-cage winding. Fan blades are added on the end of the rotor to assist in providing adequate ventilation for cooling.

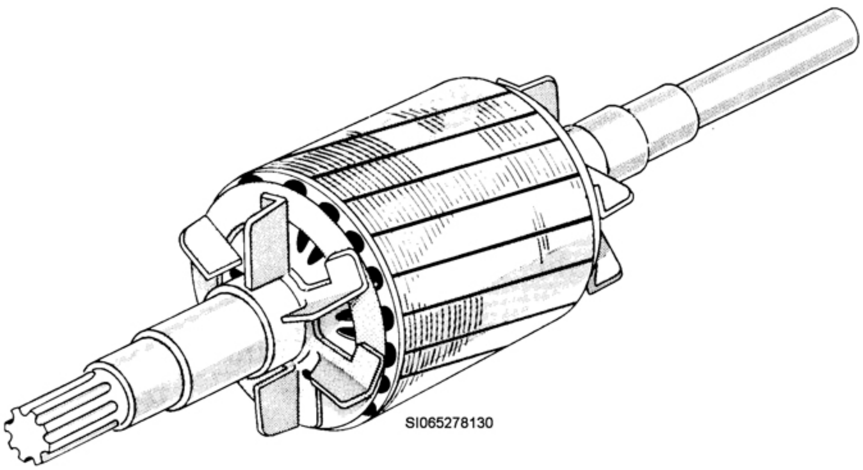


Figure 2–38. Squirrel-cage rotor.

Wound rotor

The wound rotor (fig. 2–39) has a laminated silicon steel core mounted on a shaft. The rotor winding is wound around the core. The rotor windings are made of coils similar to those used in a stator. Each coil is made up of a number of turns of insulated copper wire. The windings are connected like those of the stator, wye, or delta (discussed later). When the rotor is connected for wye operation, one end of the windings is connected together in the center, and the other end is connected to slip rings mounted on the shaft. Brushes ride on the slip rings and are connected externally to resistors for variable speed control. When connected for delta operation, the windings are internally connected into a delta configuration, and three leads are connected to the slip rings. Wound rotor types of 3ø motors are used when a low starting current is desired with an external starting device.

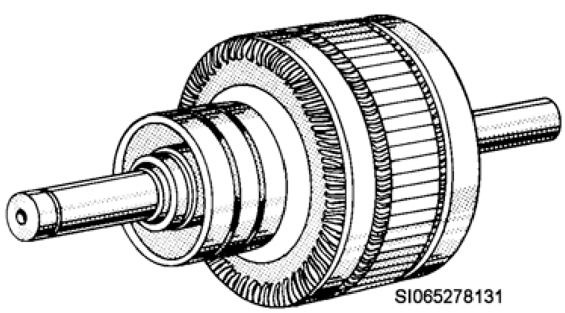


Figure 2–39. Three-phase wound rotor.

Endbells

The third basic part of the motor are the endbells. The endbells serve three functions, which are to house the bearings, support and align the rotor and shaft, and complete the frame of the motor.

Operating principles of 3ø induction motors

A 3ø induction motor needs a rotating magnetic field for operation. When current flows through the stator windings, a rotating magnetic field induces voltage in the rotor. The current flow in the rotor sets up a magnetic field that attracts the rotating field.

A rotating magnetic field is produced by several factors:

1. The difference in amount of current flow in the 3ø power caused by the characteristics of 3ø-voltage generation.
2. The reversal in direction of current flow caused by the characteristics of AC voltage.
3. The arrangement of field windings in the stator core, which establishes an evenly spread magnetic field around the stator.

The rotating magnetic field is set up by the rise and fall of current in the stator windings, as shown in the upper part of figure 2–40. When the current reaches its maximum value in one winding, this winding produces a strong magnetic field. As the current in the first winding decreases, the current in the next winding increases, thus causing the magnetic field to move to that winding. As the current decreases in the second winding, it increases in the third winding, thus causing the magnetic field to move again. The windings are distributed so that rotation of the magnetic field is uniform and continuous.

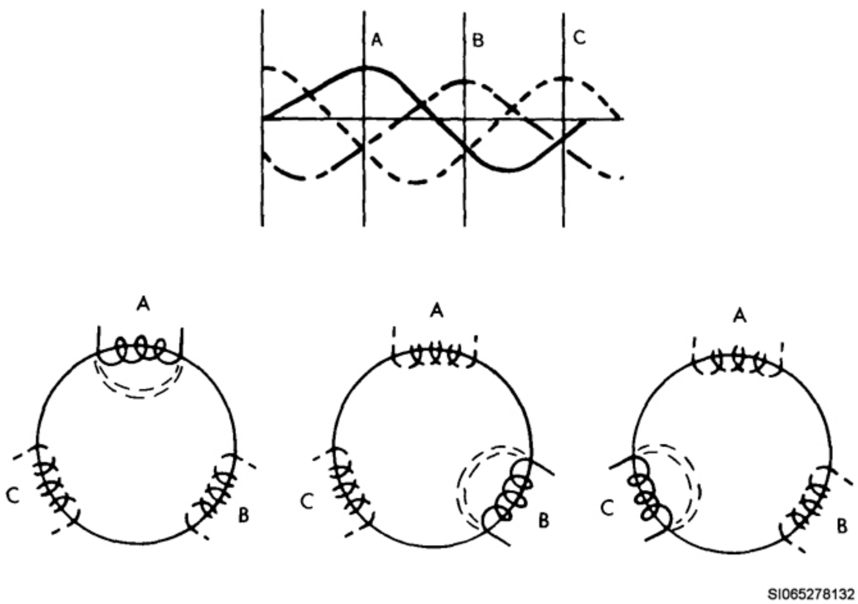


Figure 2–40. Rotating magnetic field schematic.

As you can see, the magnetic field rotates around the stator in the lower part of figure 2–40. These magnetic fields cut across the rotor, inducing voltage in the rotor. This voltage causes a current to flow in the rotor, producing a magnetic field in the rotor. Since the voltage is induced, the magnetic field in the rotor is opposite to the magnetic field that produced it. Providing the principle that unlike poles attract each other, the rotor follows the rotating magnetic fields.

413. Motor controllers

In this lesson, we cover some of the common AC motor controllers. The term “controller” refers to any switch or device normally used to start and stop a motor. A controller can be very simple or very complex, depending on the situation. As an HVAC/R specialist, you are responsible for making sure motors and their controls are operating properly. To do this, you must understand how controls work.

Motor controls start, stop, and usually protect a motor. To start and stop a motor, a motor control has a device that makes and breaks contacts in the supply lines to the motor. Also, the control normally provides some form of motor current protection. These AC motor controls are usually two basic types: manual or magnetic. Electronic motor controllers will be covered in section 3–3.

Manual control

A manual control is a device that controls a motor from a single point. Switch positions change from either manual action or mechanical action. Each controller (switch) must be able to start and stop its motor. The manual control can be a plain switch with or without overload protection. The term "overload protection" refers to a device that is sensitive to motor current. This device protects the motor windings by interrupting the current flow when an overload situation exists. Manual controllers control both 1ø and 3ø motors, which we discussed in the previous lesson. In general, they are used on small horsepower applications.

Toggle switches

Toggle switches, just like any other switch, have ratings for current and voltage. Toggle switches have a relatively low maximum current rating in comparison to other types of switches used to start and stop smaller horsepower motors.

A toggle switch is in series with the hot conductors in the circuit. You toggle the switch on to close or off to open. To operate a 240-volt motor with two hot conductors, use a double-pole switch to open or close both conductors at the same time. In a 120-volt circuit, only a single-pole switch is necessary to open or close the ungrounded conductor. A mechanical room exhaust fan operated by a toggle switch is a good example of this type of control. Remember, to safely control a motor, use the appropriate size toggle switch and ensure the amperage draw does not exceed the manufacturer's rating.

Fused safety switches

You can use the fused safety switch or disconnect switch to protect small 1ø or 3ø motors. This switch operates on the same principle as the toggle switch and uses a fuse for protection. You connect the fused safety switch to open and close all ungrounded (hot) motor conductors.

Magnetic controls

Another motor-control device that controls an electric motor is the magnetic control. This control or starter operates with an electromagnet to close the main or load contacts. This type of starter provides a safe, convenient, and economical means of controlling an electric motor. Magnetic controls are the most commonly used starters and offer the advantage of being operated by a remote control. A magnetic starter, commonly called a *line* starter, consists of two main sections: the contactor and the overload relay.

The contactor

The contactor consists of these parts: operating (or holding) coil and armature, main and auxiliary (or holding) contacts, and terminals (fig. 2–41, view A). The coil is a stationary portion of the contactor and uses a laminated iron core and a winding to produce an electromagnetic effect. The energized coil attracts the armature, or movable portion, in the contactor. In these switches, there are two sets of contacts. One set of movable contacts are connected to the armature. The other set is stationary. These contacts connect the line side of a contactor to the load side. The auxiliary contacts or holding contacts are located on the contactor. These contacts attach to the armature connecting bar so that all contacts close simultaneously. A nonconductive material ensures the phases never cross-short each other. When the electromagnetic coil energizes, a magnetic field attracts the armature. This closes the contacts and completes the circuit, thus starting the motor. When the coil is de-energized, a loss of magnetic force occurs, causing gravity or a spring to pull the contacts apart. This is the basic operation of a magnetic starter.

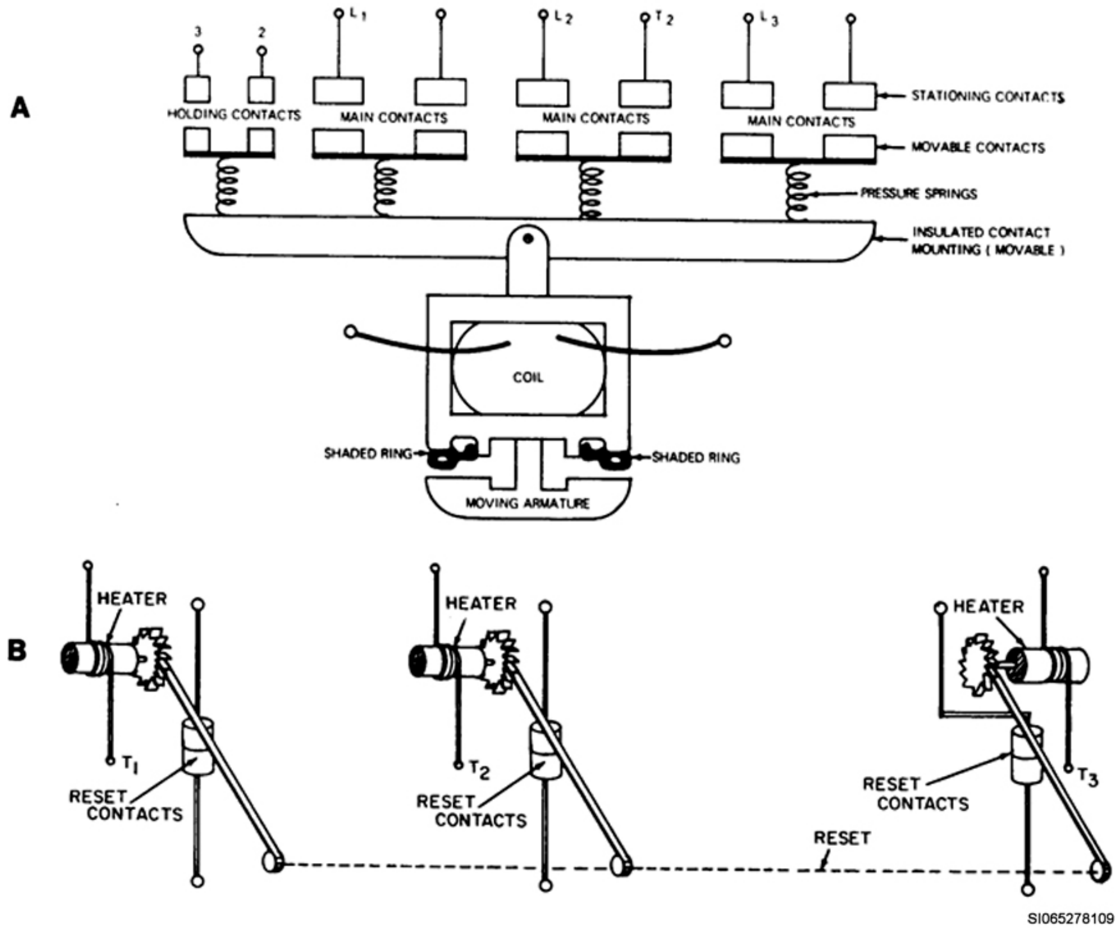


Figure 2–41. Magnetic starter contactor and overload relay.

Shaded rings are placed on the stationary core to provide a time delay during the loss of magnetic lines of force, thus preventing contact chatter and wear in the moving parts of AC magnetic starters. The contactor also provides terminals for the attachment of the supply conductors. The terminals are normally identified with the letter L. For example, terminals L1, L2, and L3 are the supply conductor terminals of a 3ø magnetic starter. The auxiliary contacts also have terminals. Auxiliary terminals used to attach conductors from control devices are identified with the numbers 2 and 3. We discuss auxiliary contacts in more detail in lesson 418.

Overload relay

Nearly all magnetic starters have some built-in overload device to protect the motor from excessive current in a running situation (fig. 2–41, view B). Current-sensitive elements of the overload relay connect directly or indirectly to de-energize the starter and stop the motor when excessive current conditions exist.

The basic need for overload protection is to allow the motor to carry its full-rated load and yet prevent any prolonged or serious overload. When motors overload mechanically, current flow through the windings increases. In turn, this increases the temperature of the motor windings.

Certain electrical malfunctions can also cause problems. The loss of one phase in three-phase motors or a partial fault in a motor winding can result in increased current draw. The increased current produces more heat in the motor windings. To give full overload protection, your “protector” must sense, or measure, the motor’s current draw and open the circuit when current flow exceeds the motor’s rated value.

There are two basic types of overload relays: thermal and magnetic. The first is a unit that is sensitive to heat. This unit may be a bimetallic type or melting-alloy type. The second type uses a magnetic device and is sensitive to motor current.

Regardless of the type device used, excessive current flow in the motor activates the overload relay. When one of these devices detects an excessive current, it reacts by opening a set of reset contacts that are in series with the holding coil. This causes the holding coil to de-energize and opens the main or load contacts.

When overload relays trip, you must reset them. You can do this in two ways: automatically or manually. Use the automatic reset overload relays *only* on equipment designed to prevent danger to life or equipment from the restarting of the motor.

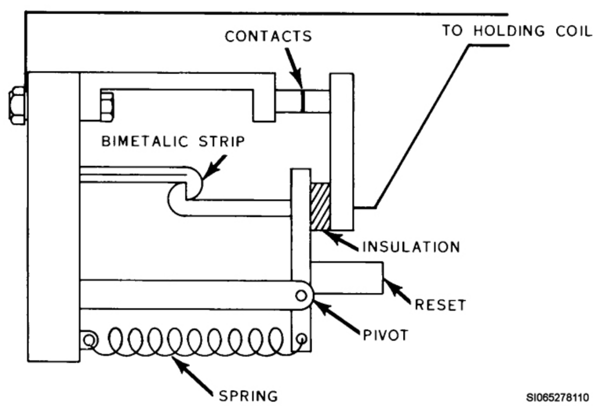


Figure 2–42. Bimetallic overload relay.

Thermal overload relays

Thermal overload relays are usually of the bimetallic or melting-alloy types. The bimetallic type features a sensing element constructed of two dissimilar metals. When heated, the two metals bend due to the different rate of expansion. A heating element in the motor-line circuit generates the heat necessary to activate the strip. Current in excess of the desired amount causes deflection of the bimetallic strip to the extent that the contacts spring apart and open the holding coil circuit. Figure 2–42 is a drawing of a bimetallic overload relay. You reactivate the mechanism by depressing the reset button once the strip cools to within its operating tolerance.

The melting-alloy overload relay uses a heating coil connected in the motor-line circuit (fig. 2–43). The heat caused by excessive current in the motor circuit melts the metal alloy (similar to solder). This releases the spring-loaded shaft and allows it to turn. Next, the reset contacts open and stop service to the motor. After the alloy cools and solidifies sufficiently, you can restart the motor by depressing the reset button. The main advantage of the melting-alloy relay over the bimetallic type is its amperage rating doesn't vary after repeated heating.

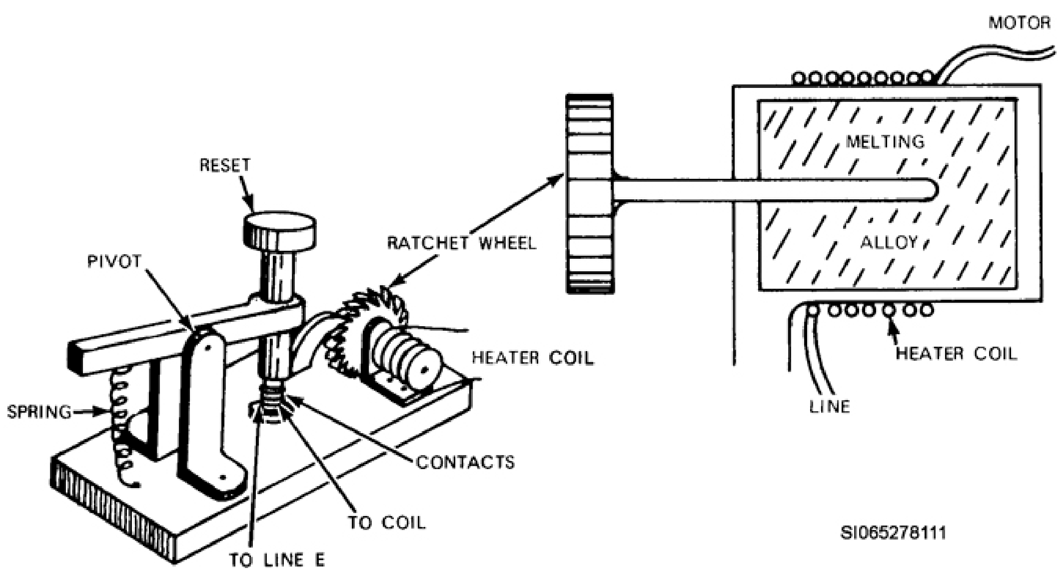


Figure 2–43. Melting alloy overload relay.

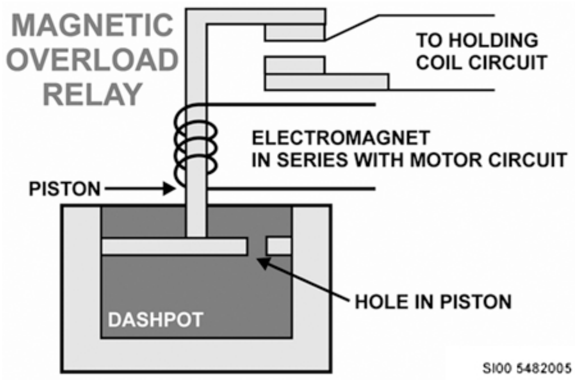


Figure 2–44. Magnetic overload relay.

Magnetic overload relays

The magnetic overload relay consists of a coil, a piston, a dashpot, and a set of contacts (fig. 2–44). The coil connects in series with the motor. When a determined amount of current passes through the coil, the magnetic field pulls the piston up and opens the contacts to the control circuit. By adjusting the length of the piston, you vary the amount of current required to pull the piston up. An oil-filled dashpot provides an added time delay. Adjusting the piston hole size changes the time delay.

When the coil pulls the piston up, the oil must flow through the hole. Now the piston must sink down into the oil before the contact in the control circuit can close. Adjusting the hole size increases or decreases the time delay. The use of a light-grade dashpot oil provides quick tripping, when required.

Selecting heaters

Full-load current of the motor being protected determines the size of the overload relay. When selecting the heaters to protect a motor, check the motor data plate to find the full-load current. Each manufacturer normally puts a heater selection table in the line starter cover.

Heaters are identified by manufacturer’s catalog number, not by amperage. By using the full-load current of the motor and referring to the manufacturer’s table, you can select the proper heater.Figure 2–45 shows three examples of manufacturers’ tables—Squared D, Allen Bradley, and Cutler-Hammond Heater).

If, for example, a motor is rated at 6.4 amps, by looking at these tables you could use either a B8.20 heater (from Square D Table), an N26 heater (from Allen Bradley Table), or an H1032 heater (from Cutler-Hammond Heater Table). Remember, you find these tables on the inside cover of the line starter.

The overload relay provides terminals for the attachment of the supply conductors. For example, terminals T1 and T2 are the load terminals of a single-phase magnetic starter and provide a point at which you can connect the conductors supplying the motor.

Motor full load current	Relay Number	Motor full load current	Relay Number	Motor full load current	Relay Number	
0.32-0.34	B 0.44	1.97-2.23	B 2.65	10.0-10.6	B-14	
0.35-0-38	B 0.51	2.24-2.50	B 3.00	10.7-11.4	B 15.5	
0.39-0.44	B 0.57	2.51-2.81	B 3.30	11.5-12.3	B 17.5	
0.45-0.53	B 0.63	2.82-3.19	B 3.70	12.4-13.6	B 19.5	
0.54-0.58	B 0.71	3.20-3.61	B 4.15	13.7-14.6	B 22	
0.59-0.66	B 0.81	3.62-4.14	B 4.85	14.7-16.6	B 25	
0.67-0.74	B 0.92	4.15-4.40	B 5.50	16.9-18.6	B 28	
0.75-0.84	B 1.03	4.41-4.78	B 6.25	18.7-20.2	B 32	
0.85-0.97	B 1.16	4.79-5.44	B 6.90	20.3-22.8	B 36	
0.98-1.12	B 1.30	5.45-6.16	B 7.70	22.9-24.7	B 40	
1.13-1.19	B 1.45	6.17-6.86	B 8.20	24.8-27.0	B 45	
1.20-1.34	B 1.67	6.87-7.64	B 9.10			
1.35-1.54	B 1.88	7.65-8.41	B10.2			
1.55-1.78	B 2.10	8.42-8.77	B11.5			
1.79-1.96	B 2.40	8.78-9.9	B12.8			

Square D Table

Heater Type No.	Full load Amps	Heater Type No.	Full load Amps	Heater Type No.	Full load Amps	Heater Type No.	Full load Amps
N 2	0.48	N 11	1.45	N 20	3.47	N 29	8.35
N 3	0.59	N 12	1.62	N 21	3.88	N 30	9.13
N 4	0.74	N 13	1.77	N 22	4.29	N 31	10.5
N 5	0.81	N 14	1.93	N 23	4.80	N 32	11.3
N 6	0.89	N 15	2.16	N 24	5.22	N 33	12.6
N 7	0.97	N 16	2.41	N 25	5.76	N 34	14.3
N 8	1.11	N 17	2.68	N 26	6.41		
N 9	1.22	N 18	2.93	N 27	7.02		
N 10	1.31	N 19	3.18	N 28	7.74		

Allen Bradley Table

HEATER COIL SELECTION TABLES

For Size 1 Starter				For Size 2 Starter		For Size 3 Starter		For Size 4 Starter	
Ampere Range	Catalog No.	Ampere Range	Cagalog No.	Ampere Range	Catalog No.	Ampere Range	Catalog No.	Ampere Range	Catalog No.
.157-.177	H1101	2.20-2.23	H1024	3.89-4.35	H1028	8.72-8.67	H1035	19.5-21.9	H1042
.178-.198	H1102	2.46-2.74	H1025	4.36-4.81	H1029	9.68-10.8	H1036	22.0-24.7	H1043
.188-.223	H1103	2.75-3.07	H1026	4.82-5.35	H1030	10.9-12.0	H1037	24.8-29.0	H1044
.224-.249	H1104	3.06-3.42	H1066	5.36-5.96	H1031	12.1-13.5	H1038	29.1-31.9	H1045
.250-.280	H1105	3.43-3.81	H1027	5.97-6.63	H1032	13.6-15.0	H1039	32.0-36.1	H1046
.281-.313	H1106	3.82-4.27	H1028	6.64-7.41	H1033	15.1-16.8	H1040	36.2-40.7	H1047
.314-.353	H1107	4.28-4.71	H1029	7.42-8.23	H1034	16.9-19.1	H1041	40.6-46.2	H1048
.354-.395	H1108	4.72-5.24	H1030	8.34-9.19	H1035	19.2-21.6	H1042	46.3-52.4	H1049
.390-.445	H1109	5.23-5.87	H1031	9.20-10.2	H1036	21.7-24.5	H1043	52.5-59.2	H1050
.446-.499	H1110	5.86-6.48	H1032	10.3-11.4	H1037	24.6-27.8	H1044	59.3-66.3	H1051
.500-.502	H1111	6.49-7.27	H1033	11.5-12.8	H1038	27.9-31.6	H1045	66.4-75.1	H1052
.563-.631	H1112	7.26-8.14	H1034	12.9-14.1	H1039	31.4-35.5	H1046	75.2-87.1	H1054
.632-.711	H1113	8.15-9.03	H1035	14.2-15.9	H1040	35.6-40.3	H1047	87.2-99.9	H1055
.712-.799	H1114	9.04-10.0	H1036	16.9-18.1	H1041	40.4-45.6	H1048	100.-113.	H1056
.800-.903	H1115	10.1-11.2	H1037	18.2-20.4	H1042	45.7-51.8	H1049	114.-129.	H1057
.904-1.01	H1116	11.3-12.5	H1038	20.5-23.3	H1043	51.9-58.6	H1050	130.-135.	H1058
1.02-1.13	H1117	12.6-13.6	H1039	23.4-26.5	H1044	58.7-65.2	H1051	---------	------
1.14-1.27	H1018	13.9-15.6	H1040	26.4-30.3	H1045	85.3-74.3	H1052	---------	------
1.28-1.43	H1019	15.7-17.7	H1041	30.4-34.7	H1046	74.4-36.3	H1054	---------	------
1.44-1.60	H1020	17.8-19.9	H1042	34.8-39.6	H1047	86.4-90.0	H1055	---------	------
1.61-1.76	H1021	20.0-22.5	H1043	39.7-45.0	H1048	-------	-----	---------	------
1.80-1.96	H1022	22.6-25.2	H1044	-------	-----	-------	-----	---------	------
1.99-2.19	H1023	25.4-27.0	H1045	-------	-----	-------	-----	---------	------

Cutler-Hammond Heater Table

SI065278113

Figure 2–45. Manufacturers' heater tables.

414. Operate and service a motor

Now we will cover the operation and servicing of a motor. Among the topics covered are measuring current draw, servicing a motor such as motor removal and capacitor testing, servicing external-drive motors, lubricating motors, and cleaning motors.

Measuring motor current draw

To measure current draw, simply place a clamp-on ammeter around one of the motor wires. Compare the meter reading to the motor data plate.

Servicing motors

The servicing of electric motors, whether they are used for driving a fan, compressor, or some other piece of HVAC/R equipment, is basically the same. Some of the servicing procedures require the removal of the motor from the location where it is installed. Keep in mind these procedures have been generalized. Some manufacturers may require you to follow specific directions for their motors.

Removing electric motors

When you are required to remove an electric motor from service, the first thing to do is to check that the circuit breaker or some sort of disconnect switch is open. You must lockout/tag out the electrical source according to the local procedures established in your area. Check with your supervisor for the specifics of how to use the lockout/tag out devices available in your area. These devices prevent the accidental energizing of an electrical circuit while you are working on it. It is essential that you follow all the safety procedures for the use of these devices.

After securing the electrical power, remove the wires from the motor terminals. It is a good idea to label the terminals for easy replacement later. Once you secure the electrical service, you can begin to loosen the hardware attached to the motor.

Most motors drive something. The method by which the motor is attached to the object it drives varies quite a bit in the HVAC/R industry. Most condenser fans are mounted directly to the fan motor shaft. Open drive compressors are sometimes mounted to the motor via a coupling, and sometimes they are connected using a belt and pulley system. In any case, you must remove the attaching hardware before you remove the electric motor for servicing. We do not cover every type of motor connection here. In the interest of safety, however, we cover the methods used for v-belts.

When the motor is connected to what it is driving via a V-belt system, you must remove the belts before conducting some services on the motor. When this is the case, loosen the tension on the belts enough so that you can remove them without damaging them. When removing belts, never pry them off the flywheel pulley or motor pulley. This may damage the pulleys. Always be extremely careful. If the belts are not loosened enough, you can easily pinch your fingers. Put safety before speed.

Testing capacitors

When a motor, whether it’s a condenser fan motor or a compressor motor, doesn’t start correctly, there is a good possibility that the problem is the capacitor. Most motors have one capacitor only; either a starting or a running capacitor. Some motors have both.

The starting capacitor is connected in series with the start winding. It’s normally wired in the circuit between the relay and the starting terminal of the motor. The running capacitor is also in the starting winding circuit, but it stays in operation while the unit runs.

Two types of capacitors are available. They are the dry type, used for intermittent operation (starting circuits), and the electrolytic capacitor, used for continuous operation (running circuits). Regardless of the type, test them the same way.

The easiest way to test a capacitor is to check it with a capacitor tester. Another way is to replace it with one that you know is good. If the motor operates properly with the good capacitor, you know the trouble was with the capacitor. Make sure the replacement capacitor is the same size as the old one. If the new one is different, it should be no more than 25 percent over capacity rather than under capacity.

CAUTION: *Never* use a capacitor that is under the capacity of the original capacitor. This could cause further damage to the motor windings.

There are specially designed instruments that technicians can use to troubleshoot capacitors. You can use these testers to find out whether the capacitor leaks or is shorted, grounded, or open.

When testing capacitors, you must discharge the capacitor before connecting it to any testing instruments. To discharge the capacitor, use a 20,000 ohm, 2 watt resistor across the capacitor terminals. Avoid shorting the terminals out. Rapid discharging may rupture the thin metal foil inside the capacitor and cause irreparable damage.

Servicing external-drive motors

We can classify most trouble with external-drive motors in two ways: electrical and mechanical. *Electrical troubles* you may encounter include open, shorted, or grounded circuits. These troubles likely occur in the windings of the motor. The recommended fix is to replace the motor or to have it rewound.

Repeated starting of a motor may cause it to overheat. Overheating the capacitor may cause the centrifugal switch and the insulation to fail. When a motor will not start, but still has the characteristic AC hum without first spinning the pulley, the hum is a sign that the capacitor or the centrifugal switch has failed. A simple way to determine which has failed is to test the capacitor with a meter that has a capacitor checker or use an actual capacitor tester.

After ensuring that the capacitor is good and the motor still fails to start, the trouble is most likely the centrifugal switch. It is difficult to repair these points, and even if they are removed and cleaned, they will not last very long. The best way to deal with a malfunctioning centrifugal switch is to replace it.

Mechanical troubles are not limited to external-drive motors. Mechanical troubles include the centrifugal switch's becoming worn and failing. Other mechanical troubles include bearing wear, endplay, excessive vibration, and misalignment of the motor with the compressor, and improper air gap between the motor and stator.

Lubricating motors

You can lubricate motors in various ways depending on the type or style of bearing used in the motor. In addition, the motor mounting position may have a factor on how you lubricate the motor. In general, however, you can lubricate motors using bronze bushings (plain or sleeve) in two different ways:

1. Wick system.
2. Slip ring system.

Wick system

The wick system uses a well or reservoir in the motor end bell. A wick (cotton or wool yarn) carries oil from the well to the bushing and shaft. This allows long periods between servicing the bearings and prevents the bearings from getting too much oil.

New motors, direct from the factory, are shipped with the wick already installed. Before installing a motor of this type, you must oil the motor with the recommended lubricant.

Slip ring system

Larger motors use the slip ring lubricating method. A brass ring rests on the shaft of the motor. The ring is large enough to dip into the oil pocket below the slip ring. As the shaft of the motor turns, the ring also turns slowly, and the wet portion of the ring lubricates the bearing.

Still another type of bearing used, and probably the most popular for heavier duty motors, is the ball bearing. These bearings are grease lubricated. Many ball bearings are of the sealed type and do not require any lubrication service.

Some ball bearings are not permanently sealed and require periodic lubrication. In this case, use a grease gun to provide the necessary amount and type of grease. Add a small amount of grease at the intervals specified by the equipment manufacturers' specifications. Use only clean grease and ensure that the fittings you use to connect the grease gun to the motor are clean before you attach your grease gun. The serviceability of the bearings depends on the quality of your maintenance. Too much grease can cause the bearing to overheat. Improper lubricating damages the bearings and causes more work in the long run.

Cleaning motors

Clean motors that are in service periodically. Lint and dust in the motor prevents the proper circulation of air. You can use compressed air to blow dirt out of the motor. Use care and the proper safety equipment when using compressed air.

NOTE: After oiling or greasing bearings, wipe off any excess lubricant. Dirt, dust, and lint collect quicker if you don't clean these surfaces.

415. Troubleshooting motors

Troubleshooting is a systematic method of locating malfunctions and defective components by indications, signs, and tests. Pay close attention to the procedures in the text, and you will reduce the time required to locate the trouble and to restore all motorized equipment to its normal operation.

NOTE: The procedures that follow are generic tasks and terms. They can be used on many different motors in our career field.

Isolating a standard motor at its terminal block would not present much of a problem, but take special care when working with a hermetic or semi-hermetic compressor with a gas charge. Attempting to loosen the terminal nuts can cause two major problems:

1. If the stud that makes the seal around the terminal block turns, it may break the winding connection in the interior of the motor. Now you do have an open in the motor that you must repair.
2. Loosening the connector nuts may weaken the integrity of the terminal block. With a refrigerant gas charge, even a partial one, the gas can shoot the stud out with the force of a bullet. Guess who is in front of the terminal block looking at it? Bottom line: use extreme caution and respect for the equipment when learning to work on it!

Motor failure

Many things that cause motor failures are not the fault of the motor. Several conditions that may cause motor failure are listed below:

- Overload.
- Loss of power.
- Bad or improper connections.
- Driven machine blocked.
- Frozen or worn bearings.

Check these conditions before disconnecting electrical power lines or troubleshooting the electrical system.

Overload

If a 3ø or 1ø motor has been operating satisfactorily and suddenly stops, a temporary overload condition may exist. Allow enough time for the overload device to cool before actuating the reset device. If sufficient cooling has occurred, the reset will hold in the locked position, and you can follow the normal starting operation. If the motor fails to start, use a step-by-step procedure for locating the trouble. Check current draw with an ammeter to determine if the motor is overloaded.

Loss of power

Use a voltmeter to determine if power is being supplied to the magnetic starter. Likewise, determine if power is being supplied to the motor.

Bad or improper connections

Before removing a motor from the line, check all electrical connections. Determine whether the control connections are in accordance with the control wiring diagram. After you check the control connections, check the terminal lead connections in both the control apparatus and the motor.

Motors with wound rotors are more susceptible to malfunctions due to their construction. Other than insulation checks, which are similar to the stator winding, rotors often have opens caused by overheating. Sometimes you can use a soldering gun to repair these opens and restore the circuit. You must replace brushes that are worn to half their original length. Check brushes for broken leads, a chipped or broken face, correct tension, and freedom of movement in the holder.

Blocked driven machine

Determine whether the driven machine is at fault. To do this, disconnect the motor from its load and try to rotate the rotor shaft of the motor by hand. If the rotor turns freely, then something is blocking whatever it is supposed to turn, such as a compressor.

Frozen or worn bearings

Try operating the motor without the load of the driven machine. Lubrication may be needed and, in some cases, will free the rotor. If the bearings are frozen or stuck, it may be necessary to take the motor apart to free the bearings. If the rotor shaft turns, look for wobbling, which indicates a bent shaft. Before handling the shaft, put on gloves, or use a piece of cloth to protect your hands from burrs or sharp edges that may be in the keyway. Check the rotor shaft for any up-and-down play (movement). Any noticeable movement indicates worn bearings, which may be causing the rotor to be dragging in the stator. This can happen when belt tension is applied. Replace the bearing if you note up-and-down movement. Also check for rotor end play by moving the rotor shaft in and out. Some end play is not detrimental; however, it must not exceed 1/64 of an inch. You can remove excessive end play by adding fiber spacer washers.

Other things to check for are misalignment of endbells, a loose pole piece, or foreign objects in the motor. If the trouble is not mechanical, then analyze the motor circuits.

Three-phase motors and motor controls

Troubleshooting electrical motors and their controls is no different than any other troubleshooting you do. Start with the locations where you know there is power and proceed on a systematic, piece-by-piece inspection.

All electrical circuits are subject to three common malfunctions: open, grounded, and shorted circuits.

Open circuits

Starting with the source of power, an open circuit may exist between any point and the rotor of the motor. Isolate the trouble on a step-by-step basis. Make the following checks on the equipment shown in figure 2–46, which shows a 3ø motor connected to a 3ø starter.

CAUTION: When you are working with an ohmmeter, do *not* connect it to a live circuit.

With an ohmmeter, check from the source of power to the line terminals of the starter, making sure continuity exists at the starter-line terminals, L1, L2, and L3. Make sure there is a continuous circuit between the start-stop station and the starter. (The conductor connected to L1 is common to both the starting and holding circuit.)

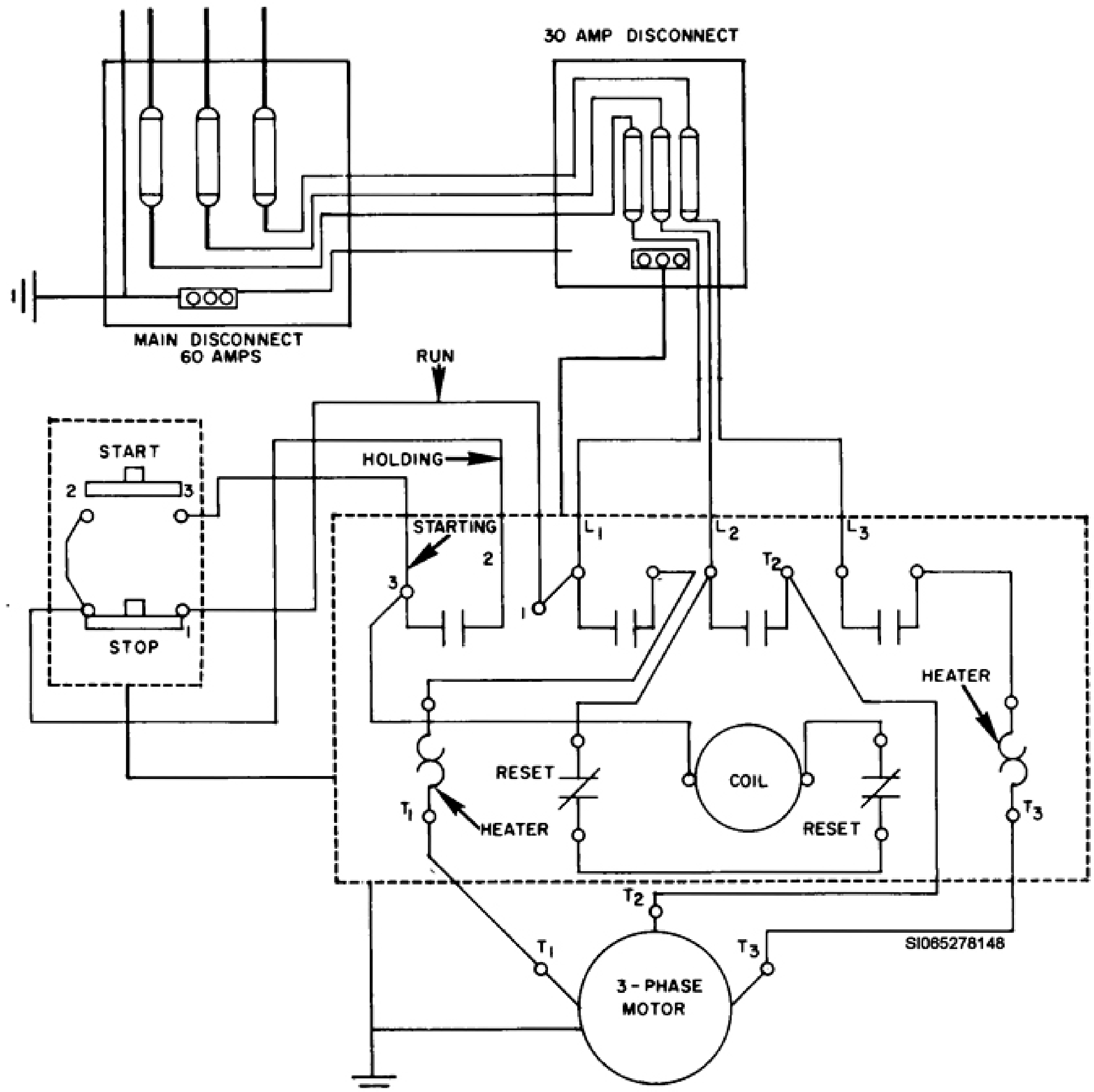


Figure 2–46. Three phase motor connected to a three phase starter.

Make sure there is a continuous path for current flow from the switch side of the starter through the holding coil and through the resets, back to L2. This circuit normally is from switch terminal 3 to starter terminal L2. Be sure you have continuity through the heaters. Move the armature until the contacts are closed, and check for continuity between L1 and T1, L2 and T2, and L3 and T3. If there are no opens at this point, power should exist at the motor terminals, T1, T2, and T3 of the starter when you push the start button.

Check for continuity between the starter terminals (T1, T2, and T3) and the motor terminals (T1, T2, and T3). If you have continuity to the motor terminals, check the stator of the motor for an open circuit. This is done in a wye-connected motor as shown in figure 2–47.

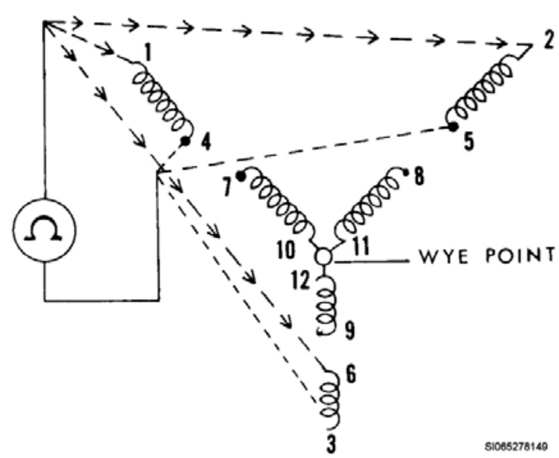


Figure 2–47. Testing a wye connected motor for an open circuit.

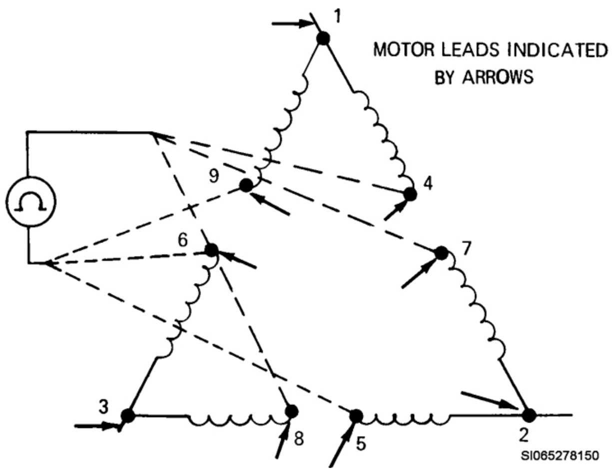


Figure 2–48. Testing a delta connected motor for an open circuit.

Disconnect the motor leads from the power leads. Check for continuity between leads 1 and 4, 2 and 5, and 3 and 6.Continuity should exist when testing across the above-mentioned pairs. Since the opposite ends of lead 7, 8, and 9 are connected at a wye point in the wye-connected motor, continuity should exist between leads 7 and 8, 7 and 9, and 8 and 9.

Check the stator of a delta-connected, 9–lead motor for an open circuit as we show in figure 2–48. Disconnect the motor leads from the power leads. Check for continuity between leads 4 and 9, 6 and 8, and 5 and 7. This will check all the windings in the delta motor

There is little likelihood that a squirrel-cage rotor will be open. If an open does exist, the motor slows down under load. It also has low starting torque. Signs of heating are usually evident. Fractures in the rotor bars are usually found either at the connection to the end rings or at the point the bars leave the laminations. If the motor has a wound rotor, it may be necessary to check for an open circuit by using the external growler. A growler is an electromagnetic device we use for finding short-circuited coils and for magnetizing and demagnetizing electrical devices.

Grounded circuits

Follow the same process in finding a grounded circuit as you used in finding an open circuit. Start with the source of power and work toward the motor. With the main disconnect open, check with the ohmmeter across each power phase to ground. Follow this step all the way to the starter to ensure that no grounds exist from the source of power to the starter.Any ground existing in the power supply or any extremity connected to L1, L2, or L3 of the starter is indicated at any point tested by a reading on the meter. This assumes that any disconnects between the source of power and the starter are closed.

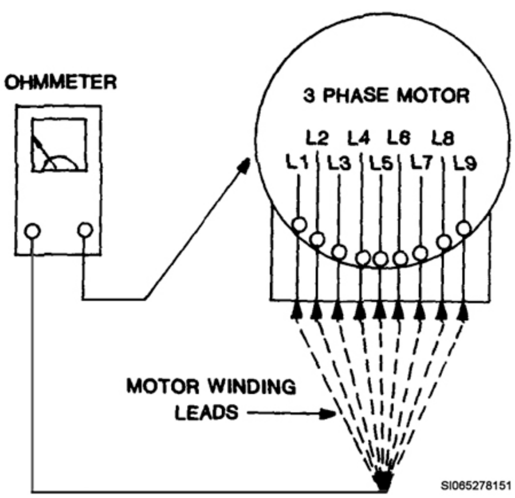


Figure 2–49. Testing a motor for grounded windings.

Disconnection of conductors at certain points is necessary to isolate the grounded circuit. Check across each of the conductors connected to the stop-start station to ground (conduit) to determine whether a ground exists at the stop-start station.

Check throughout the starter at points of possible grounds. Also check the control circuit (through the coil) and then your load circuit. In checking T1, T2, and T3 of the starter to ground, remember that any grounds existing in the connected motor are indicated at these points. Whether the ground exists in the motor or on the conduit you determine by disconnecting the motor from the starter. If the ground does not exist in the conduit from the starter to the motor, check the motor windings for grounds. Test the motor windings for grounds using an ohmmeter, as shown in figure 2–49. Position one test prod to the motor housing, being sure metal-to-metal contact is made. With the other lead, touch each station lead in succession. If the meter reads any ohms, a ground is indicated. If you discover internal motor trouble, replace the motor.

Shorted circuits

You find shorted circuits by checking across conductors with the power off. If continuity exists across two conductors when the circuit is purposely open, the circuit is shorted. As in checking for opens and grounds, in checking for shorted circuits, you start with the source of power and carry through to the motor windings. With the main disconnect open, start by checking across the fuses (bottom end). Assuming any disconnects are closed between the source of power and the starter, continuity across any two conductors indicates a short circuit exists between the main disconnect and the starter. Disconnecting conductors at certain points is necessary to isolate the short circuit. Press the stop button and check across the conductors on terminal 2 of the starter switch to L1. Pressing the stop button on the stop-start station opens the circuit to the starter. A continuity reading indicates a shorted circuit in the holding part of the circuit. (**NOTE:** This circuit is normally *closed* due to the construction feature of the stop-start station.) Continuity across L1 to number 3 in the starter indicates a shorted circuit in the starting part of the circuit. (**NOTE:** This circuit is normally *open* due to the construction feature of the stop-start station.)

When checking across the terminals (T1, T2, or T3), you must disconnect the motor leads from the source of power. Otherwise, there will be a resistance reading because of the motor windings. After you disconnect the motor leads, continuity will not exist when checking across T1, T2, and T3. Also, a short circuit could exist in the conduit between the motor and the starter.

Figure 2–50 shows how to check a wye-wound motor for a shorted stator winding. Use an ohmmeter to check across the stator leads of the motor where continuity should not exist. Continuity should exist between leads 1 and 4, 2 and 5, 3 and 6, and the leads of which the other ends form the wye point. The external leads involved in the wye are leads 7, 8, and 9. Therefore, in testing for a shorted stator, if continuity exists between any combination of lead numbers other than those forming a winding, a shorted stator is indicated.We show the procedures for checking a delta-wound, 12-lead motor for a shorted stator winding in figure 2–51. Continuity should exist across the following leads of a delta-wound stator having 12 external leads: 1 and 4, 2 and 5, 3 and 6, 7 and 10, 8 and 11, and 9 and 12. So, in testing for a shorted stator, if continuity exists between any combination of numbers other than those shown above, the stator is shorted.

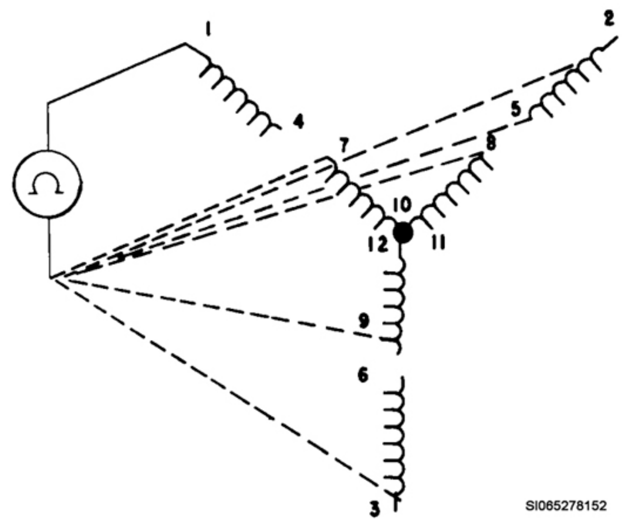


Figure 2–50. Testing a wye wound stator for a shorted circuit.

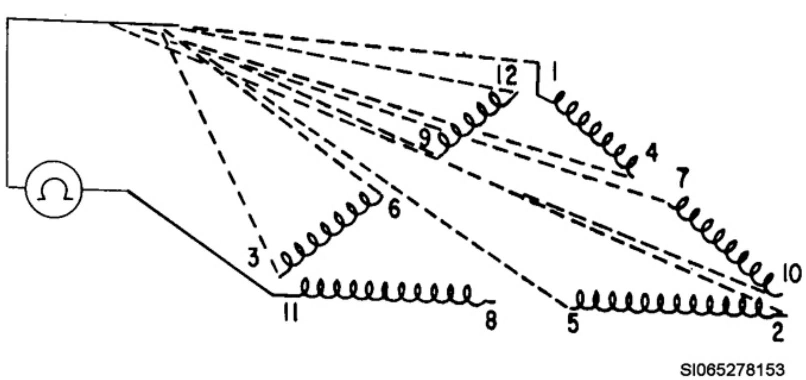


Figure 2–51. Testing a delta wound stator for a shorted circuit.

In the 9-lead motor, which is most commonly used, three end windings are internally connected.Lead 12 is connected to lead 1, lead 11 to lead 3, and lead 10 to lead 2. Continuity should exist across leads 4 and 9, 6 and 8, and 5 and 7. So, in testing for a shorted stator, if continuity exists between any combination other than those listed above, providing leads 1, 2, and 3 are not used, the stator is shorted. Leads 1, 2, and 3 are not used because internal leads 12, 10, and 11 are connected to them.

416. Correct motor malfunctions

After determining a motors fault you must correct the malfunction. You can use motor data plates to correct malfunctions. This lesson covers different motor faults and procedures to repair them. Remember, the job isn't done just because you have determined the problem, you must also correct it.

Using information on motor data plates to correct malfunctions

By the rules of the NEC, every motor must be equipped with a data plate (fig. 2–52). This data plate must be marked with certain information relative to the motor. This information is necessary in troubleshooting, testing, and balancing systems as well as motor replacement. Listed below, in no specific order, is the information required on a motor data plate:

1. Manufacturer's name.
2. Rated volts and full-load amperes (amps). These show the motor's operating voltage and the current the motor draws under full load. These are normally expressed as V for volts and A for amps.
3. Rated frequency and number of phases. These show the motor's operating frequency marked as Hz and the required phases to operate the motor marked as "ph."
4. Rated temperature rise of the insulation system and rated ambient (Amb) temperature. This is the motor's maximum operating temperature under normal conditions. This is normally listed on a motor data plate as rise 40°C or Amb 40°C.
5. Rated full-load speed. This shows the rpm of a motor under full-load condition. For example, rpm – 1725.
6. Time rating. This tells you whether the motor is a continuous or intermittent type.
7. Code letter. The code letter is used for determining branch circuit over current protection by using table 430–152 of the NEC. Code L is shown in figure 2–52.
8. Rated hp when 1/8 or more. This is used to determine circuit switch sizes. For example, hp 1/3.

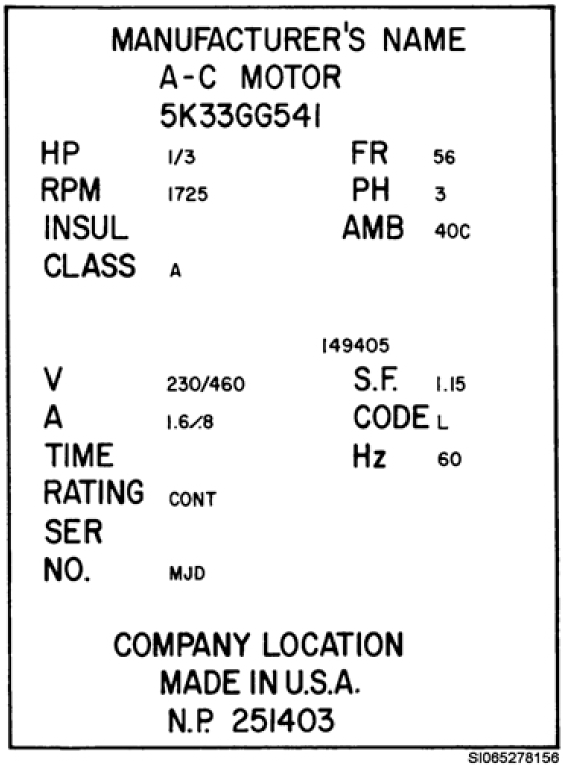


Figure 2–52. Motor data plate.

Along with required information, some manufacturers furnish data plates with useful information, such as the frame number and service factor. The frame number gives the physical dimensions of a motor; for example, shaft size, mounting configuration, size, and the overall dimensions of a motor. Frame numbers are standardized, regardless of manufacturer. This information is shown on the data plate as frame or FR.

The service factor is the amount of overload a motor can safely carry without damage to the unit. We determine this by multiplying the normal hp by the service factor. For example, a 1/3-hp motor with a service factor of 1.15 can be used to carry a continuous load of 0.38 hp (1/3 × 1.15 = .3795. The normal service factors of most motors is 1.15. This information is found on the motor data plate and is normally expressed as SF.

Malfunctions

You may correct all malfunctions in motors except malfunctions in the internal wiring. Below are common malfunctions:

- Motor will not start.
- Motor runs hot.
- Motor stops running.
- Motor operates with excessive noise.
- Motor runs slowly.

Motor will not start

The motor may not start due to a voltage failure. Check the line voltage against the data plate rating. Check for blown fuses and broken or loose connections. Replace any bad conductors. Check any capacitors in the motor circuit and the motor windings.

Motor runs hot

The motor may be operating under an overload condition. Do the following checks in this order:

1. Check the actual amperage against the data plate rating.
2. Check the rating of the overload relay against the full-load current. If the rating of the relay is too high, replace it with the power-rated relay.
3. Check the available voltage to be sure the motor is not operating on under voltage or over voltage. It may be necessary to lighten the load or install a larger motor.
4. Check for proper motor and power connections. Be sure the motor is properly connected to the available voltage.
5. Check for proper ventilation. Clean any dirt from around vents or windings.
6. Check the motor to determine if it has been properly lubricated. If it has not been, oil it according to the manufacturer's instructions. Check whether the motor is one of proper design. For instance, if the motor is to be turned off and restarted again and again, make sure it is rated for intermittent duty.

Motor stops running

If the motor stops running, allow enough time for the motor control to cool. Push the reset into locked position and push in the start button. If the motor starts, keep close watch until you can be sure the motor failure was not due to any severe circumstance. If you don't do this, there could be serious damage to the motor. A brief overload or a power failure may have been the cause of the failure. Occasionally you must replace the relay because it has become faulty. If you cannot restart the motor, it may be necessary to recheck all the items we previously discussed.

Motor operates with excessive noise

Excessive noise may result from the motor not being securely mounted. This condition may be remedied by tightening the mounting bolts and the motor support securely.Dry motor bearings may cause excessive noise while the motor is in operation. Proper lubrication may stop the excessive noise, providing there is no permanent damage to the bearings. Sufficient damage to the bearings may require replacement. Follow a regular lubricating schedule. Be certain the lubricant is the type suggested by the motor manufacturer.Excessive noise may be the result of loose motor accessories. You can eliminate this by tightening the oil well cover and the connection box cover. The motor may not be mounted on a solid surface. Replacing the mounting surface may quiet the operation of the motor.

Motor runs slowly

When a motor runs slower than it is rated to run, consider electrical slip in induction motors and be sure there is no overloading of the motor. The voltage supply may be deficient, causing a motor to run too slow. The voltage must be within 10 percent of the voltage rating for the motor; if not, correct the supply voltage.

The bearings of a motor may be binding. This can cause the motor to run at less than the rated speed. Replace the bearings if needed. Cleaning and relubrication may correct the trouble.

The driven machine may cause a motor to run slowly. When you suspect that the driven machine is at fault, disconnect the motor from its load and test it independently.

Occasionally a rotor may be open. This results in the motor's slowing down under load. Repair or replace the rotor.

When troubleshooting 1ø motors, check for such items as bad centrifugal switches, bad brushes, and bad capacitors. If a split-phase motor hums but will not start, the trouble is probably in the centrifugal switch or bad start windings. This same problem with a capacitor start motor might mean the motor has a bad capacitor. All other checks are the same for both 1ø and 3ø motors.

417. Motor replacement

Motor replacement consists of aligning motors and knowing how to wire a single phase and three phase motor. When you electrically connect a motor, you have to determine whether the wiring of the motor is delta and wye connected motors. This procedure is covered in this lesson.

Aligning motors

The alignment of belts sheaves and motor sheaves has already been discussed in a previous volume. In this volume, the alignment of a motor and a pump will be covered. Proper alignment of pump couplings is critical. If the pump and motor are out of alignment, it can cause the bearings to wear out quickly. This objective will cover what tools are used to check for proper alignment and how to use those tools to accomplish proper alignment.

Alignment

Some pumps are built with the pump and motor on one shaft. These, of course, offer no alignment problem. If a separate motor drives the pump, a link between the pump and the motor is required. This link is called a coupling and proper alignment of the pump, motor, and coupling is critical.If the pump and motor shafts are not perfectly aligned, every revolution puts a tremendous load on the pump, motor bearings, and the coupling causing them to wear out quickly. Since the coupling is the weakest component, it could be destroyed within days, sometimes within hours.

Types of misalignments

Misalignments can be broken down into two basic categories: angular and offset. Angular misalignment occurs when two shafts are not parallel. Offset misalignment, or eccentric misalignment, occurs when two shafts are parallel, but not aligned correctly. For example, if the pump shaft is 1/4 inch higher, lower, or to the left or right of the motor shaft, then offset misalignment occurs. This can be caused from the pump and motor being mounted in different positions from each other.

Alignment procedures

Safety is always a factor, no matter what the job is. Always ensure that safety is a prime consideration in anything you do. A couple of safety items that often times get overlooked are the removal of jewelry, de-energizing motors, and securing valves.

Coupling alignment checking

Before learning the actual steps to check and repair alignment, knowledge of what types of tools needed is required. One tool used to check alignment is going to be a straight edge that will determine whether the shafts are level. The next tool needed is a feeler gauge to check the gap between coupling parts. Another tool is a dial indicator that is used to measure the degree of misalignment between the two shafts. When these tools are used, measurements must be taken with them in at least four different places, roughly 90° apart. DO NOT rotate the shafts and coupling to take the measurements. Keep them steady and rotate the tools around the stationary shaft for the measurements. Sequentially check around the shaft. Start at the top then go to one side followed by the bottom, and finish off with the other side. Four measurements are only the bare minimum. More measurements can be taken to ensure greater accuracy.

The first step when checking the coupling's alignment is to remove the guard around the coupling to allow access to the shafts and coupling. Next, loosen the coupling from the shaft and remove it. Before anything else is done, inspect the old coupling for cracks, missing pieces, and deterioration. If any part of the coupling is damaged, replace it with a new coupling.

The next step is to roughly align the shafts so that they are level. If needed add shims to the motor and or pump to get them level and remove any spring that will throw off the alignment. Spring or flex is any space under the motor leg that will cause the motor to be uneven.

Now check the angular alignment of the shafts. For normal coupling hub separation, use a feeler gauge at 4 points, 90° apart. Position the units to obtain the best possible alignment. Normally, the variation should not exceed 0.001 inch multiplied by the coupling size. Couplings with non-standard shaft separation should be installed according to the machinery arrangement drawing, furnished by the coupling manufacturer. For greater coupling hub separation (such as spacers and floating shaft arrangements), use a micrometer or other suitable alignment fixture at 4 points, 90° apart and proceed as in angular alignment.

Next align shafts using a straight edge, by shimming one machine until it appears to be at right angles to the shafts. Repeat three additional points approximately 90° apart. The offset should be less than 0.001 inch multiplied by the coupling size. Recheck angular alignment and hub separation.

Now that the pump and motor are aligned, the flexible coupling needs to be replaced. Clean the hubs thoroughly and insert the flexible coupler between the hubs. For spacers or floating shaft arrangements, the flexible coupler must be inserted between each set of hubs. Draw the hubs together keeping the flexible coupler bolt in line with the hubs. Once everything is in place, tighten the hex screws. Once that is done it is time to tighten all the mounting bolts for the motor and pump. Now double check that the alignment wasn't affected by tightening the bolts.

After installing the pump correctly and ensuring all guards are in place, open all isolation valves. Before energizing the pump, check that the electrical box is not wet and that the switch is in the off position. After cleaning the area, energize the pump and check for proper rotation, that there are no leaks in the piping system, and that the pump is operating at the desired pressures.

Single phase connect

Single-phase AC motors are manufactured for single-voltage or dual-voltage situations. They can also be reversible or nonreversible in operation. These 1ø AC motors are usually made to operate on a common 1ø AC voltage; for example, 120, 208, or 240 VAC.

The single-voltage nonreversible AC motor has only two leads, T1 and T2. The single-voltage reversible motor has leads numbered T1, T2, T5, and T8. A dual-voltage nonreversible motor has four leads numbered T1, T2, T3, and T4. The dual-voltage reversible motor leads are numbered T1, T2, T3, T4, T5, and T8. Leads numbered T6 and T7 are terminals of coils that are usually connected internally.

To operate a dual-voltage motor on high voltage, the run windings must be connected in series (fig. 2–53). Leads T1 and T2 go to one set of windings, while T3 and T4 go to another set. Connecting T2 and T3 together connects the run windings in series for 240 VAC use. Connecting T1 and T3, and T2 and T4 (fig. 2–54), connects the motor for 120 VAC operations. Figures 2–53 and 5–54 show no external terminal leads for the start winding because the connections are made internally. So you see that this motor is a dual-voltage nonreversible type.

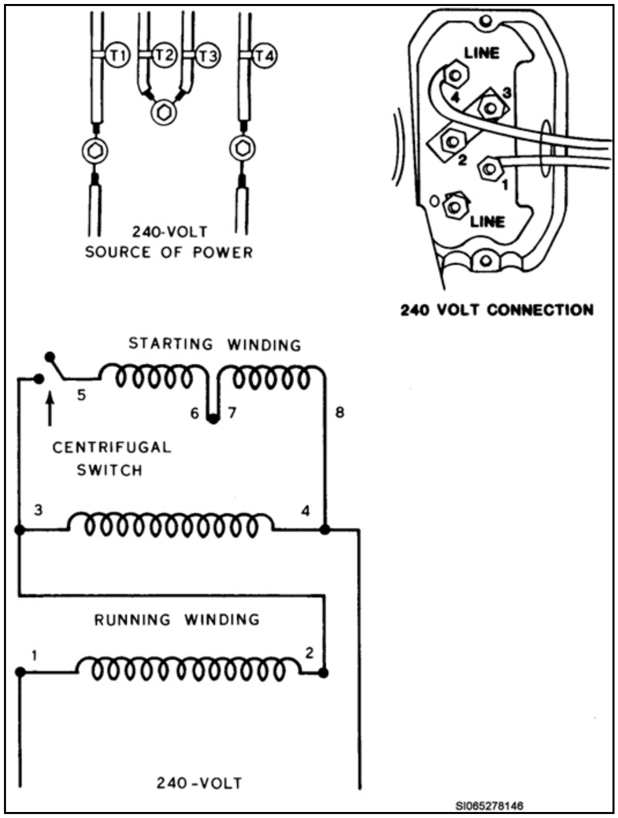


Figure 2-53. High voltage, single phase connections.

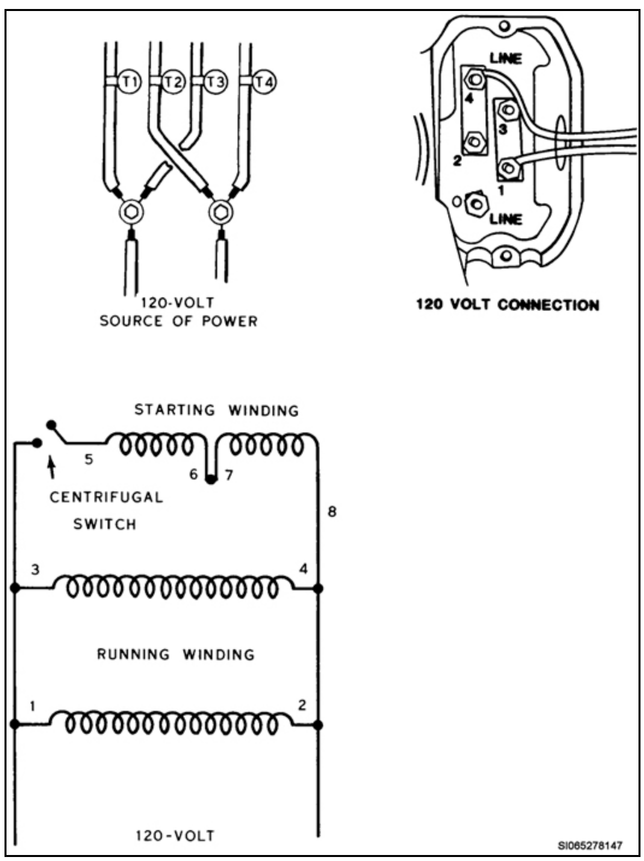


Figure 2-54. Low voltage, single phase connections.

The start winding is always connected in parallel with the run winding, regardless of which voltage (high or low) is connected to the motor. Remember the start winding cannot at any time have more than 120 VAC across it. In a reversible motor, leads T5 and T8 are externally available in the terminal box. To change rotation of a 1ø motor, you must change the direction of the current flow in the start winding in relation to the run winding. You can do this by interchanging leads T5 and T8, which changes the current flow in the start winding and reverses the rotating magnetic field. Of course, you can do reversing procedures only when the start winding leads are externally available.

Three-phase connect

Three-phase motors have both internal and external connections. All 3ø motors are wound with coils that are connected to each other internally to make three separate windings or phases in the stator. The windings of all 3ø motors have either a wye or a delta connection. The internal connections determine if the windings are connected for a delta or wye connection. The external connections are made with the leads brought out of the motor.

Some 3ø motors are single voltage, and others are dual voltage. This tells you that the single-voltage motor operates at one particular voltage (i.e., 220 volts). The dual-voltage motor operates at two different voltages (i.e., 220 or 440 volts), depending on how you make your external connections. A single-voltage 3ø motor requires only three leads to be brought out of the motor. A dual-voltage 3ø motor normally has nine leads coming out of the motor.

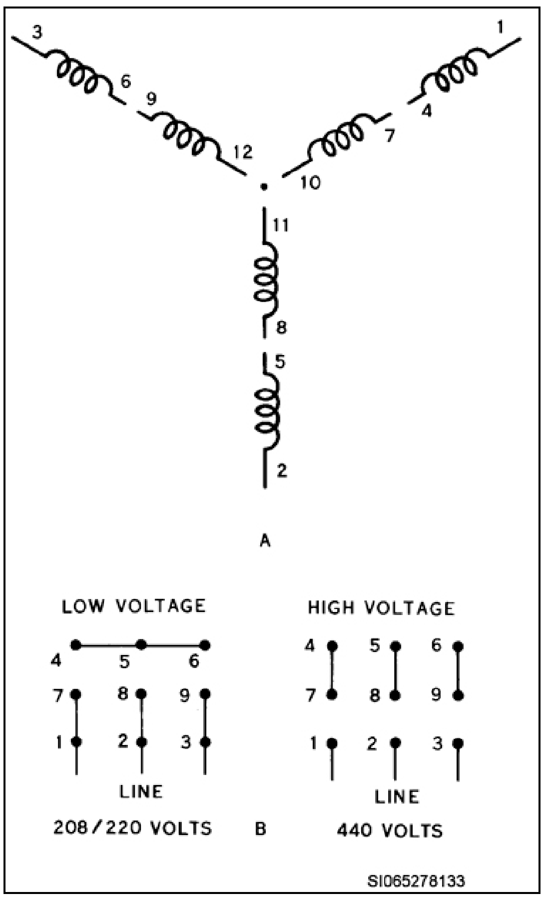


Figure 2–55. Three-phase wye connection.

Wye-connected motors

The symbol for a wye-connected motor is Y, sometimes referred to as a star. Figure 2–55 shows a schematic diagram of a wye-connected dual-voltage motor. As you can see a wye connection looks like the letter Y. Leads 10, 11, and 12 are connected together. (Normally these connections are made inside the motor by the manufacturer.) These leads are the internal connections that form the Y.The remaining nine leads are brought out of the motor for the external connections. Notice in the figure that 208/220 volts is the low voltage, and 440 volts is the high voltage. This information is given on the motor data plate, which we discuss later. Look at the connections for both high and low voltage of a dual-voltage three-phase motor.

In figure 2–56, you see a 3ø wye-connected motor for low voltage (208/220 volts). The low-voltage connections are made by splicing leads 4, 5, and 6 together and taping the connections. Leads 1 and 7 are spliced together and connected to one of the leads of the 3ø power. Respectively, leads 2 and 8 are spliced together; 3 and 9 are spliced together with each splice connected to a power lead. Windings 1–4 and 7–10, 2–5 and 8–11, and 3–6 and 9–12 are in parallel. Placing these windings in parallel causes the impedance (term we use to identify the total opposition to current flow in an AC circuit) of the windings to decrease. Remember when resistance decreases, current increases. When a motor is connected for low voltage, it draws more current than if connected for high voltage.

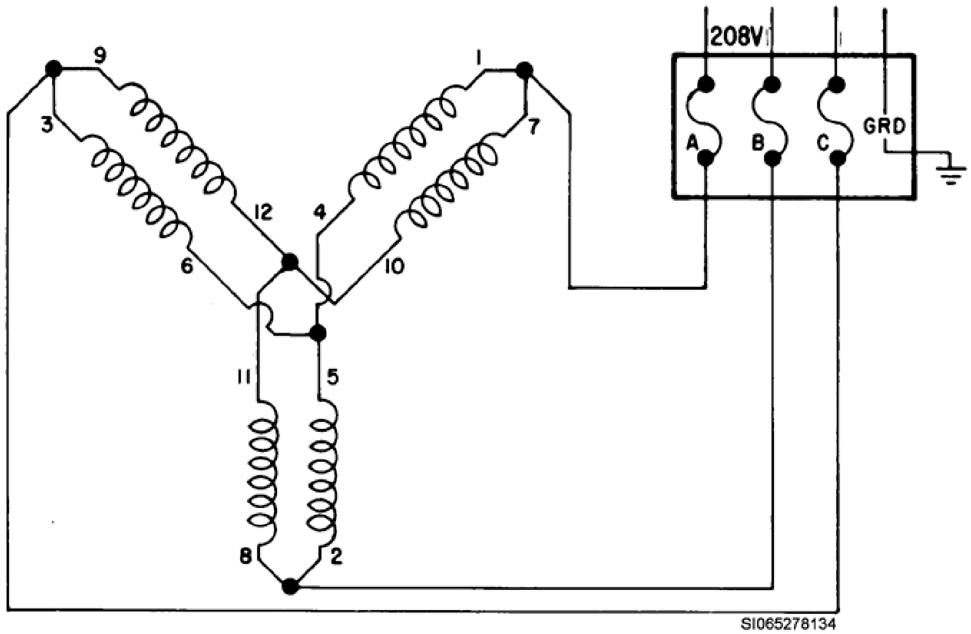


Figure 2-56. Wye connected motor for low voltage.

A schematic diagram of a wye-connected motor for high voltage is shown in figure 2–57. Leads 1 through 9 are brought out of the motor in the terminal box. For high voltage, leads 4–7, 5–8, and 6–9 are spliced together and taped. The 440-volt 3ø power is connected to leads 1, 2, and 3. Each phase is connected separately and taped. For example, the A phase of power is connected to lead 1 of the motor. Thus, you have electrically connected the windings in series for high voltage.

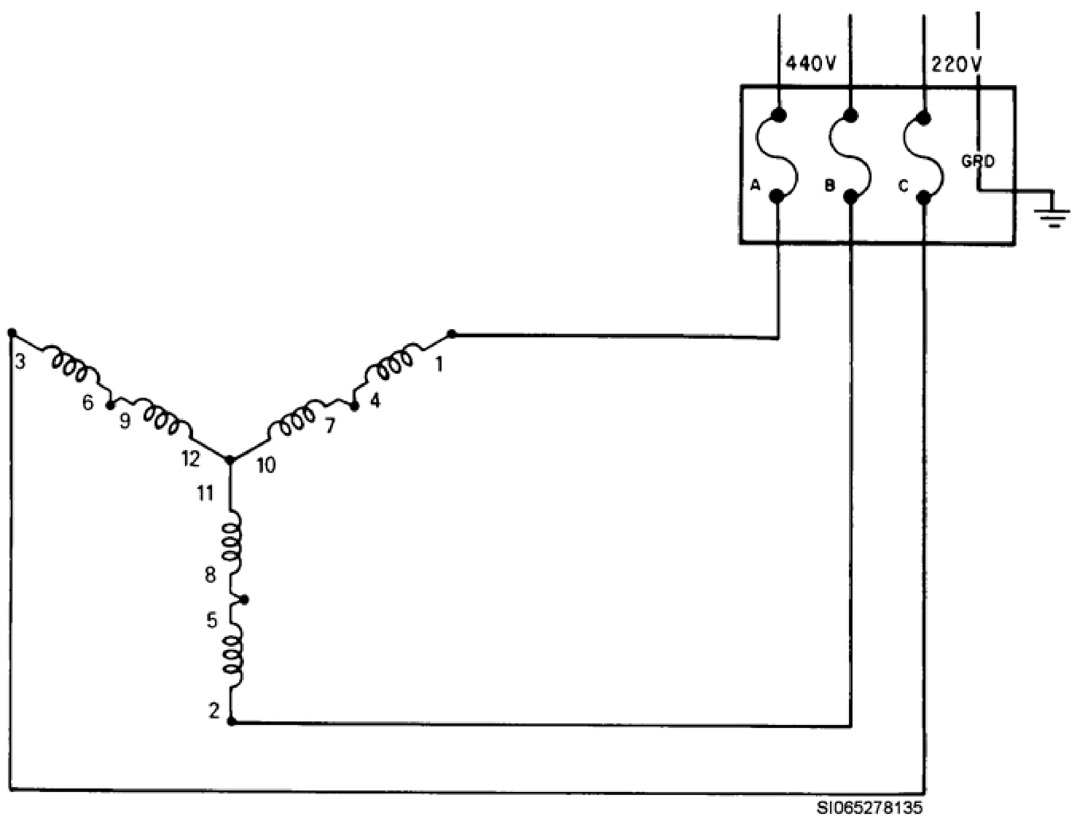


Figure 2–57. Wye connected motor for high voltage.

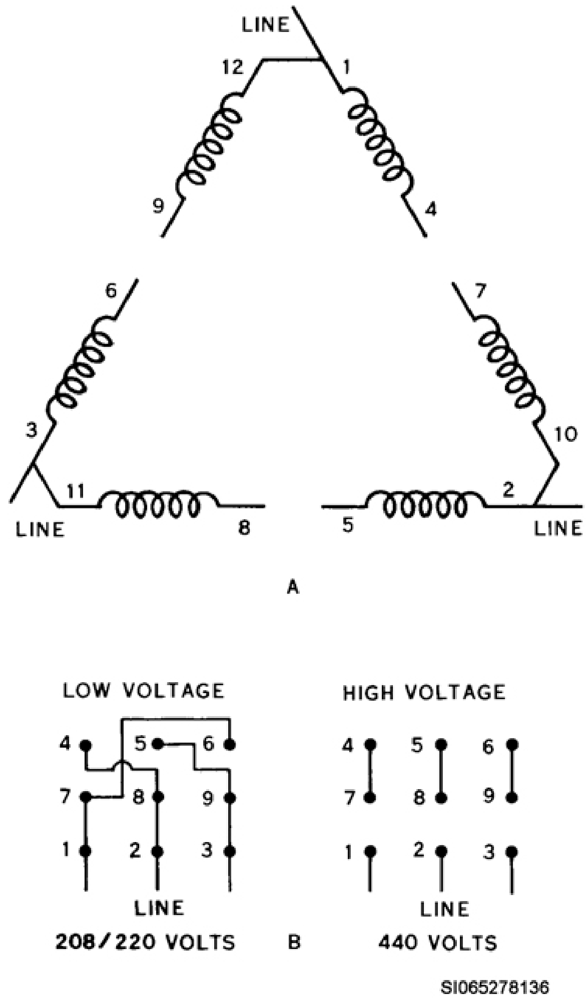


Figure 2–58. Three phase delta connection.

Delta-connected motors

The symbol for a delta-connected motor is the Greek letter delta (Δ). Figure 2–58 shows a dual-voltage delta-connected motor (the winding are in 2–58A and the connections are in 2–58B). As you can see the connection makes the delta or triangle appearance, hence the name. Leads 10, 11, and 12 are connected inside the motor to leads 1, 2, and 3 respectively. Leads 1 through 9 are brought out in the terminal box of the motor.

Figure 2–59 shows a schematic diagram of a delta-connected motor for high voltage (440 volts). Do this by connecting leads 3-7 together and taping the connection. Also splice and tape leads 5-8 and 6-9. Connect leads 1, 2, and 3 to the power source. This configuration places the windings in series for high voltage.

Figure 2–60 shows a schematic diagram of a delta-connected motor for low voltage. Connecting leads 1–6–7, 2–4–8, and 3–5–9 in this manner places the windings in parallel.Therefore, you have a higher current draw when connected for low voltage. Remember, leads 10, 11, and 12 are connected inside the motor to leads 1, 2, and 3.

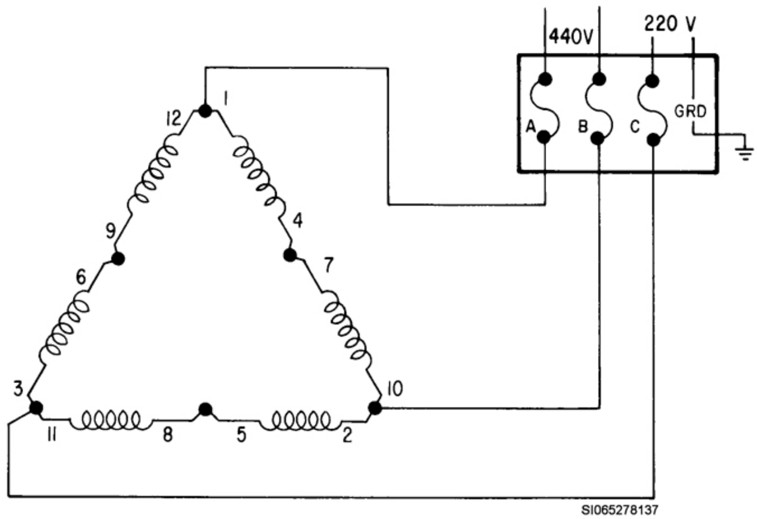


Figure 2–59. Delta connected motor for high voltage.

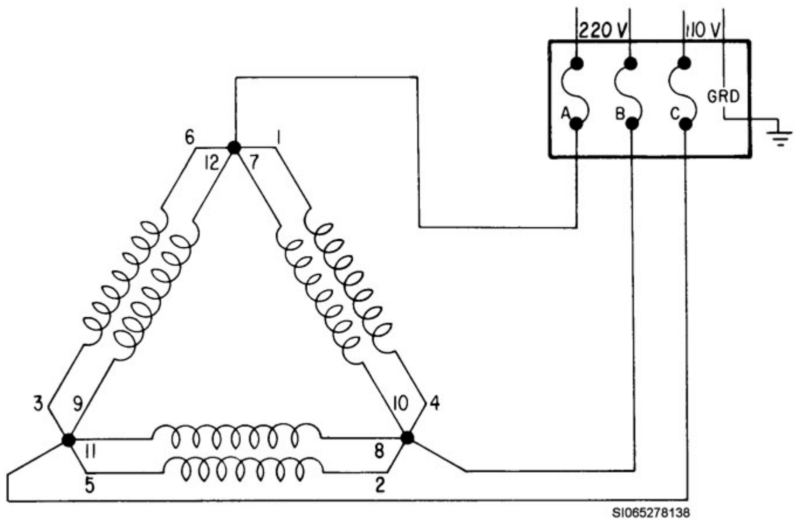


Figure 2–60. Delta connected motor for low voltage.

As you can see by the schematic diagrams, placing the windings in series offers more impedance than the parallel connection. Therefore, a motor connected for low voltage (connected in parallel) draws more current than if connected for high voltage. You should know that the voltage through each coil is the same for high- and low-voltage connections. Figure 2–61 shows the voltage drop across each coil for high- and low-voltage connections.

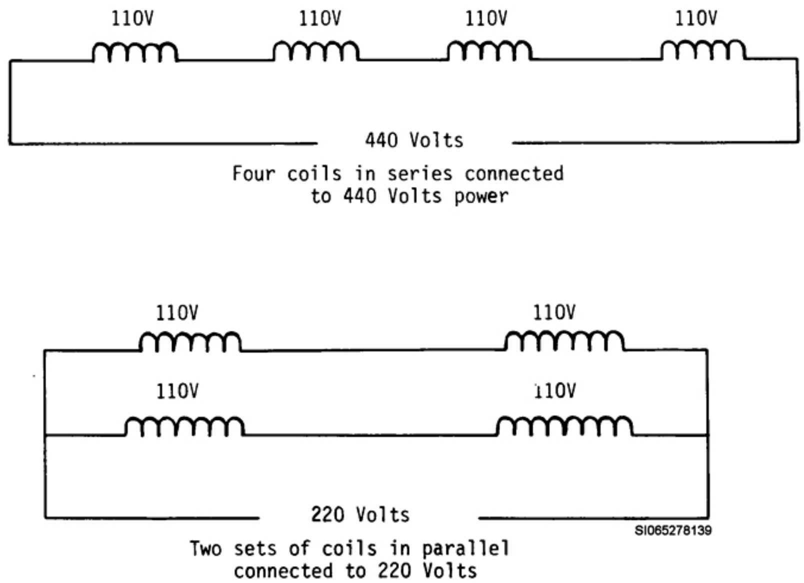


Figure 2–61. High and low voltage delta motor connections.

Remember, you must have three-phase power to operate a three-phase motor. Most 3ø motors are dual voltage and can operate on most 3ø systems; for example, 3ø–208, –240, –440, –277, and –480 voltage systems.

To determine the direction of rotation of a 3ø motor, you start it before you connect the load. If the rotation is incorrect, you can change any two power leads to reverse the rotation of the motor.

418. Wiring motor controls

On many occasions, you need to wire a motor control for a new installation or re-wire an older unit because of a problem that may have existed. In either case, knowing the basics of motor controls can be very handy. The techniques taught in this lesson will remind you of the basics and go a few more steps to help you to do a task with minimal supervision. Remember that there are many methods in our industry. Always refer to a trained peer, supervisor, and the manufacturer's instructions and recommendations for the best application.

Motor-control circuits

Connecting line starters varies only in the location of the terminals and when the starters are to serve different duties. Magnetic-line starters contain two electrical circuits: the load circuit and the control circuit. These circuits are factory wired. The load circuit contains the main or load contacts, the line terminals (L1, L2, L3), load terminals (T1, T2, T3), and the heater coil portion of the overload relay (OL) (fig. 2–62). Load circuit full-load amperage determines the size starter needed. It must have a larger rating than the connected motor. The control circuit (fig. 2–63) contains the holding coil (shown with the letters "HC" in the circle), overload relay reset contacts, and the auxiliary contacts. The control circuit is the portion of the magnetic starter that performs the function of starting, stopping, and protecting a motor. Control devices start, stop, or protect the motor. This could be a simple switch, start/stop station, or thermostat. These control devices allow the coil to energize or de-energize, depending on the situation. The overload contacts work with the current-sensing device that is in the load circuit. The current-sensing device causes the overload contacts in the control circuit to open when there is an over current condition. When these contacts open, the coil de-energizes, and the main contacts open and prevent line voltage from reaching the motor. This is how the motor, or load, is protected from excessive current/temperature. Removing line voltage from the load causes it to stop operating. These control devices are generally connected using a 2- or 3-wire circuit.

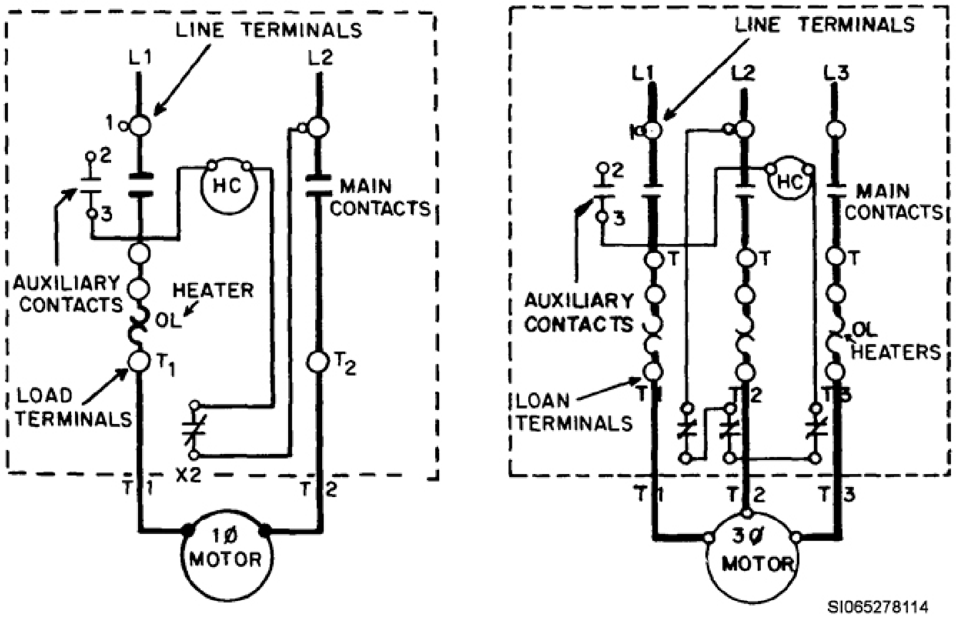


Figure 2–62. Connecting the load circuit in a magnetic starter.

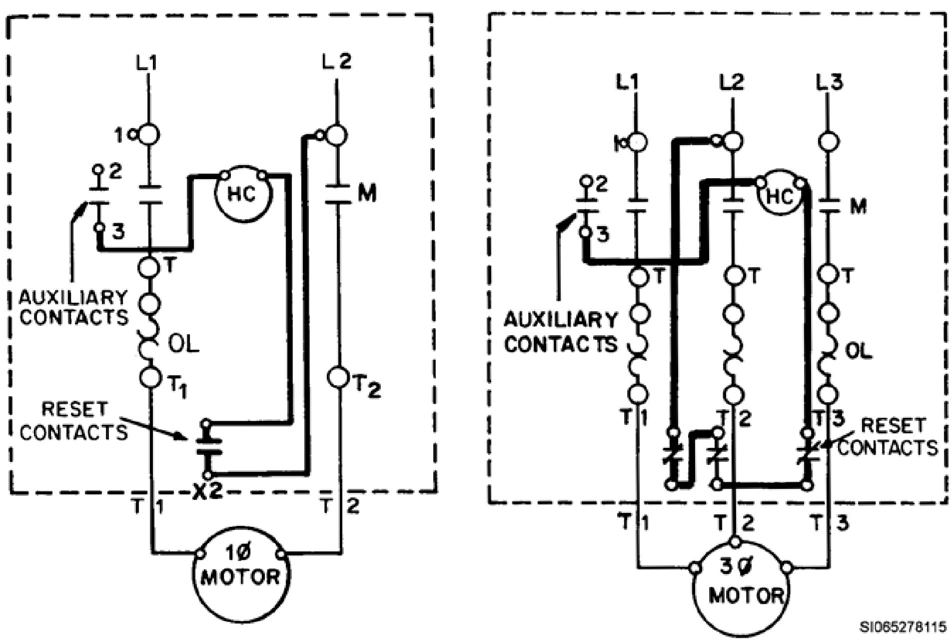


Figure 2–63. Connecting the control circuit in a magnetic starter.

A 2-wire control circuit receives its power from the incoming leads to the starter. The basic series control circuit connects at L1, through the control device, holding coil, and overload reset contacts. It completes the path by returning to L2 or neutral, depending on the voltage rating of the coil.

Figure 2–64 shows a diagram of a 2-wire control circuit using a single-pole toggle switch as a control device. The magnetic coil connects to the line on one side through the overload reset contacts and on the other side through the contacts of the toggle switch. Since the contact of the toggle switch remains closed, the contactor energizes. When you open the contacts of the toggle switch, the coil de-energizes and the contactor opens. Notice that when an overload occurs, the overload relay reset contacts opens and removes the holding coil from the circuit. When you reset the overload relay, the contactor immediately picks up because the toggle switch is in the closed position.

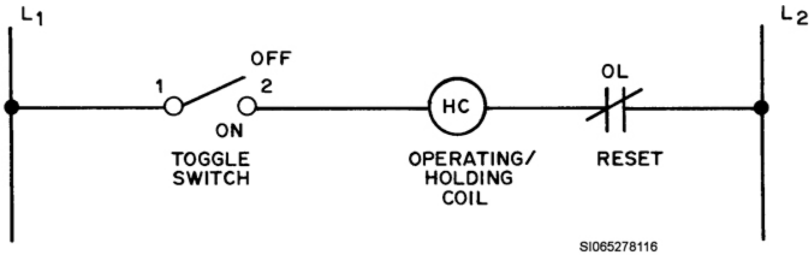


Figure 2–64. Two-wire control circuit.

A 3-wire control circuit also receives its power from the incoming leads to the starter. This circuit uses the same parts as the 2-wire circuit, except that the auxiliary contacts and a stop-start station are introduced (fig. 2–65). Remember, the auxiliary contacts are controlled by the holding coil. They close and open at the same time as the main contacts. The stop-start station is a manually controlled device containing a start and stop button. When you press the start button, a normally open set of contacts closes; and, when you press the stop button, a normally closed set of contacts opens. Spring action returns the buttons to their original position when you remove finger pressure.

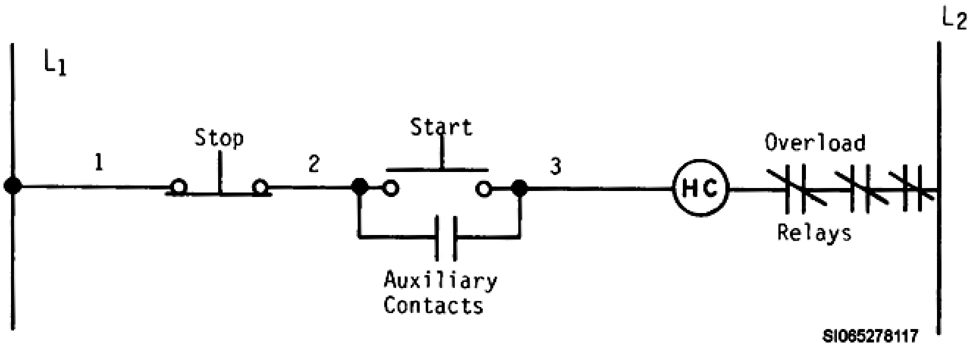


Figure 2–65. Three wire control circuit.

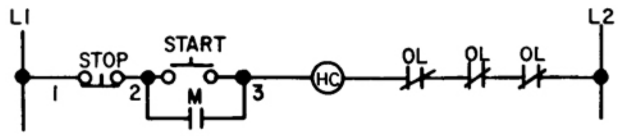
When operating magnetic starters with stop-start stations, it is necessary to connect the holding coil to the stop-start station so that, when the start button is pressed, the coil energizes. When the stop button is pressed, the holding coil circuit opens.

Three-phase controller

For control of a 3ø motor, use a 3ø–line magnetic starter. The 3ø starter has line terminals L1, L2, and L3 to which you connect the incoming power or line conductors and T1, T2, and T3 (load terminals) to which you connect the motor load conductors. You must install motor-running overload protection devices, like thermal or magnetic overload relays, under the rules of the NEC. The 3ø starter has terminals 2 and 3 of the auxiliary or holding contacts to which you connect control devices.

A typical diagram of 3ø-line magnetic starters equipped with three thermal overload relays and connected to a stop-start push-button station is shown in figure 2–66. For the motor to operate, the three sets of normally open contacts (main contacts) must close to supply power to the load circuit. The load circuit starts at the “T” terminals of the main contacts on the magnetic starter. It passes through each heater and then on to terminals T1, T2, and T3 in the magnetic starter. Finally, it connects to terminals T1, T2, and T3 on the motor. To close the main contacts, the coil energizes through the control circuit. The control circuit runs from terminal L2 through the three sets of normally closed contacts (reset contacts) through the coil and to terminal 3 on a set of normally open contacts (auxiliary or holding contacts). Although these connections are factory wired, you may have to make them if the wire becomes burnt or is missing. You must connect the control circuit to L1 to have a complete circuit for energizing the coil.

Here is where the various types of controlling take place. Now connect terminal 3 of the auxiliary contacts to terminal 3 of the stop-start station (fig. 2–66). Next connect terminal 2 of the auxiliary contacts to terminal 2 of the stop-start station to L1 of the magnetic starter. Now a circuit is complete between L1 and L2, and the coil can energize. The circuit from terminal 3 of the auxiliary contacts to L1 (fig. 2–67) is the start circuit. Another circuit known as the holding circuit is connected from terminal 2 of the auxiliary contacts to terminal 2 of the stop-start station (fig. 2–68).



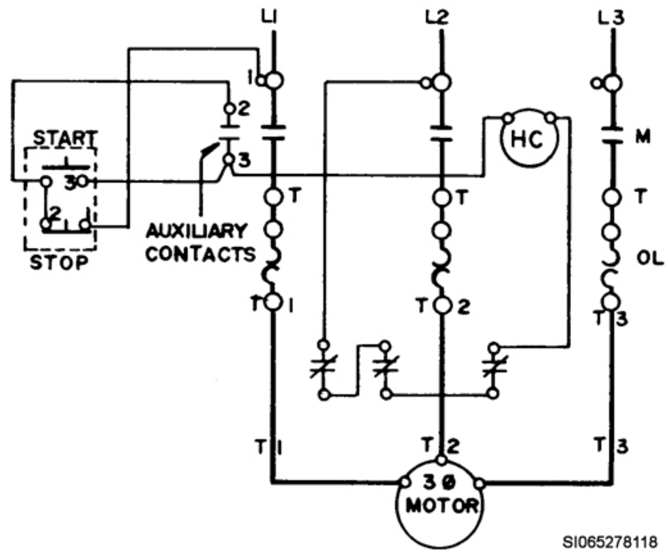


Figure 2–66. Connecting a three phase magnetic starter.

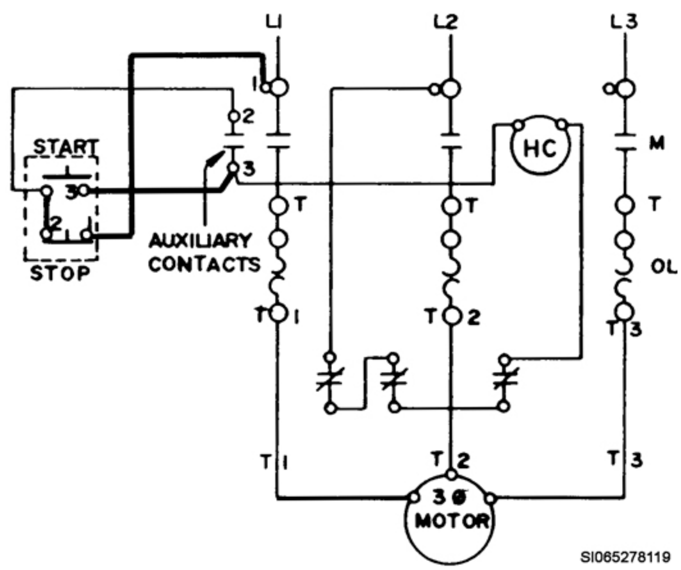


Figure 2–67. Connecting the starter circuit in a magnetic starter.

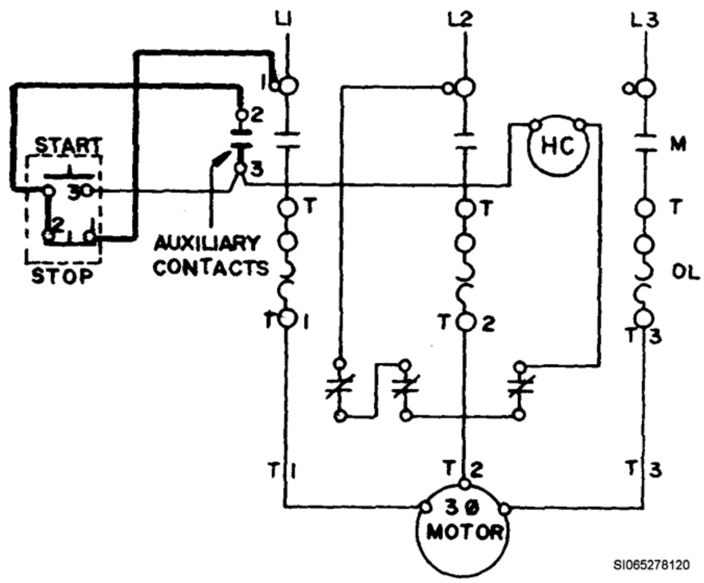


Figure 2–68. Connecting the holding circuit in a magnetic starter.

Single-phase controller

To control a 1ø motor, use a 1ø-line magnetic starter. The 1ø starter has line terminals L1 and L2 to which you connect the power or line conductors and T1 and T2 to which you connect the motor load conductors. Like the 3ø controller, the 1ø magnetic starter has an overload relay with thermal or magnetic current sensing devices installed in accordance with the NEC. The 1ø starter has terminals 2 and 3 of the auxiliary or holding contacts to which you connect control devices.

Figure 2–69 illustrates a diagram of a typical 1ø-line magnetic starter equipped with one thermal overload relay and connected to a stop-start station. This time, only two sets of main contacts must close to supply power to the load circuit for the motor to operate. Like in the 3ø starter, the 1ø–starter load circuit is wired the same minus the third phase. Again, to close the main contacts, the coil must energize through the control circuit. When a 1ø starter has a dual-voltage coil, the coil voltage connection is the only change to the control circuit wiring. The dual-voltage coils (fig. 2–70) are wound for several different voltages. The most common are 110 or 220 volts and are labeled or color coded (colors not shown). If the coil is color coded, the red lead is the common and is used with either voltage connections. You must connect the white lead to the reset contact terminals when 110 volts (low voltage) is required. However, when using 220 volts (high voltage), the black lead connects to the reset contact terminal. Again, you would wire a stop-start station to the 1ø starter as you did to the 3ø starter.

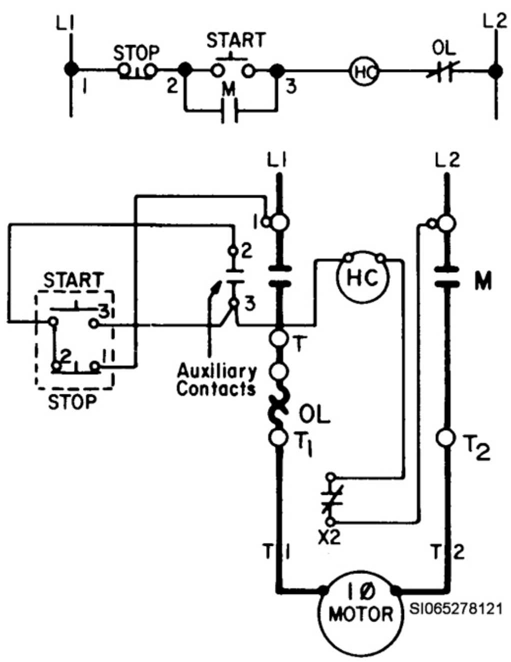


Figure 2-69. Single phase magnetic starter.

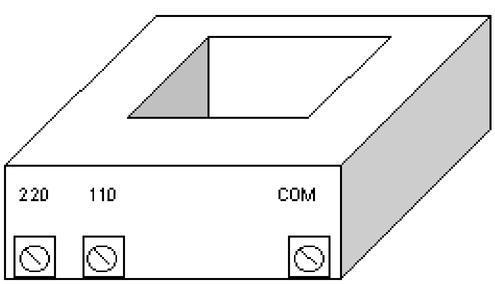


Figure 2-70. A dual voltage holding coil.

Automatic devices

Automatic devices control or operate magnetic starters. We describe some of the most common types in the following paragraphs.

Float switches

Usually float switches control fluid levels. In these switches is a set of contacts that open or close mechanically by a lever and float assembly. By using motor-driven pumps controlled by a float switch, the level of liquid is increased or decreased automatically. An example of a common use of a float switch is to control the water level in a boiler.

Pressure switches

Pressure switches are used to control the pressure of gases, air, and liquids within a desired range. For example, a motor on an air compressor is controlled by a pressure switch.

Thermostats

A thermostat is a device that is sensitive to temperature and is used widely to control heating and cooling systems. When you use a thermostat, a float switch, a pressure switch, or any automatic control to control the magnetic starter, the holding circuit is not used. So you connect an automatic control, such as a thermostat, to terminal L1 and terminal 3 of the auxiliary contacts on the 3ø or 1ø magnetic starters (fig. 2–71). The contacts in the thermostat or float switch give you a circuit to keep the coil energized. Therefore, the auxiliary contacts are not needed.

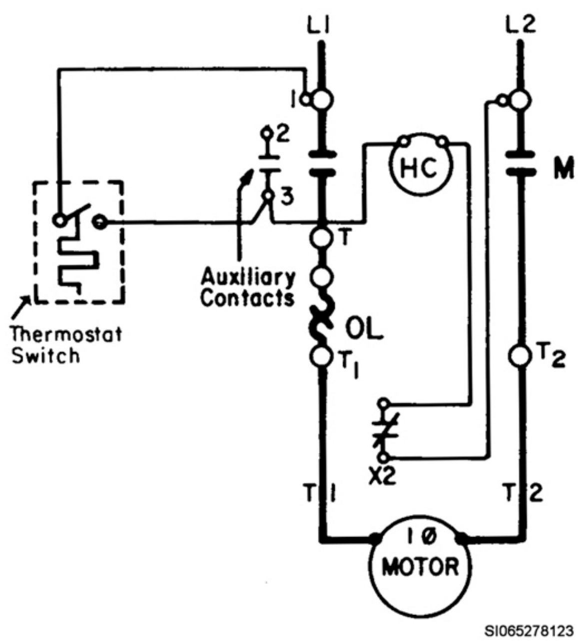


Figure 2–71. Thermostat controlled motor system.

Hand-off-auto switch

A hand-off auto (HOA) switch is a three-position selector switch (fig. 2–72). You can stop, manually operate, or automatically operate a motor system by moving the selector knob from one position to the other. HOA switches are used in various control systems.

For example, an HOA switch may be used with a thermostat (fig. 2–73). Here you connect terminal 3 of the HOA switch to one of the terminals on the thermostat. Next, connect terminal 4 of the HOA switch to terminal 3 (pressure clip) in the magnetic starter. Then connect the open terminal of the thermostat to terminal 3 (pressure clip) in the magnetic starter. There will now be three conductors under the pressure clip at terminal 3 in the magnetic starter. Finally, connect either terminal 1 or 2 of the HOA switch, since they are common, to terminal L1 in the magnetic starter.

When you turn the HOA switch to the automatic position, the thermostat contacts must close before the magnetic starter energizes. When you place the switch in the hand position, the thermostat is bypassed and the magnetic starter energizes.

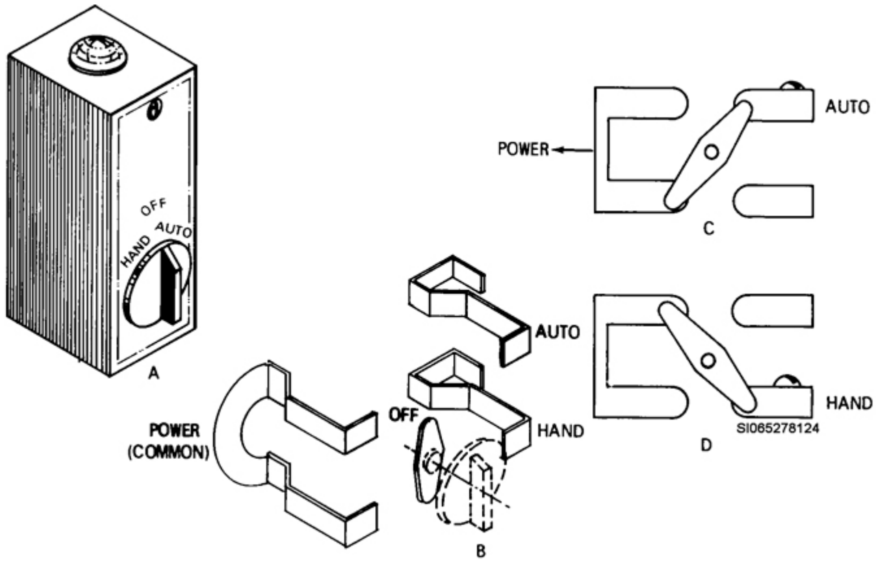


Figure 2–72. HOA switch.

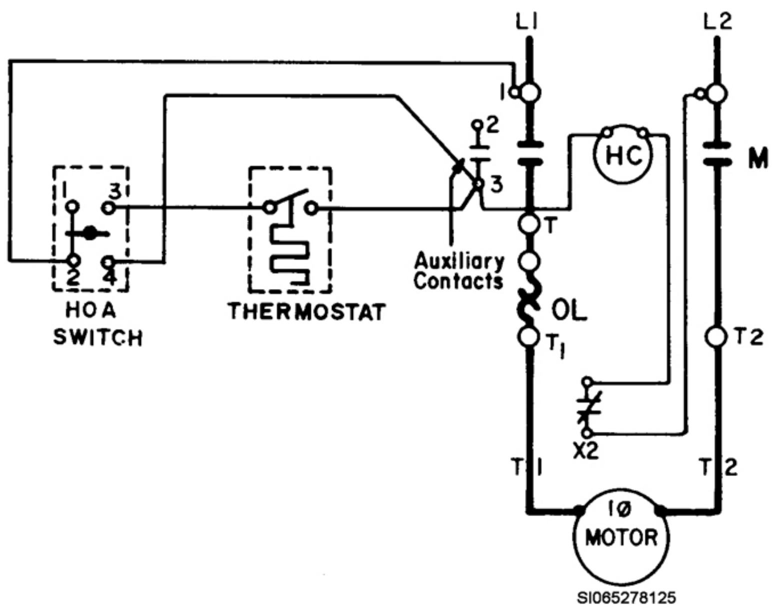


Figure 2–73. HOA combined with thermostat.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

412. Motor concepts

1. Where is the run winding *usually* located in the stator?

2. Where is the start winding usually located in the stator?

3. What happens to the flyweights of the centrifugal switch as the rotor turns?

4. How is a magnetic field created inside the stator?

5. What causes the rotor to turn?

6. When does the centrifugal switch cut out the start windings?

7. When does the centrifugal switch contacts close?

8. In a capacitor run motor, when are the run and start windings in the circuit?

9. In a permanent-split capacitor motor, how many turns does the start windings have compared to the run windings?

10. What are the operating characteristics of a permanent-split capacitor motor?

11. In a shaded-pole motor, what effect does the copper band have on the magnetic field?

12. In a squirrel-cage rotor, what does the end rings do to the rotor bars?

13. With a wound-rotor connected for wye operation, where are the ends of the windings connected?

14. What happens when the current in one winding reaches its *maximum* value?

413. Motor controllers

1. How does an overload device protect the motor windings?

2. How do you operate a 240-volt motor with two hot conductors?

3. When does current-sensitive elements de-energize the motor starter?

4. What happens to the holding coil and main contacts when the reset contacts open?

5. When dealing with a melted alloy overload relay, when can you restart the motor?

6. When does the magnetic overload relay pull the piston up and open the control circuit contacts?

414. Operate and service a motor

1. What affects the lockout procedures?

2. When removing electric motors, what step is performed *after* securing the electrical power?

3. For easy replacement, what should you do to wires *after* you remove them from the motor terminals?

4. Besides the wires, what must be removed *before* you can remove the electric motor for servicing?

5. When the motor is connected to what it is driving via a V-belt system, what must be removed *before* conducting some services on the motor?

6. When would the dry type capacitor be used?

7. Why should you *never* use a capacitor that is under the original capacitor capacity?

8. How should a capacitor be discharged?

415. Troubleshooting motors

1. Which conditions should you check *before* disconnecting electrical power lines or troubleshooting the electrical system?

2. How do you determine if the driven machine is at fault?

3. What rotor shaft action would indicate a bent shaft?

4. When should the bearing be replaced?

5. If you have continuity between the starter terminals (T1, T2, and T3) and the motor terminals (T1, T2, and T3), for what should the stator of the motor be checked?

6. What happens if an open exists in a squirrel-cage rotor?

7. How do you check for shorted circuits across conductors?

8. What will continuity across any two conductors indicate?

416. Correct motor malfunctions

1. What is the *second* check to perform if a motor is running hot?

2. What is the *third* check to perform if a motor is running hot?

3. How could a noisy motor issue be resolved?

4. Under what condition will proper lubrication stop excessive noise?

5. What is a possible result of the voltage supply being deficient?

6. What is the result of a motor binding?

417. Motor replacement

1. When does angular misalignment occur?

2. When does offset misalignment occur?

3. What is the *first* step when checking the couplings misalignment?

4. After you remove the coupling from the shaft to check alignment, what should you do next?

5. When aligning the coupling, after you align the pump and motor, what do you do to the hubs?

6. What determines if the windings are connected for delta or wye connection?

7. How many leads are coming out of a dual-voltage 3ø motor?

8. In a wye connected motor, how are leads 10, 11, and 12 connected?

9. How is 440-volt 3ø power connected in a wye motor?

418. Wiring motor controls

1. How is the motor starter size determined?

2. Where does a two-wire control circuit receive its power from?

3. When would a holding circuit not be used with a magnetic starter?

4. What happens when the HOA switch is placed in the hand position?

Answers to Self-Test Questions

409

1. At a distribution panel.
2. Never.
3. At construction sites or deployed locations.
4. Indefinitely.
5. In voltage and amperage.
6. It will not fit.
7. In low capacity branch circuits only.
8. Round.
9. To protect control circuits, alarm systems, and electronic circuitry.
10. To protect the circuit.
11. It cannot be rated any higher.
12. You may have to order a replacement.
13. The fuse would blow as soon as the high current condition exists and the motor wouldn't start.
14. Time delay.
15. At 500 percent of the maximum current rating.
16. It weakens the metal and it's not safe.
17. To not break the fuse clips or holders.
18. Excessive heat and the chance of explosion or rupture.
19. Ask an electrician.
20. The original could have been the wrong size.
21. A circuit breaker can be reset without having to remove or replace it.
22. Because it does not open immediately when the overload occurs.
23. By the size of the overload.
24. Because they are sealed units.
25. It is connected to another terminal on the GFCI instead of to the neutral bar in the panel.
26. The breaker panel door.
27. Flipping the breaker.

410

1. In amperes and volts.
2. Applied voltage.
3. The number of circuits that can be completed through the switch at any one time.
4. The number of times you can move the toggle or plunger of the switch in one direction.
5. By an insulator.
6. By a permanent magnet.
7. Burning the contacting surfaces and switch failure.
8. To complete the circuit.
9. In a water-resistant case.

411

1. To the circuit requiring the changed voltage.
2. A magnetic field cuts through the turns of a coil.
3. Based on the number of turns. If a transformer has fewer turns in the secondary, its output voltage is stepped down, and if a transformer has a higher number of turns in the secondary, its output voltage is stepped up.
4. It has little resistance to magnetic lines.
5. If voltage is leaving the secondary side of the transformer.
6. By ohming out each side.
7. STOP! This means you do not have voltage going to the transformer, so you must find out why.
8. O.L.
9. Manually or automatically.
10. When the current is shut off to the coil.
11. Terminals C1 and C2.
12. When a coil energizes it changes the position of its corresponding contacts.
13. Closed.
14. That voltage is being applied to the coil.
15. That voltage is not being applied to the coil.
16. Turn off the power to the system and then verify the system is dead.
17. Label the wires you are removing to match the terminal you took them from.
18. Turn the system on and ensure it operates correctly.
19. When current passes through the coil, the magnetic field developed around the coil pulls the movable iron core down into the coil.
20. A coil that is both waterproof and fungus proof.
21. Turn the system ON and observe the system to ensure it runs properly.
22. Verify power.

412

1. At the bottom of slots in the stator.
2. On top of the run winding in the stator.
3. They are pulled out by centrifugal force.
4. When voltage is applied to both the start winding and run winding, the current in the run winding lags the voltage more than the current in the start winding.
5. The rotating magnetic field induces a current in the rotor which sets up a magnetic field. The magnetic fields combine in such a manner as to cause rotation of the rotor.
6. When the motor reaches 75 percent of full speed.
7. When the motor stops.

8. At all times.
9. The start windings in this motor are not high-resistance windings and have the same number of turns and wire size as the run windings.
10. Poor starting torque with a high-current draw.
11. It delays the magnetic field.
12. They short circuit or connect the rotor bars and end rings together.
13. One end of the windings is connected together in the center, and the other end is connected to slip rings mounted on the shaft.
14. The winding produces a strong magnetic field.

413

1. By interrupting the current flow when an overload situation exists.
2. Use a double-pole switch to open or close both conductors at the same time.
3. When excessive current conditions exist.
4. The holding coil de-energizes and opens the main contacts?
5. After the alloy cools and solidifies sufficiently.
6. When a determined amount of current passes through the coil.

414

1. The local procedures established in your area.
2. Removing the wires from the motor terminals.
3. Label the terminals.
4. The attaching hardware.
5. The belts.
6. For intermittent operation.
7. This could cause further damage to the motor windings.
8. Use a 20,000 ohm, 2 watt resistor across the capacitor terminals.

415

1. Overload, loss of power, bad or improper connections, driven machine blocked and frozen or worn bearings.
2. Disconnect the motor from its load and try to rotate the rotor shaft of the motor by hand.
3. Wobbling.
4. If you note up-and-down movement.
5. An open circuit.
6. The motor slows down under load.
7. Start with the source of power and carry through to the motor windings.
8. A short circuit between the main disconnect and the starter.

416

1. Check the rating of the overload relay against the full-load current.
2. Check the available voltage to be sure the motor is not operating on under voltage or over voltage. It may be necessary to lighten the load or install a larger motor.
3. By tightening the mounting bolts and the motor support securely.
4. If there is no permanent damage to the bearings.
5. Motor running too slow.
6. This can cause the motor to run at less than the rated speed.

417

1. When two shafts are not parallel.
2. Occurs when two shafts are parallel, but not aligned correctly.

3. Remove the guard around the coupling to allow access to the shafts and coupling.
4. Inspect the old coupling for cracks, missing pieces, and deterioration.
5. Clean the hubs thoroughly and insert the flexible coupler between the hubs.
6. The internal connections.
7. Nine.
8. They are connected together.
9. To leads 1, 2, and 3.

418

1. Load circuit full amperage.
2. From the incoming leads to the starter.
3. When you use a thermostat, a float switch, a pressure switch, or any automatic control to control the magnetic starter.
4. The thermostat is bypassed and the magnetic starter energizes.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

35. (409) Where is a permanent distribution panel mounted?
    a. At a construction site.
    b. Outside of a tent in the desert.
    c. At a forward operating base only.
    d. In a wall or other frame structure in a facility or home.

36. (409) What happens to the circuit when a fuse blows?
    a. It creates a short.
    b. It creates an open.
    c. It creates a ground.
    d. It closes the circuit.

37. (409) How does a magnetic-type circuit breaker open the circuit?
    a. Automatically after 8 seconds.
    b. Automatically after 10 seconds.
    c. Through delay action.
    d. Instantly.

38. (410) In a push-button switch, why are the push buttons insulated from the movable contact?
    a. To prevent the switch from closing when it is pushed.
    b. To avoid injury from electrical shock.
    c. To create heat from the current.
    d. To complete the circuit.

39. (410) How must a snap-action switch close to avoid excessive arcing?
    a. Quickly or slowly.
    b. Quickly.
    c. Slowly.
    d. Within one minute.

40. (411) Which coil of a transformer is always connected to the incoming power?
    a. Both coils.
    b. Primary coil.
    c. Secondary coil.
    d. The control side.

41. (411) What is generated around the coil if AC flows through it?
    a. Conduction.
    b. Relative motion.
    c. DC voltage.
    d. An alternating magnetic field.

42. (411) What happens when an alternating magnetic field is generated by one coil and cuts through the turns of a second coil?
    a. DC current will flow.
    b. DC voltage is created.
    c. A magnetic field stays in the primary coil.
    d. A voltage is induced in the second coil.

43. (411) What happens when 24 volts is applied to a relay coil?
    a. Contacts change positions.
    b. Contacts will only close.
    c. Contacts will only open.
    d. Contacts will maintain their position.

44. (411) What is the *principal* cause of a solenoids coil malfunction?
    a. Excessive heat.
    b. Refrigerant.
    c. The armature.
    d. Technician negligence.

45. (412) In a split-phase motor, if the start winding is *not disconnected* after a short period of time, it will
    a. burn up.
    b. increase efficiency.
    c. increase running torque.
    d. open after five additional minutes.

46. (412) How does the split-phase motor operate after the start winding is removed?
    a. By the rotating magnetic field produced by the run winding and endbell.
    b. By the rotating magnetic field produced by the run winding and rotor.
    c. By the twisting magnetic field produced by the run winding and stator.
    d. By the rotating magnetic field produced by the DC sine wave.

47. (413) How is a toggle switch wired with the hot conductor in the circuit?
    a. Wired to create an open.
    b. Directly to the neutral.
    c. In parallel.
    d. In series.

48. (413) What prevents the contactor chatter?
    a. Shaded rings.
    b. Solenoid.
    c. Rubber gaskets.
    d. Control voltage.

49. (413) When replacing a heater, how are they identified?
    a. Use the same one you are replacing.
    b. Catalog number.
    c. By size.
    d. By color.

50. (414) The *first step* in removing an electric motor is to ensure the circuit breaker
    a. or disconnect switch is closed.
    b. is closed and the disconnect switch is open.
    c. is open and the disconnect switch is closed.
    d. or disconnect switch is open.

51. (414) When an external-drive motor starts but hums, what is the probable cause?
    a. A bad capacitor or centrifugal switch.
    b. A bad motor.
    c. A bad stator.
    d. A bad rotor.

52. (415) When troubleshooting motor failure, how do you determine if a motor is overloaded?
    a. Take an ohm reading.
    b. Take a megohm reading.
    c. Take a current draw with an ohmmeter.
    d. Perform a current draw with an ammeter.

53. (415) What should the motor shaft be check for when troubleshooting motor failure?
    a. Depth.
    b. Width.
    c. Length.
    d. Any up or down play.

54. (415) What does a meter reading of ohms mean when checking a circuit to a grounded surface?
    a. An open.
    b. A ground.
    c. The circuit is not grounded.
    d. There is no resistance to ground.

55. (416) What could create *excessive* noise from the motor?
    a. Rotor is aligned.
    b. Motor is disconnected.
    c. Belts are at proper deflection.
    d. Motor not being securely mounted.

56. (416) How can motor accessory noise be eliminated?
    a. Placing tape over wire nuts.
    b. Tightening the wire nuts.
    c. Tightening the oil well cover and connection box cover.
    d. Placing electrical tape over connection box.

57. (417) When checking coupling alignment, what should you do if any part of a coupling is damaged?
    a. Use coupling glue to fix it.
    b. Tape it together.
    c. Refurbish it.
    d. Replace it.

58. (417) How must the run windings be connected, to operate a dual-voltage motor on high voltage?
    a. Directly to the transformer.
    b. Directly to the thermostat.
    c. In parallel.
    d. In series.

59. (417) How do you change the rotation of a three-phase motor?
    a. Change all three power leads.
    b. Change any two power leads.
    c. Connect one lead to neutral.
    d. Wire it for a single-phase application.

60. (418) Where are the load terminals connected in a three-phase controller?
    a. T1, T2 and T3.
    b. L1, L2, and L3.
    c. L1 and L2.
    d. T1 and, T2.

61. (418) What contacts must close for supply power to be sent to the load circuit?
    a. The normally open main contacts.
    b. The normally open line contacts.
    c. The normally closed main contacts.
    d. The normally closed line contacts.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Types of HVAC/R Controls

THIS UNIT COVERS HVAC/R controls. Controls are essential to the proper, efficient and safe operation of any piece of HVAC/R equipment. Whether it is a simple switch or a complex electronic board controls are monitor and operate our systems. Controls can be an intimidating topic for a new HVAC/R technician but with repetition and patience you can be very proficient in this sector of HVAC/R.

This unit opens up with air compressors and their preventative maintenance. Next, we lay a strong foundation by covering control fundamentals. After you understand the fundamentals we dive deeper and learn the about electric and electronic controls. Finally, we conclude the unit with a discussion on Direct Digital Controls, Emergency Monitoring Control Systems and subsystem control strategies. Let's get started with the interesting unit.

3–1. Air Compressor Types and Maintenance

Air compressors used to be used more commonly in the Air Force because control systems used to be pneumatic. Technology has allowed newer and more efficient systems to be created. Regardless, air compressors are still out there at many, if not all, Air Force bases. This section will cover air compressor types and general maintenance procedures for them.

419. Air compressor types

Air compressors are very similar to refrigeration compressors. They both compress gases and change a low pressure vapor to a high pressure, high temperature vapor. Just like refrigeration compressors, air compressors come in different designs and configurations and have different methods of compression. As you continue to read the information, try to visualize the similarities of the refrigeration compressor with the air compressor.

Oil-free systems

Oil-free compressors are used in applications that cannot tolerate lubricants getting downstream from the compressor. It is critical to remove unwanted oil aerosols and vapors from compressed air, not just moisture. The best way to remove them is not to put them there in the first place. Although aerosols and vapors are found in ambient air, many of them are generated by an oil lubricated compressor. If the compressor runs for an extended period of time, the oil will heat up and turn into a vapor. This oil ends up degraded and oxidized by the heat of compression. Once heated, the oil can carbonize and form a solid, varnish-like substance on downstream equipment, causing valves and air tools to malfunction. If the oil is mixed with water, it forms a sludge that can gum up components of the air line.

Downstream from the compressor, an air receiver stabilizes system pressure, serves as a demand reservoir, and holds some moisture. Downstream from the receiver an air drier provides the correct pressure dew point and traps the remaining moisture. If either of these fails, there is still a coalescing filter after the drier to provide protection. A dry receiver can also be installed after the coalescing filter to stabilize pressure and serve as a reservoir for times of high demand.

Lubricated systems

These types of systems use a lubricant to alleviate friction between moving parts. In rotary screw compressors, the lubricant is used to seal clearances between the screws and as a coolant by removing the heat of compression, thus cooling the compressor. The viscosity of the lubricant used in the compressor will depend largely on the operating ambient temperature. The lubricant must offer adequate lubrication for bearings and rotors at its normal operating temperature. In addition, it must have a pour point suitable to provide fluidity at low starting temperatures during the cold months.

A modern, lubricated rotary screw compressor and a high-efficiency purification system can produce compressed air with very high purity. These systems are very similar to the oil-free system, consisting of a wet receiver, an air drier, and a coalescing filter. There is, however, a charcoal filter between the coalescing filter and the dry receiver that removes any leftover vapors and odors.

The more common air system that you will encounter during your military career will be the industrial air compressing system which is commonly found as a lubricated air system. The types of compressors that you will find on these systems are reciprocating, rotary, screw, and centrifugal compressors.

Climate control system

A climate control air compressing system is the heart of a pneumatic controls system. The air compressor supplies the necessary pressure to power the pneumatic controls used in HVAC systems. Compressors used for climate control systems can be oil-less reciprocating or lubricated reciprocating. A lubricated compressor uses oil to lubricate the piston rings, while the non-lubricated air compressor uses self-lubricating rings, so lubricating oil is not required. Climate control lubricated reciprocating compressors usually run at lower speeds than industrial air compressors in order to create less heat and prevent oil from migrating into the compressed air. Proper operation of pneumatic control systems requires a supply of clean, dry, oil-free air as the primary power source for actuation of pneumatic controls.

Industrial air compressing system

Unlike the climate control air compressing system, an industrial air compressing system operates at a higher volume and higher pressures. It is also more elaborate in design. In the industrial air compressing system the air compressor can supply pressure for pneumatic controls used in HVAC systems, paint spraying, and air operated tools. These applications require the air to be moisture free and in some applications, like painting, require oil free air. In other applications, like tool use, require oil injection for lubrication of tools.

420. Preventative maintenance

Air compressor maintenance is vital to keep the equipment running for as long and as efficiently as possible. Failure to perform maintenance could lead to compressor failure, costly repairs, and mission downtime.

Maintenance schedule

Recurring maintenance is set up on a schedule and could be in operating hours, monthly, seasonal, annual or semiannual schedule. It is set up according to system needs and geographical locations, and it is up to shop supervisors to setup and maintain these programs.

Maintenance procedures

Below is a general list of items that should be checked during maintenance. (**NOTE**: The manufacturer's manuals take precedence and must be followed.)

1. Ensure all guards and covers are in place.
2. Air compressor.
   a) Check oil level by either looking in the sight glass or using a dip stick. If the compressor has a sight glass it should be half full when it is not operating. The dip stick will have an "L" mark on the bottom of the stick for low. At the upper part of the stick there will be an "F" mark for full.
   b) Check air distribution system for leaks. The best way to do this is by using a soap solution on connections while the system is under pressure. Just look for bubbles. If there are bubbles, then tighten the connection or replace that part if tightening does not stop the leak.
   c) Operate safety valves by pulling up on the ring on top of the valve until you hear the rush of air. This proves that the valve is not jammed and will open if there is an over pressure problem.
   d) Check and replace intake filter (more often if necessary).
   e) Check belt tension. Push up in the middle of the belt between the motor pulley and the larger compressor pulley. There should be about 1/4" to 1/2" of movement on the compressors in the lab.
   f) Check pressure control switch setting. The setting should between 80-100 pressure per square inch (psi). To increase the pressure, turn the screw clockwise. To decrease the pressure, turn the screw counterclockwise.
   g) Inspect all electrical contacts. Contacts should not appear burnt or pitted.
   h) Check amp draw on motors. The reading should not be more than full load amperage (FLA) on the motor's data plate.
   i) Change oil.
   j) Change or clean the intake filter.
   k) Manually drain the receiver if not equipped with an automatic drain to get rid of built up moister in the tank.
3. Air Driers.
   a) Check air driers for proper air drying.
   b) Change the filter media if required on desiccant driers.
   c) Check the operation of the automatic drain. Press the test button and there should be a blast of air and a little moisture.
   d) Repair or replace drier if necessary.

4. Filters.
   a) If filters are supplied on regulators then replace them. Drain out condensation if there is a drain valve in the bottom of the regulator.
   b) Check the operation of the automatic drains, if supplied.
   c) Manually drain the condensation accumulated in the particulate, coalescing, and moisture filters if not equipped with automatic drains.
   d) If filters are not operating properly, repair or replace as needed.
5. Pressure Regulating Valve.
   a) Check the air pressure regulating valves for proper operation. The pressure that leaves the regulator depends on what is the air system is supplying. Pneumatic tools are usually around 125 psi while pneumatic controls are 20 psi.
   b) Adjust, repair, or replace if necessary.
6. Check, clean, and tighten terminals at motors, motor starters, disconnect switches, etc.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

419. Air compressor types

1. When are oil-free compressors used?

2. What happens to compressor oil after it heats up and vaporizes?

3. What happens if oil mixes with water?

4. What does the lubricant in a rotary screw compressors seal?

420. Preventative maintenance

1. What are the guards and covers checked for during preventative maintenance?

2. What should you check the air distribution system for when during preventative maintenance on an air compressor?

3. How are safety valves operated?

4. When checking air compressor filters during preventative maintenance, what should you do if there is a manual drain valve in the bottom of the regulator?

3–2. Control Fundamentals

In this section, we start by discussing control types, loops, and terms. This will give you a strong foundation to build upon. The section wraps up by getting into the different modes of HVAC control systems. Study this section carefully. It will serve as the backbone of your controls knowledge for the rest of your career. Controls are always evolving and becoming more computerized. You must understand the fundamentals of controls to be efficient in the field.

Keep in mind that controls create more efficient HVAC/R systems. As HVAC/R Airmen, we are responsible for our systems running efficiently as possible to ensure the American taxpayer is spending their money smartly. Also, the more efficient our systems are, the less energy we waste. We are stewards of the environment and cannot afford to waste energy.

421. Control types

Three control types you must know are the self-actuating or self-contained, electromechanical, and electronic. Knowing these types of controls is a good starting point on your journey to becoming highly efficient with HVAC controls. We focus on *temperature* controls to get you started.

Self-actuating or self-contained

The self-actuating or self-contained temperature control gets its name because there is no need for an external source of power. This type of control usually has a remote bulb connected by a capillary tube to a bellows in a control device. The remote bulb and the bellows contain a vapor, gas, or liquid that changes its temperature and volume with changes in the controlled-medium temperature. As the temperature of the air around the bulb increases, the vapor pressure within the bulb increases. This pressure transmits through the capillary tube to the bellows. The pressure flexes the bellows, which moves the valve stem or damper actuator. There is no need for another source of power. Because the volume obtained in the sensing bulb is many times the volume in the bellows and the capillary, temperature gains to the bellows and capillary do not affect the final control temperature.

Electromechanical

The electromechanical automatic temperature control system, shown in its basic form in figure 3–1, has a bimetal temperature-sensing element, electrical current-carrying contacts, and an electrical actuator motor. A change in temperature at the bimetal element causes the bimetal to warp and move either toward or away from the electrical contacts, which makes or breaks those contacts. When it makes contact, an electrical circuit is completed, and the actuator motor runs until the circuit opens. Some actuators have a spring mechanism to return the motor to a normal position when the circuit is broken.

Electronic

An electronic automatic temperature control system has a resistance type of temperature-sensing element, a resistance-measuring circuit, an electronic voltage amplifier, and a controlled device. Figure 3–1 shows a block diagram of a typical system. The temperature-sensing element is of the resistance wire or semiconductor type—the resistance of which to current flow is a function of ambient (surrounding) temperature at the sensing element. The resistance to current flow usually increases with an increase in temperature and decreases with a decrease in temperature. An exception is the thermistor, which has a negative coefficient of resistance. Its resistance decreases on a temperature rise and increases on a temperature drop.

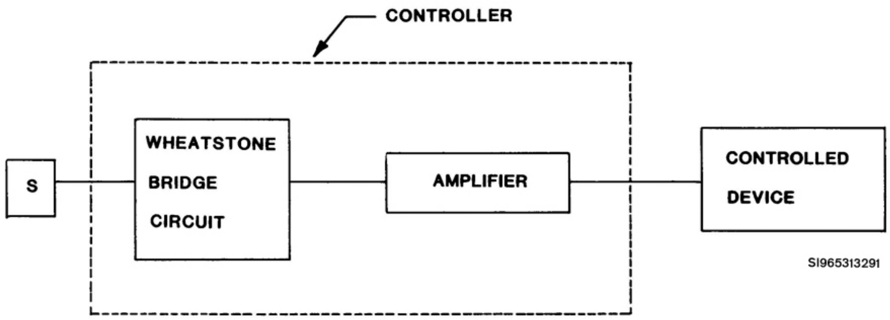


Figure 3–1. Basic electronic control system.

422. Control loops and terms

This lesson is absolutely critical to your foundation of knowledge about controls. This may be the most important section for controls because if you do not have the knowledge in this lesson you cannot understand any further discussion about controls.

First, control loops will be discussed. Control loops represent the most basic concept of controls. After loops are taught, we will move toward control terms. This will conclude the lesson. Let's get started with the most basic of control loops.

Basic control loops

A simple control system has three basic parts: sensor, controller, and controlled device. We add many auxiliary devices, such as adapters and transmitters, to the basic elements to give signal indication and to create complex control systems. All systems also need an energy source for motive power. In order to have the most effective control system, you must fully understand each element, use proper selection methods selected, and the correct application. You can see the interrelationships among elements in figure 3–2.

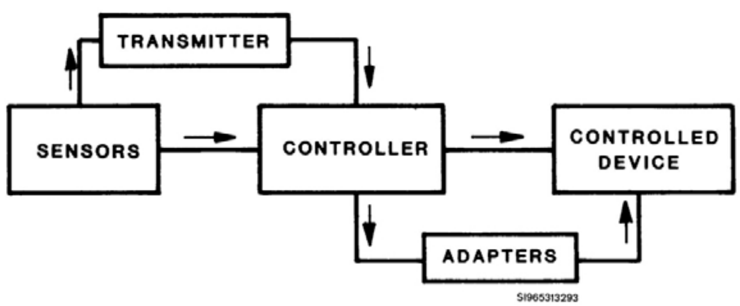


Figure 3–2. Interrelationship of control system elements.

Sensor

The sensor measures a variable condition, such as temperature, humidity, pressure, dew point, liquid level, or rotative speed (revolutions per minute), and generates an appropriate output signal. For local sensing the sensor can be built into the controller, or mounted separately for remote sensing.

Controller

The controller is the local brain of the system. Controllers may be *direct* acting or *reverse* acting. In a direct-acting controller, the output signal increases as the measured variable increases. In a reverse-acting controller, the output signal decreases as the measured variable increases. Many modern controllers are microprocessors.

Controlled devices

The controlled device reacts to the signal received from the controller to change the condition of the controlled medium; for example, air or water. Typical controlled devices are valves, dampers, electric relays, or magnetic starters for motors driving fans or pumps. In basic control systems, the controlled device varies the flow of the controlled medium. Typically, the medium controlled is air flowing through a damper; steam, water, or some other fluid flowing through a valve; or an electric current. The variable is the controlled condition. This may be temperature, humidity, pressure, flow rate, or on-off status. We classify control systems as open loop, closed loop, or a combination of open and closed loop. These loops are discussed in the "Modes of control" lesson.

Bringing it together

Think of controls systems as different people talking to each other. For example, replace the sensor, controller, and controlled device with three Airmen. One Airman in the room realizes it is hot and walks down the hall to tell the SSgt that is in charge. The SSgt takes this information and makes a decision. After he makes the decision, he walks down the hall to another Airman and tells him to close the hot water valve. The valve is closed and the temperature in the room starts to drop.

Now, let's replace these Airmen with the control devices. The sensor talks to the controller and let it know that it is hot. The controller, the brain, makes a decision and tells the controlled device what to do. It is that simple.

Terms

In this main point, you will read about common terms used when discussing controls. Before you can obtain a deeper understanding of controls, you must have a firm grasp of these terms.

Throttling range

There are two ways of defining throttling range—controller throttling range and system throttling range.

Controller throttling range

The controller throttling range (CTR) is the change in the measured variable needed to change the controller output signal by a specified amount. The specified amount varies from manufacturer to manufacturer. Most controllers, but not all, have adjustable controller throttling range.

System throttling range

The system throttling range is the change in the measured variable needed to cause the controlled device to move from fully open to fully closed or vice versa. The system throttling range is, thus, a system performance number and not just a dial setting. In addition, there must be a controlled device for a system throttling range to exist. The system throttling range may or may not be the same as the controller throttling range.

If the system throttling range is too small, a small change in the controlled variable results in the operator moving to the extreme end of its stroke, and an unstable control, often called *operator hunting*, occurs. That action may cause the same effect on two-position control, either fully on or off. If the system throttling range is too large, a large change in the controlled variable results in only a small movement of the actuator or controlled device. In this case, the space conditions move further from the desired conditions because the system cannot catch up with load changes.

Controller sensitivity

The change in the output signal of the controller for a unit change at the sensor is the controller *sensitivity*. For example, if a sensor sees a change of 5°F and the controller output changes 10 psi, the controller sensitivity is 10/2, or 2 psi. As with throttling range, if the controller sensitivity is set too high, the control system is unstable.

Set point

There are two concepts associated with the term *set point*—controller set point and system set point. This is also a source of confusion.

Controller set point

Controller set point is the value of the measured variable that produces a specified controller output. For the specified controller output, most manufacturers use a value equal to the middle of the controller throttling range. Some specify other conditions. We need this number to calibrate a controller.

System set point

System set point is the value for the measured variable that causes the controlled device to be at the middle of its minimum and maximum throttling range.

Offset

A properly operating proportional control system settles down with the measured variable remaining stable and within the system throttling range. The difference between the measured variable and the desired condition is *offset.* As the system throttling range is increased, the possible offset is also increased.

Normally open

This term describes the usual position of contacts. Normally open contacts are closed when their switch or switching device (relay) is actuated.

Normally closed

This term describes the usual position of contacts. Normally closed contacts are open when their switch or switching device (relay) is actuated.

Cut-in

This is the point at which a device will come on. It is often based on temperature or pressure. For example, a system has a cut-in of 73 degrees. Once the space reaches 73 degrees the system will cut-in, or turn on.

Cut-out

This is the point at which a device will shut off. It is often based on temperature and pressure. For example, a system has a cut-out of 68 degrees. Once the space reaches 68 degrees the system will cut-off, or turn off.

Differential

This is the difference between the cut-in and cut-out. To continue to use the examples from above the difference between the two temperatures is 5 degrees. (73 – 68 = 5) Do not get overwhelmed by the word *differential* when you hear people use it. Remember that it simply means the difference between two numbers. When you hear the term used, take a second to think about what two numbers are being discussed and then subtract the two.

Feedback

Feedback is the signal being sent to the controller from the sensor. For instance, a temperature sensor senses a temperature of 85 degrees and sends a signal to the controller so the controller can make a decision on what to do.

Feedback is similar to what your supervisor gives you. He/she gives you feedback on your work performance. The sensor is giving the controller feedback on the performance and conditions of the HVAC/R system.

423. Modes of control

In this lesson, we discuss opened, closed, and combination control loops. Also, we discuss on-off control, timed on-off control, various types of proportional control, and direct digital control.

Open loop

In the open-loop system (fig. 3–3) the sensing element on the controller measures some variable (such as outside temperature) other than the controlled variable (such as inside temperature) and causes the control system to operate. In this type of system, the controller does not see the effect of its control action. We can see this schematically in figure 3–4. Normally, you only use open-loop systems for rough control with final control for space comfort performed by a closed-loop system.

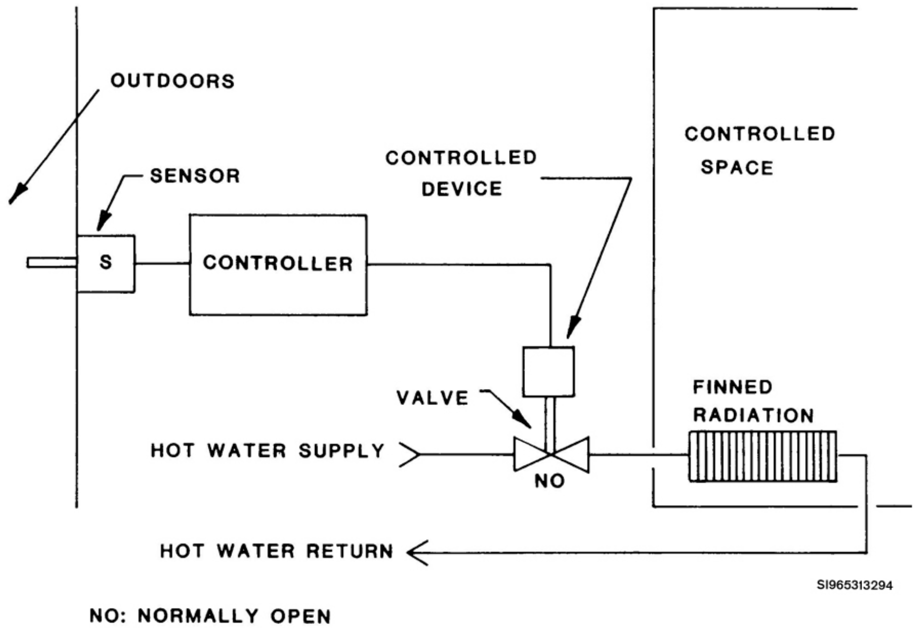


Figure 3–3. Example of an open-loop control system.

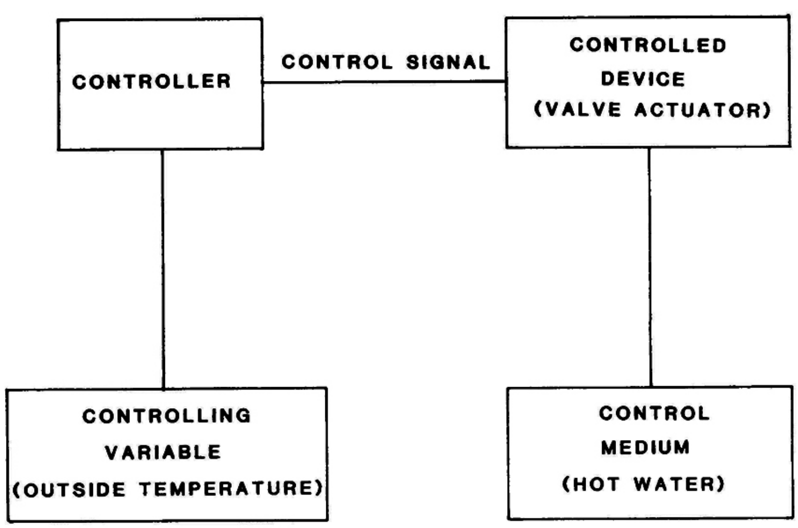


Figure 3–4. Open-loop control system.

Closed loop

In a closed-loop system (fig. 3–5) the sensor/controller measures the controlled variable, and a change in the value of this variable causes the control system to operate. This forms a closed loop (fig. 3–6) in which the sensor sees the effect of the action of the controlled device. Almost all final comfort control applications use a closed-loop system.

A sensor will measure a variable and send the signal to the controller. The controller compares the signal to the desired condition and changes or maintains the output signal to the controlled device. The controlled device changes or maintains its position which in turn modifies the variable that was originally sensed by the sensor. The sensor senses the change (or no change) and sends a signal to the controller again. This process describes how the loop is closed.

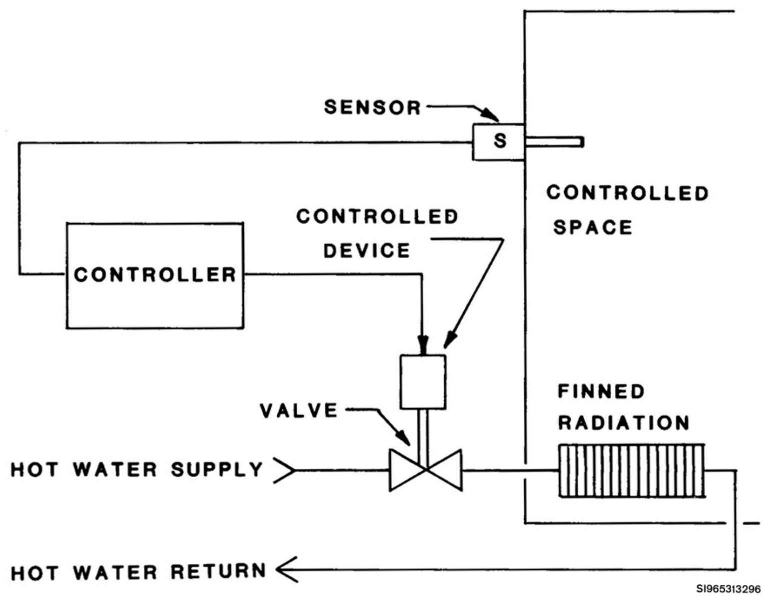


Figure 3–5. Example of a closed-loop control system.

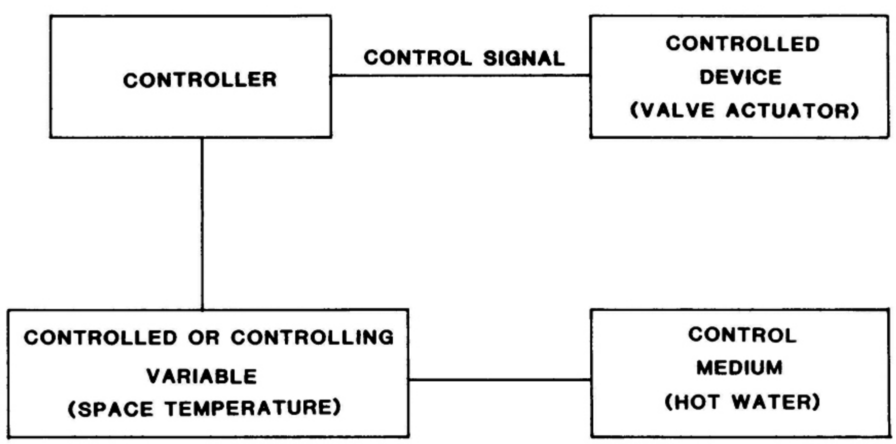


Figure 3–6. Closed loop control system.

Combination loops

To refine the control system more, open loop and closed-loop control systems often are combined (fig. 3–7). In the example, both inside and outside conditions affect the control actions, giving improved control. The most typical application of a combined open-and-closed-loop system is in the reset of a closed-loop system from an open-loop temperature, such as changing the supply water temperature as the outdoor air temperature changes (hot water reset).

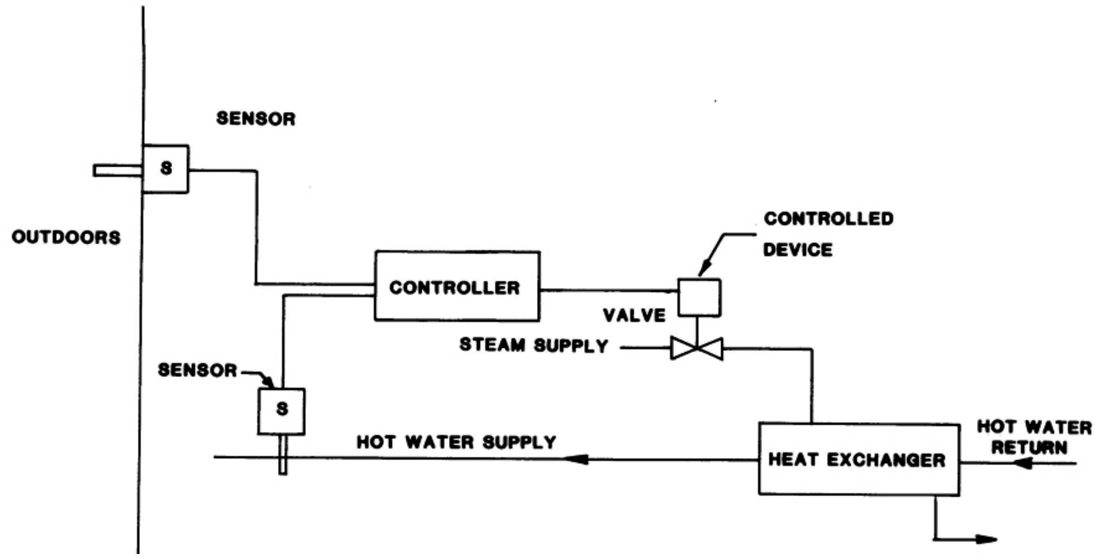


Figure 3–7. Combined open-closed loop system.

We can further classify control systems according to the modes of control action. Below are the most common modes:

1. On-off.
2. Timed on-off or anticipation.
3. Floating.
4. Proportional control.
5. Proportional control with reset.
6. Proportional integral control.
7. Proportional integral derivative (PID) control.
8. Direct digital control.

On-off control

On-off control is self-explanatory; you can position the controlled device to only one of two positions, ON and OFF. On-off could also be referred to as maximum and minimum. There are no intermediate positions. The simple bimetal electric thermostat found in residential systems (fig. 3–8), is the most obvious example. It is simply a temperature-actuated switch, either on or off. The term “differential” is associated with on-off control. There are two types of differential—manual differential and operating differential.

1. Manual differential—is the amount of change in the sensed variable needed at the controller to cause the control device to change position. Manual differential usually is adjustable.
2. Operating differential—is the maximum difference in the sensed variable that is actually experienced in the controlled space. The operating differential is equal to or greater than the manual differential. The difference between manual and operating differential depends on how fast the system and the building respond to changes.

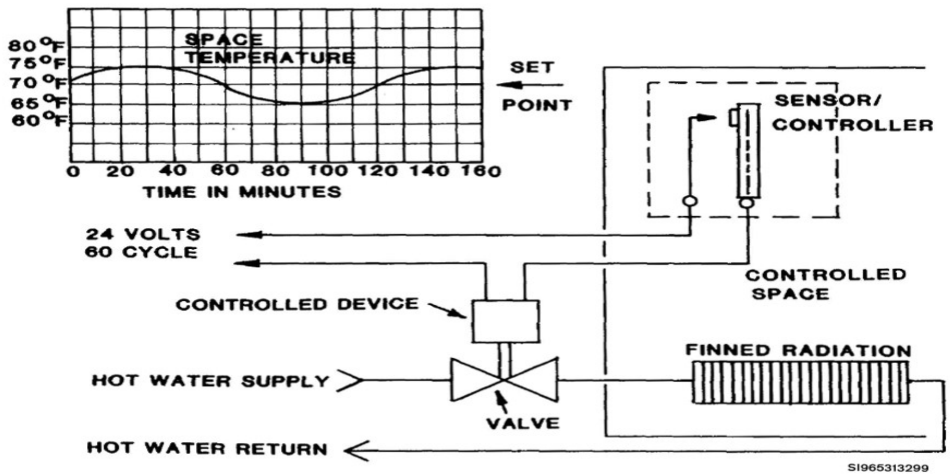


Figure 3–8. Temperature response with two-position control.

Timed on-off control

Timed on-off control minimizes the difference between manual and operating differential. Timed on-off control gives shorter cycles with smoother control than does the basic on-off control. The usual way to get timed on-off control, sometimes called *heat anticipation*, is to artificially heat the bimetal element in a thermostat, whenever the thermostat is calling for heat (fig. 3–9). A small resistor, wired in series with the switch contacts, is under the thermostat cover so that it warms the bimetal strip and causes the unit to cut off early, before the space can overheat. This causes the controller to call for smaller additions of heat more frequently. It is a good idea to use timed on-off control whenever possible for space comfort control applications where on-off-control-type conditioning equipment is used.

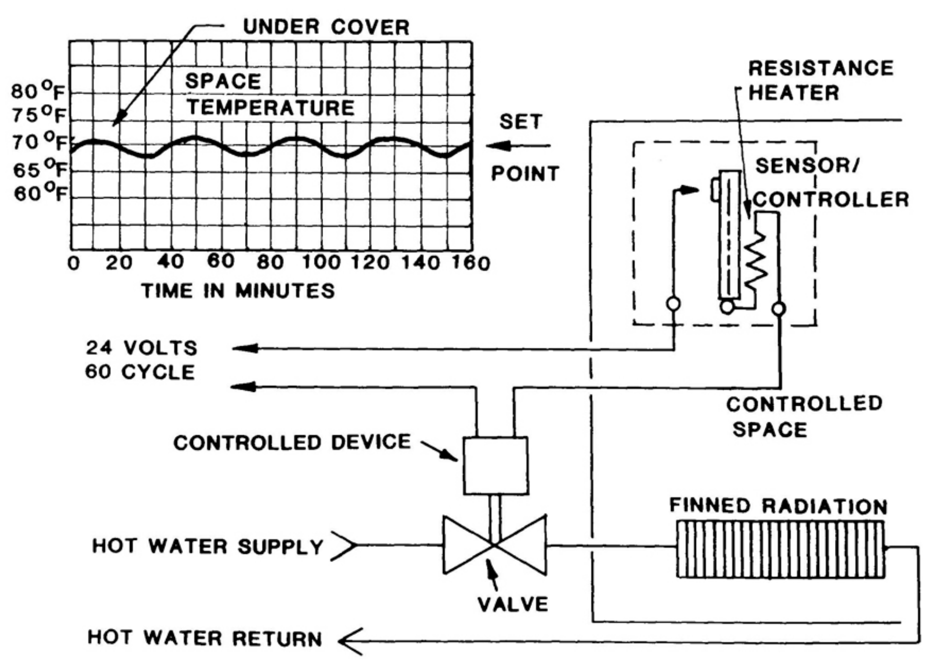


Figure 3–9. Timed two-position control.

There are also cooling anticipators that allows current to flow to the anticipator during the off cycle. The heat from the current allows the thermostat to heat up faster than normal. The cooling system is turned on just before the conditioned space reaches the cut-in temperature. Once the cooling system turns on, current will no longer flow to the anticipator. This anticipator is used because once cooling is on it takes a while before it starts to produce cool air so by the time the supply air is cool the space would have reached its original cut-in set point. This allows cool air to flow exactly when it is needed.

Floating control

Floating control is a modification of two-position control. The controlled device can move toward either the open or the closed position, or it may stop at any point in between. There are three components necessary for floating control action:

1. A switch with single-pole, double-throw (SPDT) action and a neutral or floating area.
2. A sensing element to position the switch.
3. An adjustable-speed, reversible actuator that can stop at any point in its travel.

When the value of the controlled variable moves outside the differential of the controller, the controller then moves the actuator in the proper direction to bring the variable back within the limits of the controller differential (fig. 3–10). When the value of the controlled variable is within the differential of the controller, the contact arm is in a neutral area, not touching either contact but floating free of contact. As long as the contact arm is in the neutral area, it sends no control signal to the actuator, so the controlled device does not move. A typical application is the control of static pressure in a variable air volume system. Keep in mind that the float in the figure does not make it a “float control.”

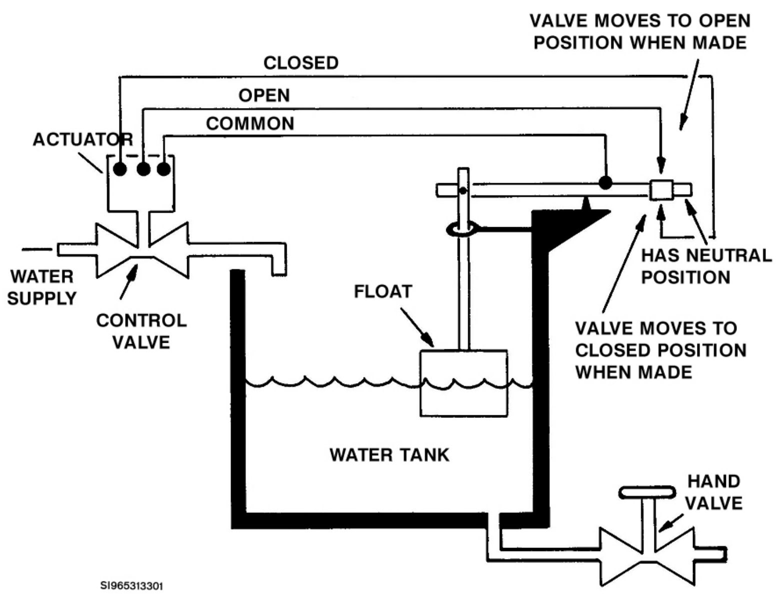


Figure 3–10. Floating control.

Proportional control

With proportional control, the output of the system is in proportion to the need as measured by the sensor/controller. For example, in a heating system if the room is at a temperature slightly colder than desired, the system provides only a little heat. If the room is very cold, the system provides a lot of heat. System response is in proportion to the need.

Proportional-with-reset control

Many proportional control systems work better if the system set point automatically changes as conditions change. For example, in a hot water heating system, if we do not use reset, the system set point may be a constant 180°F regardless of the outside temperature. On a mild day, such a system puts out more heat than necessary, which wastes energy and overheats the space. For better control, we can use a second sensor measuring the outdoor temperature to change (reset) the hot water system set point. As an example, when the outdoor temperature is 0°F, the system set point could be 180°F, and as the outdoor temperature changes to 60°F, the system set point could change or reset to 100°F. Note that, as this happens automatically, we are only changing the system set point. The controller set point is a manual adjustment and does not change as the outdoor air temperature changes. This is also an example of a reverse reset system because, as the outdoor temperature increases, the hot water system set point decreases. A direct reset system has an opposite effect.

Proportional integral control

Proportional integral (PI) control does not always keep the controlled variable at the desired condition. Generally, there is a difference between these two values (offset). The offset may cause poor control and increased energy use. To correct the problem, some controllers add *integral action* to the proportional control. Integral control slowly adjusts the controller output up or down as needed to eliminate the offset. Some manufacturers call this integral control *automatic reset*, a name that you should not confuse with the reset action described earlier. PI controllers need an adjustment for the integral action besides the controller set point and throttling range adjustments already discussed. Typically, this adjustment is called *integral gain* or *reset rate.*

Proportional integral derivative control

PID is somewhat different from the PI control. The derivative enhancement allows the controller to analyze the variable's rate of change and predict what the control point will be based on its current value and how fast or slow it is changing. This allows the controller to anticipate changes in the variable and control the output signal to avoid overshooting the set point. Basically the derivative capability allows the control to predict the future of the state of the variable. This type of controller takes into account the amount of offset and takes into account the amount of time there has been offset. Also, it accounts for how quickly the offset is changing.

Direct digital control

In a direct digital control (DDC) system, a local microcomputer makes all control decisions. The DDC gets analog inputs (such as temperature and pressure) and digital inputs (such as status of relays, contacts, and switches), and calculates the appropriate control outputs. The controlled devices then receive the digital or analog output signal. The DDC unit replaces controllers and adapters with a smaller computer chips and boards. We can accomplish ***all modes of control*** with DDC. DDC will be covered more in-depth later in this unit.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

421. Control types

1. As the temperature of the air around a remote bulb increases, what happens to the vapor within the bulb?

2. How is the valve stem or actuator moved by the bellows?

3. What is the *usual* relationship of resistance and temperature in an electronic circuit?

4. How is the thermistor different from the usual resistance temperature relationship in an electronic circuit?

422. Control loops and terms

1. What are the three basic parts of a control system?

2. What is the relationship between the controlled device and the controlled medium?

3. What is the relationship between the sensor and the controller if the conditioned space temperature is hot?

4. What does the controller do with the information it receives from the sensor?

5. What is the *system* throttling range?

423. Modes of control

1. In an open loop system, how does the sensing element operate?

2. Why would a timed on-off control be used instead of basic on-off control?

3. When a thermostat is calling for heat, how can timed on-off control be accomplished?

4. When using floating control, how does the controller move the actuator when the value of the controlled variable moves outside the differential of the controller?

5. In floating control, where is the contact arm when the value of the controlled variable is within the differential of the controller?

6. How does the integral control work to eliminate offset?

7. How does the derivative portion of PID help predict the control point?

3–3. Electrical Controls

Not all control systems use the same types of action to achieve their purposes. Even though digital controls are becoming more popular, you will still run into electrical controls. Electrical control systems may use switches, relays, transformers, and other devices to get the right response to the control mode.

424. Electrical devices

An important aspect of your job is to know the function and operation of electrical devices. In this lesson, we will cover switches, transformers, actuators, and linkages.

Switches

The two main types of switches used in electrical controls are snap-acting and mercury switches.

Snap-acting switches

These switches have fixed contacts that attach securely to the controller base. The fixed contacts mount inside a permanent round magnet that provides a magnetic field in the area of the contacts. The movable contact attaches to a bimetal element or some other sensing element (humidity, pressure, etc.).

The bimetal works as follows: with a decrease in temperature, it moves toward the fixed contact. As the movable contact enters the magnetic field, the magnetic field "pulls" the contact against the fixed contact with a positive snap. As the temperature increases, the bimetal gets warmer and tries to pull the movable contact away from the fixed contact. However, because the movable contact is in the magnetic field, at this point the bimetal does not have enough force to overcome the magnetic force. As the bimetal continues to warm and bend, it soon develops enough force to overcome the magnetic field, and the movable contact breaks away with a positive snap.

Other controllers work the switch in a like way, but a different type of sensor does the operation. Figure 3–11 shows a single-pole, single-throw (SPST) snap-acting switch. Figure 3–12 shows a single-pole, double-throw (SPDT) snap-acting switch. If you have to clean the contacts, use a cardboard approved contact cleaner. Never use a file or sandpaper for this purpose.

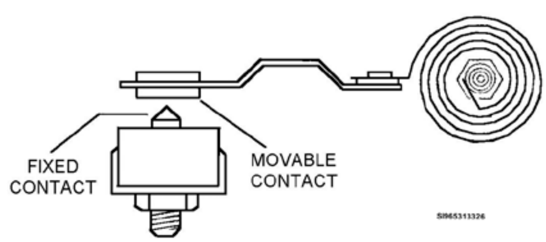


Figure 3–11. SPST snap-acting switch.

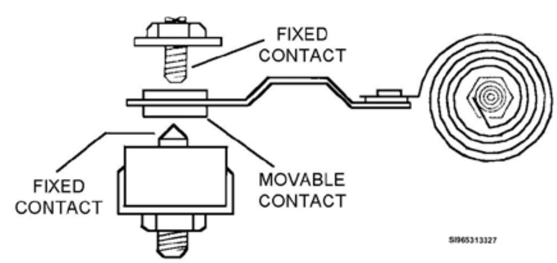


Figure 3–12. SPDT snap-acting switch.

Mercury switches

These switches do the same switch actions as the snap-acting switches but in a different way. The switching happens through a globule of mercury moving between two or three fixed probes sealed within a glass bulb. Figure 3–13 shows a mercury switch attached to the bimetal element.

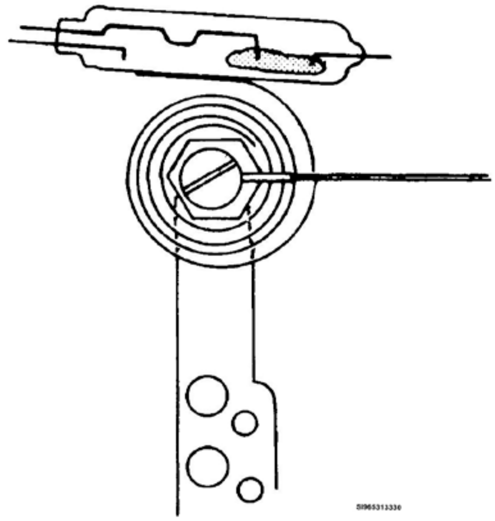


Figure 3–13. SPDT mercury switch.

Control transformers

We use transformers to step up or to step down AC voltages or pulsating DC voltages. Some controls work off line voltage. The term *line voltage* as applied to controls is voltage in the range of 115 to 230 volts. Otherwise, line voltage connects to the primary side of a step-down transformer (fig. 3–14, left side of transformer) to get the necessary low-voltage supply. The control transformer in figure 3–14 is of a multitap type. Figure 3–14 shows the voltages you can get by tapping (numbers 1 through 4) the secondary coil at different places.

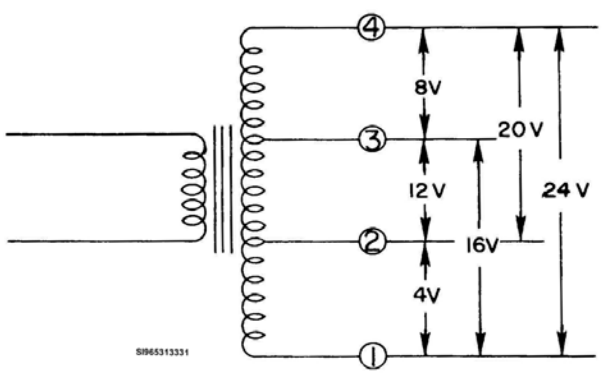


Figure 3–14. Control transformer.

Many actuators are not attached directly to their regulators. Many are attached by linkages. It is important that these two devices work together without binding or they will end up damaged. Attaching these two devices takes patience and practice. Since HVAC/R technicians are excellent in all they do, we will take some time to learn how to connect these two devices properly!

Actuators

These devices can be solenoids, relays, or contactors. These are the devices that operate valves, dampers, and motors. Electrical applications use many types of relays to open or close circuits. They usually use low voltage to energize a higher voltage circuit, but they may be of the same voltage. To automatically start and stop larger electric motors, you can use a *magnetic starter*—a control relay that electrically operates two or more switch contacts.

Adjusting linkages

There are different types and brands of dampers, valves, and linkages. We will discuss general adjustment procedures, but if you are going to actually perform this task, you should refer to the manufacturer's instructions and/or manuals.

A mechanical linkage is what connects dampers and valves to an actuator. The actuator will then move them through their complete range of motion. The complete range of motion depends on the type of control. The range of motion could vary from being fully open, fully closed, or anywhere between the two extremes.

The mechanical linkage must be connected to the actuator (sometimes called an operator) and regulator so that it doesn't bind. Binding can cause damage to the actuator or the regulator. Refer to the manufacturers data for the most complete instructions on connecting the actuator to the control device with the linkage. To adjust the linkage, first establish the starting point and stopping point of the actuator; this is called the *stroke*. Remember, the control device should move through its complete range of motion without binding and stopping prematurely. The control device should not continue to move the regulator when it is at the end of its stroke. This will cause damage to the linkage assembly and possibly to the diaphragm, seals, gears or motor depending on the type of controlled device used.

Stroke adjustments

Before adjusting the linkage, the stroke of the actuator needs to be adjusted according to the manufacturer's procedures. When adjusting the stroke, the actuator should be energized and controlled manually.

CAUTION: Be very cautious when manually controlling the actuator. Fingers can be lost if they are in the wrong place.

Link the actuators to the dampers so that when energized they will complete their full stroke without binding. (**NOTE**: Binding is when the damper has reached the end of its movement, but the actuator is still trying to drive it.)

Setting linkage

Below are the steps for setting the linkage:

- Step 1. Loosen the ball joints that connect the linkage, actuator, and damper together. Remove damper rod and rotate the actuator to one of its two extremes. Once the actuator has completed its rotation, place the damper in the appropriate position (fully open or fully closed).
- Step 2. Replace damper rod and tighten the ball joints to the linkage assembly. Check the rotation to see that there is no binding of the linkage assembly when in operation.
- Step 3. If the damper has reached the end of its movement and the actuator is still trying to drive it, de-energize the actuator and re-check steps 1 and 2.

Safety

Safety must always be considered when adjusting linkages. Always be aware of your surroundings. Linkages are most often connected to dampers and they may be located in confined areas or high spaces. Use proper safety practices when working in such areas.

CAUTION: Be aware of your fingers when there is actuator movement because an actuator can cut off your finger(s). Small details like attaching an actuator to a regulator are very important to the proper operation of HVAC/R equipment. Laziness and indifference to the equipment can cause hundreds of dollars in damaged equipment and unnecessary use of man-hours.

425. Operation of two-position, proportional, and floating controls

As stated earlier, the method by which a control system acts is the *control mode*. The next few paragraphs cover the two-position, proportional, and floating controls more in depth.

On-off control

In two-position controls, the final control element occupies one of two possible positions (full on or full off). These systems can use on-off control operation:

1. Domestic heating systems.
2. Electric motors on unit heaters and refrigeration machines.
3. Water sprays for humidification.
4. Electric strip heaters.

On-off is snap-acting in nature. The device responds to a temperature change or pressure change and does so by making a definite movement. In a typical example, a fall in temperature would close the thermostat contacts and bring on the burner. When the temperature has risen sufficiently the thermostat is satisfied and the contacts open stopping the burner. As you can see with this type of control, there is no intermediate capacity control. The unit is either on or off.

One of the disadvantages with two-position control is that it keeps the equipment energized for long periods. You have already learned about heat anticipators in an earlier volume. The snap-acting control is a good example of why a heat anticipator is necessary. The residual heat left in a system when the burner cycles off is enough to carry the room, house, and so forth, past the comfortable temperature the system's thermostat was set for. The heat anticipator applies false heat at the thermostat's sensing element, causing it to shut down the burner before it gets too hot. The table below gives the characteristics of the simple two-position control and time two-position control. Notice the improvements of timed control over the simple control.

TWO-POSITION CONTROLS	
Simple two-position control	• The first and oldest. • Standard in the past. • Fairly elementary. • Cannot replace lost heat precisely.
Timed two-position control	• Later development. • Rapidly replacing simple two-position control. • Heat delivered in "percentage on time" basis.

Two values of the controlled variable decide the position of the final control element. Between these values, there is a zone in which the controller cannot initiate an action of the final control element. This zone is the *differential gap*. In simple two-position control, the controller and the final control element interact in the way we have described previously, without modification from any source, either mechanical or thermal. The controlled variable fluctuates between two values determined by the differential and the lag in the system. In addition, the controller never catches up with the controlled condition; instead of correcting the condition taking place or about to take place it corrects a condition that has already passed. Consequently, simple two-position control applies only to systems in which total system lag is small.

The ideal way to heat any space is to replace lost heat in exactly the amount needed. With two-position control, this is obviously impossible, since the burner is "full on" and the heat delivered at any specific instant is usually too much; so the space heats up, and the unit turns off.

On the other hand, we can achieve a close approximation of the ideal method of heat delivery by using timed two-position control. In this method of control, it delivers heat in a "percentage on time basis," so that fluctuations of the control point are, for all practical purposes, eliminated. For example, suppose there is a need for a domestic heating system with a two-position control to make up a heat loss of 20,000 British thermal units (Btu or BTU) in one hour at a certain load. The total capacity of the burner is 40,000 Btu per hour. This means that the burner must operate 30 minutes out of the hour, whether it is on for 30 minutes and off for 30 minutes, on for two 15-minute periods and off for two 15-minute periods, on for six 5-minute periods and off for six 5-minute periods, or any other combination with the same ratio.

In most cases, the longer cycles would be unsatisfactory, because the variations in temperature would be too great. To give a closer desired result, we must divide the heat on-and-off time into smaller packages. In timed two-position control, the basic action between the controller and the final control element is the same as for simple two-position control (fig. 3–15). As an example, a cam mechanism may provide mechanical operation. The chief disadvantage of this method is that only the relative duration of the on-and-off periods may vary with changes in load. The frequency stays fixed.

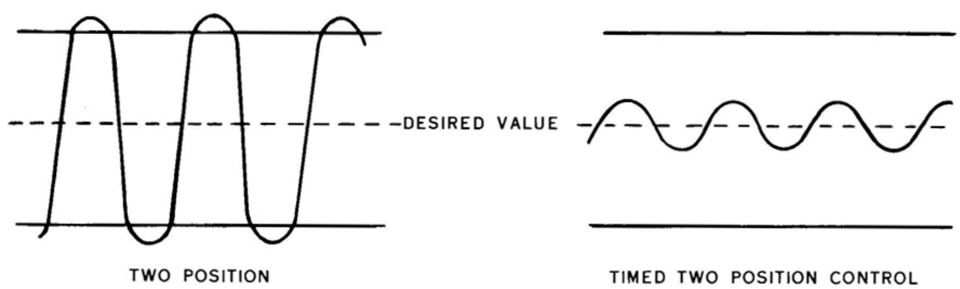


Figure 3–15. Comparing simple two-position with timed two-position control.

Thermal-timing devices are more convenient and flexible. Placing a heating element beside a temperature-sensitive element and controlling the power supply to the heating element creates a thermal timer. As long as the ambient temperature is within certain limits, the thermal timer cools, and the temperature-sensitive element closes the contacts to energize the furnace. Current passes through the thermal timer when the contacts close, which heats up and gives a false room temperature to the sensing element, thus opening the contacts and de-energizing the furnace. When the contacts open, the thermal timer cools and starts the cycle over again. This thermal action applies for either heating or cooling (fig. 3–16). In the figure, you can see that the heat anticipator (wired in series) heats when the contacts are closed. Also, note how the cold anticipator (wired in parallel) heats when the contacts are opened and cools when the contacts are closed.

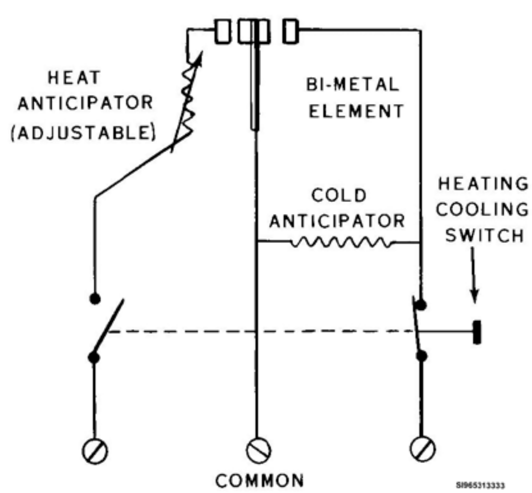


Figure 3–16. Heating-cooling thermostat.

The advantage to timed two-position control over simple two-position control is that it greatly reduces swings in the controlled variable resulting from a large total lag. Since the controller does not have to wait until it can detect changes in the controlled variable and then signal for corrective action, control system lags have no significant effect. Additionally, the lags in the heat source and distribution system serve only to smooth out the “humps” and “valleys” in heat delivery to approximate closely the results of a continuous delivery system with proportional-position control.

In timed two-position control, the addition of heat to the thermostat bimetal is a factor to offset. In analyzing the cycle of a thermostat used in this type control, you can see that the control point must vary if the bimetal is to heat and cool at different rates needed to time the cycle for the various load conditions. As outside air temperature decreases, heat loss from the space increases, and the ON cycle of the burner lengthens to replace heat lost at an increased rate. This means that the heating rate of the thermostat bimetal must be slower so that the burner stays on longer. It also means that the cooling rate of the bimetal during the off part of the cycle must be faster so that the burner comes on sooner. Both of these demand that the difference between the bimetal temperature and the air temperature become greater. This difference comes from a sustained deviation of the room temperature called *offset.*

Proportional control

In proportional control, the final control element moves to a position proportional to the amount that the controlled variable has moved from the set point. There is one, and only one, position of the final control element for each value of the controlled variable within the throttling range (proportional band) of the controller. Thus, the position of the final control element is linear to the value of the controlled variable.

Because there is but one position of the final control element for each value of the controlled variable, you need a sustained deviation to place the final control element in any position other than the middle of its range (assuming the set point to be in the middle of the throttling range). Offset, therefore, becomes a major problem in proportional control. As an example, suppose you have proportional control of a hot water coil used to heat a room. Under ideal load conditions, the thermostat is in the middle of its throttling range, the coil valve is halfway open, and there is no offset. Now, suppose the outside temperature drops, increasing the load on the heating coil. At once, there is need for more heat in steady supply to replace the heat being lost from the room at a greater rate. To deliver the needed heat, the coil valve must open farther and stay in that position as long as the increased load exists. To do this, the temperature must deviate from the set point and sustain that deviation, because the position of the final control element is proportional to the amount of deviation. As the load condition increases from the ideal, offset increases toward colder; and, as the load condition decreases from the ideal, offset increases toward warmer.

Floating control

Floating control is a mode of control in which the final control element moves at a predetermined rate in a corrective direction until the controller is satisfied or until there is desire for a movement in the other direction. The direction of movement corresponds to the direction of deviation of the controlled variable (fig. 3–17). We can divide floating control further into several subclasses, two of which are of interest to us:

1. Proportional-speed floating control, in which the final control element moves at a rate proportional to the deviation of the controlled variable.
2. Single-speed floating control, in which the final control element moves at one speed throughout its entire range.

Either subclass type is adaptable to systems having a fast reaction rate, a slight transfer lag, and a slow load change. In general, we can use proportional-speed floating control in systems having somewhat faster load changes than those operating successfully with single-speed floating control.

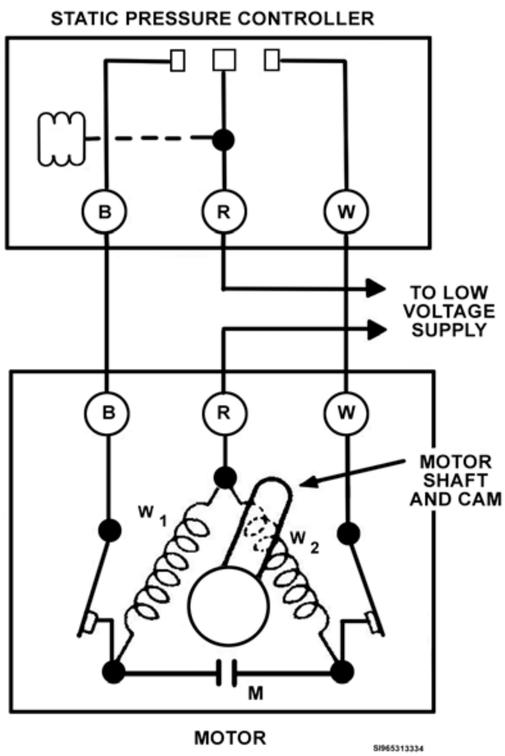


Figure 3–17. Complete series 60 floating control circuit.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

424. Electrical devices

1. How is the movable contact pulled against the fixed contact in snap-acting switch?

2. In a snap-acting switch, what will eventually happen as the bimetal warms and bends?

3. What is the relationship between an actuator and the valves and dampers it is connected to?

4. How must the mechanical linkage be connected to the actuator?

5. What is the *first* step in adjusting a linkage?

6. When following the steps to set the mechanical linkage, what is the next step if the damper has reached the end of its movement and the actuator is still trying to drive it?

425. Operation of two-position, proportional, and floating controls

1. How does on-off control react to temperature change?

2. In proportional control, how does the final control element move in relation to the controlled variable?

3. What is the relationship between the final control element and the controlled variable in proportional control?

4. To deliver needed heat for proportional control, how long must the coil valve stay open?

3-4. Electronic Controls

This section provides information about electronic control systems used to control HVAC equipment. An electronic control system has a sensor, a controller, and a controlled device. The sensors used in electronic control systems are simple, low-mass devices that give stable, wide-range, linear, fast response. The electronic controller is a solid-state device that gives control over a discrete part of the sensor range and generates a correction signal to control the last control element. Electronic controllers provide two-position, proportional, or PI control. Many manufacturers combine several components in a single box to control an entire HVAC system. These boxes are complicated and difficult to maintain. This section describes only the operation of basic control components. Figure 3–18 shows a simple electronic control system. Electrical devices have moving parts; electronic do not.

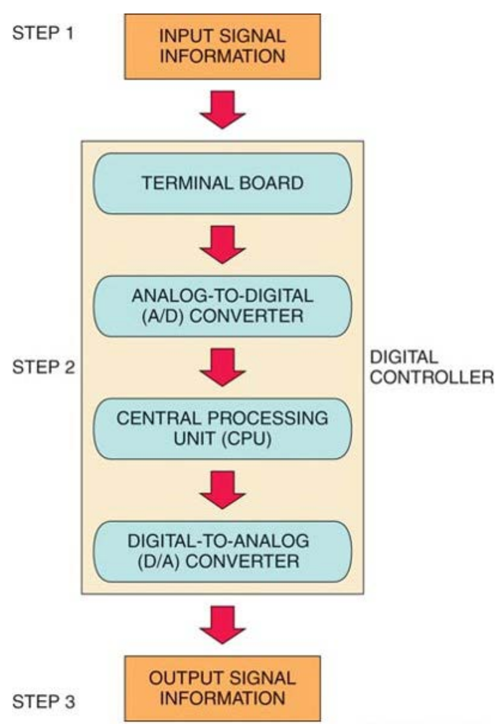


Figure 3–18. Simple electronic control system.
(Reprinted courtesy of Honeywell, Inc.)

426. Electronic terms and devices

As the HVAC/R industry continues its shift into the electronic world it is becoming more vital for technicians to learn about electronic devices and terms.

Algorithms

Algorithms are a set of instructions or commands that are programed into a computer. These algorithms produce outputs based on the inputs the computer receives. Algorithms are stored in the central processing unit and are performed by the microprocessor. They allow increased efficiency and control of HVAC/R systems.

Consider an example that will demonstrate the amount of work algorithms saves: An Airman goes to a building and realizes it is very cold inside and it is winter time. He then walks to the mechanical room and manually opens the hot water valve to allow more heating. He then goes to each zone in the building and manually opens zone dampers to allow more warm air to flow into the conditioned space. He then goes to the space and realizes it is now to hot. He goes back to the mechanical room adjusts the valve and adjusts each zone damper again. The commands he is performing based on the inputs he receives are very time consuming. Imagine this type of attention being needed at every building on base. The Air Force would need a few Airmen at every building on base! A central processing unit with algorithms can perform these commands and process inputs and outputs in seconds and that makes them much more efficient and practical.

Terms

Now we will cover some crucial electronic terms. These terms give you an understanding of electronics that you can use to better comprehend HVAC/R systems when you are troubleshooting them.

Diodes

Diodes allow flow in only one direction. There are two sides of a diode; the negative side called the cathode and the positive side called the anode. Diodes are usually marked on the cathode side with a stripe. Electrons flow through the diode from the cathode to the anode. Diodes are sometimes referred to as rectifiers because they perform the function of turning AC into DC.

Diacs

Diac stands for *di* for diode and *ac* for alternating current. This is a solid state device that allows AC flow in both directions. Current only flows once voltage reaches a designed level. This voltage is called *break-over* voltage. Once this voltage is met current will flow as long as the voltage stays above the predetermined level. If the voltage drops below this level it will go back to having a very high resistance and not allow current flow. Diacs are found as part of motor control circuits and it prevents the motor from running during low voltage conditions.

Silicon-controlled rectifier

The silicon-controlled rectifier (SCR) has three terminals: cathode, anode, and a gate. Flow is similar to the diode and travels from the cathode to the anode. The voltage applied must be over the break-over voltage for current to flow. The difference with this device is that voltage can come from the gate and does not have to be at the break-over voltage. These devices are often used to convert DC to AC voltage in a component called an *inverter*. Inverters are found in variable frequency drives which is defined later.

Triac

Triac stands for *tri* for triode and *ac* for alternating current. The triac operates much the same way as an SCR, but it allows current to flow in both directions. They are used in AC motors to control motor speed.

Solid State

In modern air conditioning, you may hear the term *solid state* used quiet often. This term is often used interchangeably with semiconductor. These devices have no moving parts such as contacts. The traits of these devices change and allow or disallow current to flow.

I/O

Input/output (pronounced "eye-oh"). This is used to describe any program, operation, or device that transfers data to or from a computer. Inputs and outputs are the heart of the controls concept. An output from one device is the input into another. When a sensor sends a signal to the controller, the sensors output is the controller's input. The controller takes the input and outputs a signal to the controlled device; now the output from the controller is the input to the controlled device.

Semiconductors

Semiconductors are substances that have other substances added to them to make them conduct electricity. Silicon is a common substance used in semiconductors. Semiconductors are currently the foundation of electronics. They are called *semi*conductors because their conductivity falls in between the range of conductors and insulators. So they are semi, or somewhat conductors and insulators. This has been a very simple explanation of semiconductors. The full scope of these devices is not necessary to know as an HVAC/R technician.

Transistors

These are three terminal semiconductors and they mostly used as electronic switches or amplifiers.

Rectifiers

As mentioned previously, rectifiers convert AC to DC.

Inverters

Inverters convert DC to AC. These are crucial components of variable frequency drives.

Circuit board

This board is insulated with thin layers of conductive metal pathways that connect electronic devices that are soldered on the board. In HVAC/R, if the board is determined to be "bad" then it can be replaced. If a device on the board is deemed to be bad then the whole board is usually replaced.

Microprocessor

These devices accept inputs, store them, and create a pre-programmed output. Microprocessors are the brains of the computer system. They are combined with inputs and outputs to give us our complete control system.

427. Electronic sensors

A sensing element provides a controller with information on changing conditions. We use analog sensors if the conditions, such as pressure or temperature, are continuously changing. Some electronic sensors use an inherent attribute of their material, such as wire resistance, to provide a signal and can connect directly to the electronic controller. Other sensors require conversion of the sensor signal to a type or level that the controller can use. For example, a sensor that detects pressure needs a transducer or transmitter to convert the pressure signal to a voltage that the controller can use.

These sensors, in most cases, are resistors that change their resistance as the measured variable changes. The most common variables are temperature and humidity.

Temperature sensors

Electronic temperature sensors are made of special materials that change resistance when the temperature changes. They have no moving parts and usually have no calibration adjustment. Most sensor materials increase their resistance as the temperature increases, and the reverse is true if the temperature decreases. A few manufacturers use sensors called "thermistors" that decrease their resistance as the temperature increases.

Temperature sensors come in many shapes and sizes, depending on the application. Besides the familiar wall-mounted room sensor, one of the other common types is the *averaging bulb*. These sensors average the temperature changes caused by stratification (different layers of air caused by a difference in fluid density of the layers within the duct).The sensing element is quite long, as much as 20 feet, and you install it across the duct cross-section so that it can sense the average temperature in the duct.

Another type of sensor is the *ceiling diffuser sensor*. You install these sensors at the center of the ceiling diffuser. Because of circulation of the room air into the center of the diffuser, the sensed temperature is the same as the room temperature.

Humidity-sensing elements

Humidity sensors are unique components, and it is very important that you follow specific manufacturer instructions. Humidity sensors are sensitive to dirt and vibration, and they tend to drift out of calibration with time. For this reason, you must handle them carefully and check their calibration frequently.

There has been the use of many materials over the years for electronic humidity sensors. One state of the art device is the *resistance cellulose acetate butyrate* (CAB) element. Its construction is of a multilayered film with a conductive carbon core encased in a humidity-sensitive polymeric film. As you expose the element to higher moisture contents, the polymeric film swells and expands, causing the carbon core to stretch.

As the carbon core expands, the carbon molecules move farther apart. This expansion increases the resistance to electric current flow. On a decrease in the moisture content, the polymeric film shrinks and the carbon molecules move closer together, decreasing the electrical resistance.

Another state of the art device is the *hygroscopic salt-coated element*. The conductivity of the coating changes when exposing the element to higher moisture content. These devices need a special power supply, such as 5 volts square wave AC. Application of the standard 20 VDC power supply destroy this device. The design of typical humidity-sensing elements is to have a nominal resistance of 2,500 ohms at 50 percent relative humidity (RH). Humidity-sensing range is normally 0–100 percent RH.

A recent development is the *capacitative thin film humidity sensor*. Originally developed in Finland in 1973 for process controls, these reasonably priced dew point sensors received packaging only recently for us in HVAC system controls. This system operates on the principle of the capacitance change in a 1-micrometer (µm) thin polymer film as it absorbs water vapor, translating to the capacitance change into a proportional electronic signal.

428. Electronic controllers

The electronic controller receives a sensor signal, amplifies and/or conditions it, compares it with the set point, and derives a correction if necessary. The output signal typically positions an actuator. Electronic controller circuits allow a wide variety of control functions and sequences from very simple to multiple input circuits with several sequential outputs. Controller circuits use solid-state components such as transistors, diodes, and integrated circuits. Controller circuits include the power supply and all the adjustments needed for proper control.

Electronic controllers

The type or types of inputs electronic controllers accept such as temperature, humidity, or enthalpy categorizes them.

Temperature controllers

Temperature controllers normally require a specific type or category of input sensors. Some have input circuits to accept resistance temperature device sensors, such as BALCO or platinum elements, while others contain input circuits for thermistor sensors (solid-state sensors with a negative temperature coefficient). These controllers have set point and throttling range scales labeled in degrees Fahrenheit (F) or Celsius (C).

Relative humidity controllers

The input circuits for relative humidity controllers typically receive the sensed relative humidity signal already converted to a voltage or current signal. Set point and scales for these controllers are in percent relative humidity.

Enthalpy controllers

Enthalpy controllers are specialized devices that use specific sensors for inputs to measure heat content. In some cases, the sensor may combine temperature and humidity measurements and convert them to a single voltage to represent enthalpy of the sensed air. In other cases, individual dry bulb temperature sensors and separate wet bulb or relative humidity sensors provide inputs, and the controller calculates the enthalpy. In typical applications, the enthalpy controller provides an output signal based on a comparison of two enthalpy measurements, indoor and outdoor air, rather than on the actual enthalpy value. In other cases, we assume the return air enthalpy is constant so that only the outdoor air enthalpy is measured. You compare it against the assumed nominal return air value.

Control modes

You can select the control modes of some electronic controllers to suit the application requirements. Control modes include two-position, proportional, and proportional-integral. Other control features include the addition of a compensation sensor as well as remote set point or reset capability, and override or limit control.

Output control

Electronic controllers provide outputs to a relay or actuator for the final control element. The output does not depend on the input types or control method. The simplest form of output control is two-position, in which the final control element can be in one of two states. For example, you can turn an exhaust fan in a mechanical room either on or off. A common output form provides a modulating output signal that can adjust the final control device (actuator) between 0 and 100 percent, such as in the control of a chilled water valve.

Output devices

Actuators, relays, and transducers are output devices that use the controller output signal (voltage, current, or relay contact) to do a physical function on the final control element such as starting a fan or modulating a valve. We can divide actuators into devices that provide two-position action and those that provide modulating action.

Two-position

Two-position devices such as relays, motor starters, and solenoid valves have only two discrete states. These devices interface between the controller and the final control element. For example, an energized solenoid allows water to enter a coil that heats a room. The solenoid valve provides the final action on the controlled media, water. The design of damper actuators also can be as two-position devices.

Modulating

Modulating actuators use a varying control signal to adjust the final control element. For example, a modulating valve controls the amount of chilled water entering a coil so that cool supply air is sufficient to match the load at a desired set point. The most common modulating actuators accept a varying voltage input of 0 to 10 or 2 to 10 VDC or a current input of 4 to 20 mA. Another form of actuator requires a pulsating (intermittent) or duty-cycling signal to do modulating functions. One form of pulsating is a pulse width modulation (PWM) signal.

NOTE: In some applications, a transducer converts a controller output to a signal usable by an actuator.

Indicating devices

You can enhance an electronic control system with visual displays that show system status and operation. Many electronic controllers have a built-in indicator that show power, input signal, deviation signal, and output signal. An indicator light can show on/off status; or, if driven by controller circuits, the brightness of a light can show the relative strength of a signal. If a system requires an analog or digital indicating device and the electronic controller does not include this type of display, you can provide separate indicating devices.

Interface with other systems

It is often necessary to interface an electronic control device to a system such as a microprocessor-based building management system. An example is an interface that allows a building management system to reset the set point or compensation for a specific controller. You must verify compatibility of the two systems before they are interconnected.

Performance

The single-input controller (which has only one sensor) varies its output signal (DC volts) as the measured variable changes. Again, the sensor may be built into the controller or it may be a remote component. The calibration of the controller determines how it varies its output. To describe the performance of a controller, you need to know the following:

1. Controller action; direct or reverse (DA or RA).
2. Controller throttling range (TR_c) or controller sensitivity ($Sens_c$).
3. Controller set point (T_{sp}).
4. Calibration voltage corresponding to the controller set point (V_{cal}).
5. Voltage span corresponding to the controller throttling range ($span_c$).

All electronic adapters have a specific purpose. Let's discuss a few.

High-low selector

The high-low signal selector is available to select the highest and lowest of multiple-input signals. To calibrate the adapter, find the voltage of all input signals and measure the output signal. If using a low selector, change the calibration adjustment until the output voltage equals the lowest of the input signals. If using the high selector, change the calibration adjustment until the output voltage is the highest of the input signals.

Electronic sequencing relay

A sequencing relay adds or subtracts a specified voltage to or from an input signal and the output is the resulting modified signal.

Electronic reversing relay

A reversing relay reverses the input signal. In other words, an input signal of 6 to 9 VDC becomes 9 to 6 VDC.

Electronic minimum position selectors

Minimum position selectors in electronic circuits are generally precision potentiometers. When in the "automatic" position, they maintain a minimum output signal between 2 and 15 VDC regardless of the input signal. A potentiometer knob setting determines the 2 to 15 VDC. When in "manual" position, the selector gives a selected output signal of between 2 and 15 VDC, regardless of the input signal.

Paralleling relay

The use of this device is to provide adequate signal strength to operate several controlled devices in parallel when the combined output load of multiple-controlled devices exceeds the output load rating of the controller. In a typical application, an input signal is measured and duplicated from a suitable power source and transmits duplicated signals to the multiple actuators. To calibrate, measure the input and change the calibration adjustments until the voltage output equals the voltage input.

Electronic limiting relays

These devices measure temperature and control a single-pole, double-throw SPDT switch. In a high-limit switch, the relay switches opposite of normal on a rise in temperature above set point. A low-limit switch switches opposite of normal on a fall in temperature below set point. This component may have two adjustments—a set point and a differential. The set point temperature less the differential equals the temperature where the relay switches back. The set point is normally adjustable, and the differential may be fixed or adjustable. To calibrate, measure the temperature sensed, change the set point, and verify that the device switches near the sensed temperature. Reset to set point or adjust as needed.

Electronic valve actuators

The actuator accepts a DC voltage from a controller or adapter and modulates from fully retracted to fully extended over its voltage span. Typical voltage spans are 3 VDC or 8 VDC. Actuators normally have a fixed span, but some are adjustable, and they may have a fixed or an adjustable start point. Some actuators have a spring return that returns the actuator to fully retracted on a loss of power. To ensure that an actuator is operating properly, determine the start point and the voltage span of the actuator. Change the voltage input and verify that the actuator starts at the start point and moves to fully extended (stop) over the actuator voltage span.

Electronic damper actuators

This actuator also accepts a DC voltage from a controller or adapter and modulates over its full stroke. Checking the operation of a damper actuator is identical to checking the valve actuator.

Electronic staging relays

This device accepts a signal from a controller or an adapter. The signal controls a single-pole double-throw switch. The relay has adjustments that specify the relay pull-in voltage and the differential. The differential specifies the relay drop-out voltage. In other words, the drop-out minus the pull-in voltage equals the differential.

429. Variable frequency drive

A variable frequency drive or VFD is used on an electric motor to fine tune the revolutions. This gives a piece of equipment the ability to function within a broad range. We could use a table top fan as an example. If you use the fan on a hot day after you finish working, you would want to turn the fan on a high speed to move a large amount of air to cool you down. When you start cooling off, you might want to turn the fan down to a medium speed and when you are satisfied, you turn the fan down to low speed, just to maintain your level of comfort.

Description and purpose

A VFD works with the same principal, automatically and with a wide range of applications. Ideally, whatever piece of equipment that is driven by an electric motor can have a VFD running the motor. VFDs are commonly used on air handling equipment or pumps and now being used in condenser fans and compressors. Fan or pump speeds can be modified to push a portion of the fan's designed output or can be driven to full output. This gives an engineer a lot of flexibility for creating customer comfort and system efficiency.

Principle

A VFD is a microprocessor based electronic device. It works from a standard input frequency and modifies it. The output is a digitally modified sine wave. The output voltage is typically the same as the input. This means that if the input voltage specification is 440 VAC, at 60 Hz, 3∅, the modified output voltage may be 440 VAC, 20 – 60 Hz, 3∅, (variable). If this example is driving a motor that turns 1725 rpm at rated input, it can be modified to turn 573 rpm at 20 Hz through 1725 rpm at 60 Hz.

The VFD needs a signal from a source to know what the output should be. This feedback control source could be internal or external from the VFD. An internal source may be a control on the front of the VFD panel to put the drive into an automatic or manual mode. In manual mode the VFD holds a specific output until a person adjusts it further. Automatic mode can use a sensor or transducer located in the controlled medium stream to provide feedback to the VFD. An external source could be something such as Energy Monitoring Control System (EMCS) or DDC systems. In either case, the VFD tries to maintain an optimum output that is good for customer comfort or efficiency.

The AC voltage that is input into the VFD is changed with a converter to DC voltage. The brains of the VFD, microprocessors, select the proper output signal and convert the DC back to AC. The device that converts the voltage back to DC is called an *inverter*. The term inverter is sometimes used interchangeably with VFD.

Remember one of the main purposes of the VFD is energy efficiency. If a motor doesn't need to run 100 percent, then why have it run 100 percent? It is best to use only what is needed. There is no need to waste energy.

Safety

Use caution with a variable frequency drive. Some VFDs can independently start at any time. They may appear to be turning so slow that you might think that power is not applied. Do not attempt maintenance or troubleshooting until you verify that the unit is de-energized. Another safety issue rises with the VFD's principle of operation. Since the output is a *modified* sine wave, some meters may not recognize or correctly tell you about the voltage. Make sure that you use the right test equipment when working on this equipment. A good hint and the best place would be to check the power *into* the VFD for verification that it is de-energized.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

426. Electronic terms and devices

1. Why are diodes referred to as *rectifiers*?

2. When will voltage flow through a diac?

3. How does voltage flow through a silicon-controlled rectifier?

4. What is the difference between the flow of current in an SCR and a triac?

427. Electronic sensors

1. How does temperature affect resistance in a thermistor?

2. How does time affect a humidity sensors calibration?

3. How must you handle humidity sensors since they are sensitive to dirt and vibration?

4. How does the *capacitative thin film humidity sensor* operate?

428. Electronic controllers

1. How is enthalpy calculated with multiple individual sensors?

2. How do modulating actuators adjust the final control element?

3. How does an electronic sequencing relay work?

4. With an electronic reversing relay, what is the output range if the input range is 6 to 9 VDC?

429. Variable frequency drive

1. What does a VFD do to the frequency?

2. What happens to the AC voltage that is input to the VFD?

3. How is the proper DC output of the VFD selected?

4. When should be the only time you attempt maintenance on a VFD?

3–5. Direct Digital Control and Energy Monitoring Control Systems

Advanced new technology has become a major part of the HVAC/R field. The energy monitoring control systems (EMCS) and the DDC systems are an example of this new technology. These systems utilize modern electronics to save energy and manpower. The EMCS systems now use an (enhanced) desktop computer to monitor or control the network for several HVAC/R systems from a remote location. This gives immediate feedback to the EMCS operator or supervisor, which can be very helpful in identifying equipment failure or maintenance problems with HVAC/R systems. Since EMCS systems and DDC systems are now interfacing, these components are becoming a very common sight in our job. In this section, we cover their specific components and applications in an effort to enhance your capabilities as a HVAC/R journeyman.

One theory behind the logic of automation systems is to provide better control of the building. Lack of control results in money loss. With an EMCS system, most Air Force installations now have better control of their energy consumption by accurately managing HVAC/R parameters and expediently identifying any maintenance problems of a building. Upon maintaining a positive control of these functions, *you* develop an efficient building operation. Why run equipment if it is not needed? Why let lights burn if no one is there? Why keep comfort conditions at optimum during unoccupied periods? Perhaps energy costs weren't so critical in years past, but now with strict energy saving guidelines from the federal government standards and less operational funds—EMCS makes sense. These following lessons covering EMCS and DDC applications give you the understanding of its components and how they relate to each other.

430. Emergency monitoring control systems fundamentals

In this lesson, we'll discuss some features and functions of the EMCS system and how the system components interact with each other. Some items covered will be EMCS specific components, networking, and software capabilities.

Features of the EMCS

The modern EMCS has a central computing system with interfacing components designed to manipulate, monitor, and record information from HVAC/R systems throughout your base. Of course, the EMCS central computer (CCU) must be hardwired (networked) to the DDC systems in your mechanical rooms to receive or send information. The CCU is basically your high performance desktop or personal computer with special software, and enough storage to monitor, and record month after month of information. The software used is powerful enough to provide a graphic intensive environment with animations and so forth, and usually developed by a specific company. This software allows the main computer to manage and monitor HVAC/R systems throughout several locations of the base.

The vast coverage permits it to be a central alarm center. If one of the HVAC/R systems has failed, that particular DDC sends that signal and the CCU sends an alarm to the system's operator. EMCS software is powerful enough to do other applications beside HVAC/R, which we discuss later. The CCU is located somewhere with-in the CE squadron and managed by a system's operator.

Subsystem components

These are the components that provide an interface with the EMCS main computer. They tell the EMCS what is going on in the HVAC/R system.

Radio frequency equipment

The radio frequency (RF) system has a single transmitter, usually near the CCU, and several receivers placed throughout the base housing on the HVAC/R equipment. The CCU sends commands to the transmitter, which relays them to the receivers. The RF equipment helps regulate the electrical power peaks throughout the base by cycling the HVAC/R equipment.

Interface device

This is where DDC comes into the picture. Simply put, the direct digital controller located in your HVAC/R mechanical room provides this interface with the CCU (fig. 3–19). Naturally, there are other components in between the EMCS and DDC, but we do not discuss them here. The DDC controller or microcomputer consists of a microprocessor with random access memory (RAM), communications interface, digital and analog input/output (I/O) cards, a control panel, and power supplies. The controller must have the capabilities to operate in a non-communicating (stand-alone) mode, doing basic monitoring and control routines.

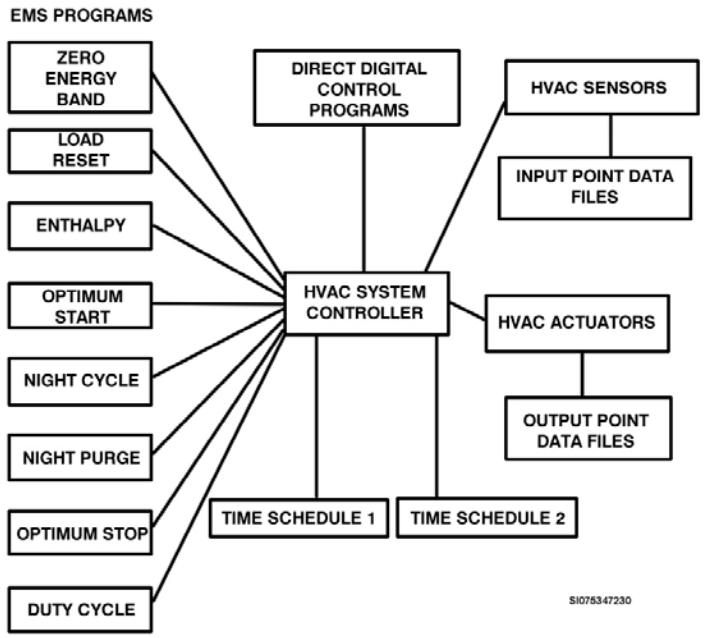


Figure 3–19. Relationship of DDC and EMCS programs, HVAC sensor files, and time schedules.

You can program the DDC controller to do optimization routines when there are special requirements or to make the HVAC/R system more cost effective or efficient. Even though the DDC controller is programmed to perform optimization routines, you can use a computer to schedule or record these routines over a period of time.

The DDC controller does what any HVAC/R controller is designed to do—-control the HVAC/R system. However, DDC can control it more accurately with many more features. We will cover these features later in the DDC lesson 431.

Networking

The CCU is networked, via telephone line, fiber optic, or some other type of distribution line that permits communication with the DDC controller/s (field interface units or FID) at their locations. This network of communication can allow instantaneous response from a building's DDC controller to the CCU for constant monitoring, recording, changing of parameters, or sending an alarm to the system operator. In most EMCS systems, this communication requires a modem at both the CCU and DDC location. In some situations, the EMCS is networked via the local area network (LAN). The LAN is a network that most bases now use, which only base populace can access.

The EMCS system is designed to automatically check all DDC systems for alarms, status, and so forth. The system operator can also perform a manual check as well. These systems will send a notification to system operators to notify them of a problem.

System operator

The system operator is (an individual) that supervises the system and monitors the performance of the CCU, and should be able to correct some of the problems associated with the EMCS environment. This individual should be your first contact if a problem arises in the EMCS or the operation of a specific HVAC/R system (if connected to it). The system operator also can provide you with several types of historical reports that aid in troubleshooting your HVAC/R system. This operator has the ability to modify set points, fan/pump schedules, and sometimes modify the operating sequence as well. At some bases, the operator may be one person or a group of people, while some bases allow the technician to make changes. The technician can make changes to the system by either using a computer in the shop or connecting a laptop to the control board in mechanical rooms. Oftentimes, while troubleshooting, you may *have* to connect a laptop to diagnose a problem.

Software

Energy and building management is one of the primary reasons for EMCS. EMCS provides an excellent media for energy or building management because of its capabilities in monitoring, storing, recording, and temporally changing parameters with-in the HVAC/R systems. When you look at the DDC controller in your mechanical room, it has the energy and building management software programmed into its functions but this microcomputer has a limited memory compared to the EMCS or CCU computer. Unlike the DDC controller, the CCU does have a vast amount of storage capability and can record such things as temperature variations over a period of weeks or months from your HVAC/R system. Your EMCS and DDC systems software permit energy savings and building management that can have the following features:

- Optimum start.
- Optimum stop.
- Night cycle.
- Night purge.
- Enthalpy.
- Zero energy band.
- Load reset.
- Duty cycle.
- Distributed power demand.
- Alarm lockout.
- Alarm monitoring.
- Run time.
- Time and event programs.

Optimum start

Based on measurements of indoor and outdoor temperatures and a historical multiplier adjusted by startup data from the previous day, the optimum start program uses an algorithm and calculates a lead time to turn on heating or cooling equipment at the last possible moment to bring temperatures to proper level by the time of occupancy (fig. 3–20).

Outdoor air dampers and ventilation fans should be inactive during preoccupancy warm-up periods. For weekend shut down periods, the program automatically adjusts to provide longer lead times. The program adapts itself to seasonal and building changes.

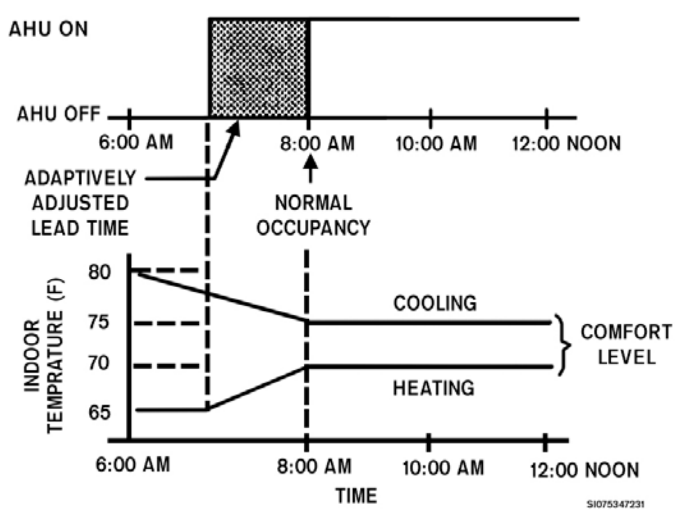


Figure 3–20. Optimum start.

Optimum stop

The optimum stop program (fig. 3–21) uses stored energy to handle the building load to the end of the occupancy period. Based on zone temperatures that have the greatest heating and greatest cooling loads and the measured heating and cooling drift rates, the program adjusts equipment stop time to allow stored energy to maintain the comfort level to the end of the occupancy period. This program adapts itself to changing conditions.

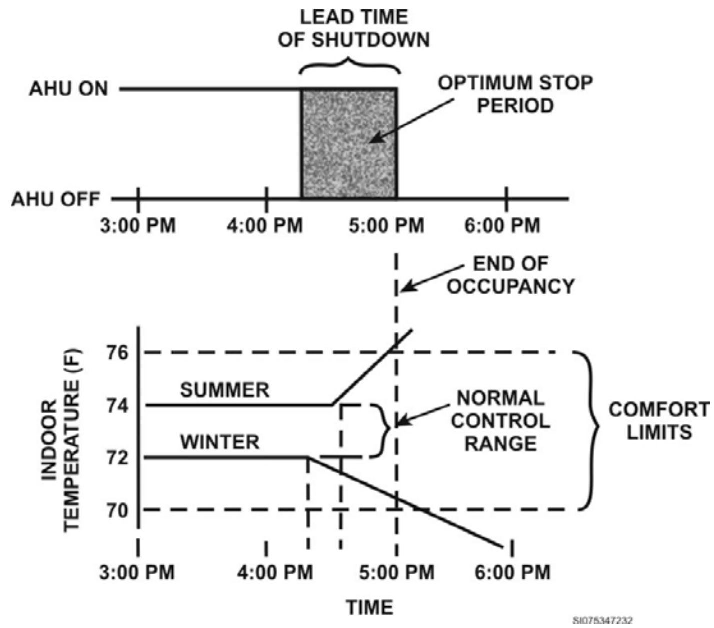


Figure 3–21. Optimum stop.

Night cycle

The night cycle program (fig. 3–22) maintains a low temperature limit (heating season) or high temperature limit (cooling season) during unoccupied periods by cycling the air handling unit while the outdoor air damper is closed.

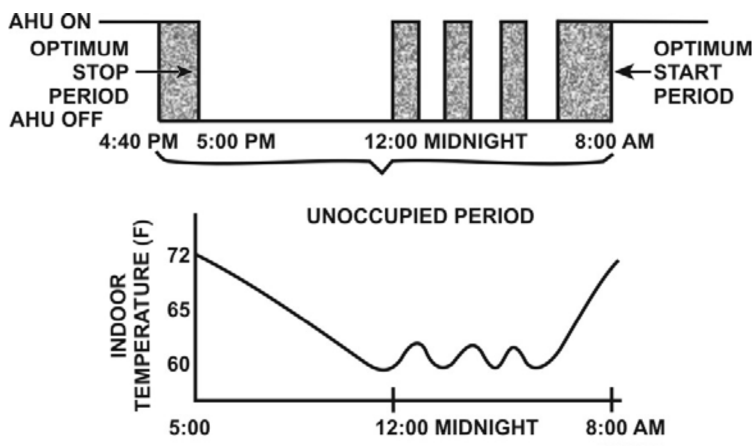


Figure 3–22. Night cycle.

Night purge

The night purge program uses early morning outdoor air to precool the building before turning on the mechanical cooling. Outdoor temperature, outdoor dewpoint, and space temperature are analyzed. One hundred percent outdoor air is admitted under these typical conditions.

1. Outdoor air above a summer-winter changeover point such as 50°F.
2. Outdoor temperature below space temperature by a specified or determined differential.

3. Outdoor air dew point less than 60°F.
4. Space temperature above some minimum for night purge such as 75°F.

Enthalpy

The enthalpy program (fig. 3–23) selects the air source that requires the least total heat (enthalpy) removal to reach the design discharge-air dry-bulb temperature. The selected air source is either the return air with a selectable minimum amount of outdoor or return air as determined by local control from discharged-air or space temperature measurement. Measurements of return-air enthalpy and return-air dry bulb are compared to outdoor air conditions and used as criteria for the air source selection.

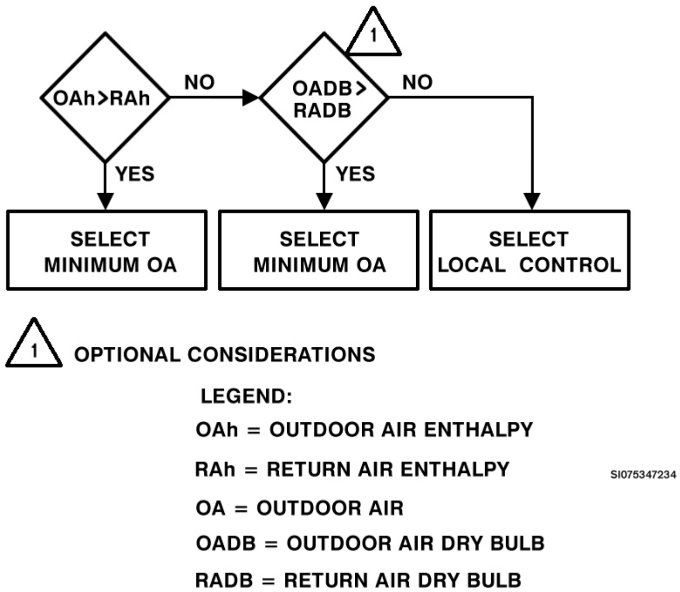


Figure 3–23. Enthalpy decision ladder.

Zero energy band

The zero energy band (fig. 3–24) program provides a dead band where neither heating nor cooling energy is used. This limits energy use by allowing the space temperature to float between minimum and maximum values. It also controls the mixed-air dampers to use available outdoor air if suitable for cooling. On multi-zone fan systems with simultaneous heating and cooling load capability, reset controls the hot and cold deck set points.

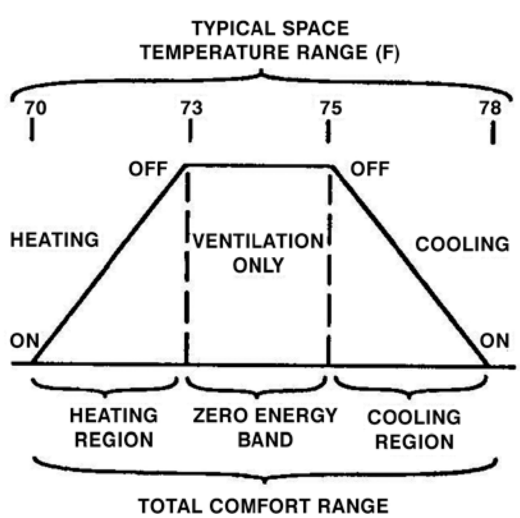


Figure 3–24. Zero energy band.

Load reset

The load reset program (fig. 3–25) assures the use of only the minimum amount of heating or cooling energy to satisfy zone temperature requirements. Samples of zone temperatures are taken and the zone with the greatest load is used to reset the temperature of the heating and cooling source.

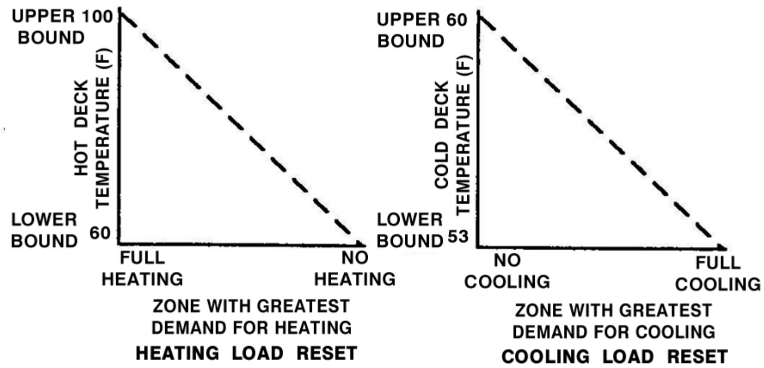
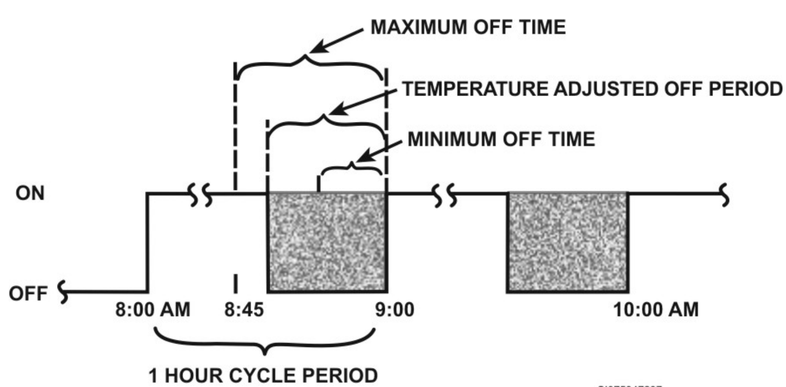


Figure 3–25. Typical load reset schedules.

Duty cycle

The duty cycle program (fig. 3–26) recognizes that the air handling equipment is sized for design load conditions and need not run continuously except at design temperatures. This program cycles equipment on and off at conditions other than design, without loss of comfort. To assure that comfort conditions are maintained, space temperature feedback is used to adjust the off time from a preset minimum to a preset maximum. When comfort limits are exceeded, duty cycling stops. To prevent excessive cycling of equipment, minimum on and off times are programmable.

In duty cycle applications where multiple loads are involved, the cycle periods of the loads should be staggered to achieve load leveling. Please note that you should not use duty cycling in conjunction with load reset or on variable air volume systems.



3–26. Typical duty cycle application.

Distributed power demand

The distributed power demand program (fig. 3–27) applies only to microprocessor controllers with intercommunications capability. The demand program is resident in a single controller that monitors the electrical demand and transmits the required load shed or restore messages to other controllers on the communications bus or within the network. Each individual controller has prioritized shed tables so that, when it receives a message to shed a specific number of kilowatts, it can respond by shedding its share of the load. The basic demand program normally uses a sliding window demand algorithm and has provision for sequencing so that the same loads are not always shed first when a peak occurs.

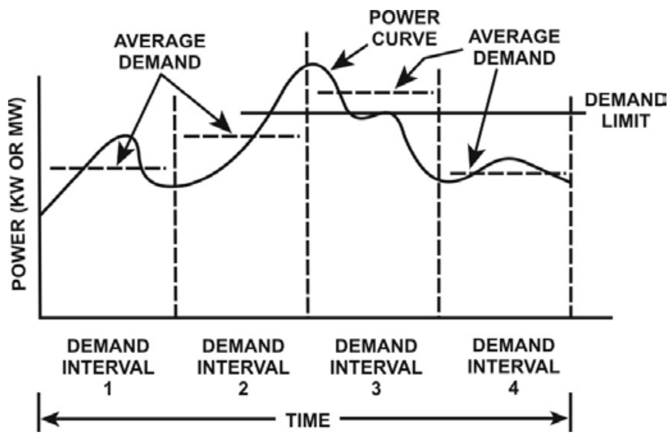


Figure 3–27. Typical power curve over four successive demand intervals.

You should note that there is interaction between the power demand program, duty cycle program, time schedule programs, and optimum start and stop programs. Therefore, a priority structure program is necessary to prevent issues.

Alarm lockout

This program permits alarm points to be locked out from reporting process depending on the status of another point, e.g., discharge temperature alarm can be locked out when the fan is off and during initial start-up periods.

Alarm monitoring

Scans all analog and digital points and tests for alarm status. Your DDC controller is programmed to send an alarm when a limit either exceeds or goes below a set parameter. Example would be when a fan should be running but the controller senses no air flow, or temperatures that went beyond set points. The EMCS or CCU picks this alarm up and the system's operator notifies your shop. This alarm can also be sent from the system to a cell phone.

Run time

Accumulates equipment on or off time and transmits totals periodically to the central system. On-off cycle counting also can be accumulated as a maintenance indicator. If run time or cycle count limits exceed, alarm annunciations occur.

Time and event programs

Initiates a predetermined series of control actions based on an alarm condition, a point status change, time of day, or elapsed time. Points acted upon can be resident in any controller.

Other applications

The primary task of the CCU is to do monitoring and control functions automatically. However, the control functions do predict environmental conditions and rate of power consumption, calculate equipment operating points, and produce control signals to operate equipment in the real-time environment. Its use is to report alarms or failures from the HVAC/R systems

EMCS also may do other functions, such as maintenance management, monitoring of sewage lift stations, environmental effluents, potable water systems, sewage treatment plants, fire alarm reporting, security, and other non-energy related tasks.

431. Direct digital control/Building Automation System

The use of DDC is often in place of conventional pneumatic or electronic control loops. There are several industry-accepted definitions of DDC. DDC can be defined as a "control loop in which a digital controller periodically updates a process as a function of a set of measured control variables and a given set of control algorithms."

Overview

Central controllers and most terminal unit controllers are programmable, meaning the direct digital control program code may be customized for the intended use. The program features include time schedules, set points, controllers, logic, timers, trend logs, and alarms. The unit controllers typically have analog and digital inputs that allow measurement of the variable (temperature, humidity, or pressure) and analog and digital outputs for control of the medium (hot/cold water and/or steam). Digital inputs are typically (dry) contacts from a control device, and analog inputs are typically a voltage or current measurement from a variable (temperature, humidity, velocity, or pressure) sensing device. Digital outputs are typically relay contacts used to start and stop equipment, and analog outputs are typically voltage or current signals to control the movement of the medium (air/water/steam) control devices.

When DDC controllers are networked together the control system may speak “proprietary” or “open protocol” language such as Building Automation Control Network (BACnet). These systems may be mated with a software package that graphically allows operators to monitor, control, alarm and diagnose building equipment remotely. See figure 3–28.

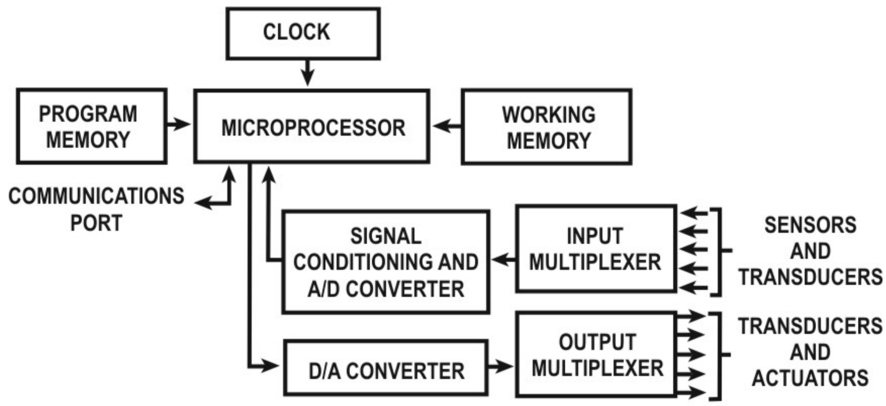


Figure 3–28. Microprocessor showing input/outputs

Capability

A set-up in a multi-story automated building would have many DDC building automation controllers serving different types of air conditioning and heating equipment (DDC is not limited to just HVAC applications). Every building is different and it is important for the engineer to select the proper HVAC control system and programs to control the various types of systems in a particular automated building. For building automation systems to be effective, it is important that the system is installed and tuned properly. Below are some advantages of a good HVAC DDC building automation system:

- Schedules of operation for the equipment and lighting systems so that energy savings can be realized when the building or spaces in the building are unoccupied.
- Allow the equipment optimal start with adaptive learning. Optimal start is allowing the equipment to be brought on in an ordered and sequential manner automatically on a schedule before the building is reoccupied so that space set points can be realized before occupation. Adaptive learning allows the system to compare space temperature, outside air conditions, and equipment capabilities so that the equipment can be turned on at an appropriate time to ensure space set points are achieved before occupation.
- Have trim and respond capabilities. Based on zone demand the set point for various heating and cooling sources will change according to demand from the zones. In a variable air volume (VAV) system all the VAV boxes are served from a central air handling unit. If all the zones are at set point then the supply air temperature set point of the air handler is automatically changed to prevent mechanical cooling from occurring when it is unnecessary. When the zones grow warmer the supply air temperature set point is automatically lowered to

allow mechanical cooling to satisfy demand. Older systems have a single supply air temperature set point of 55° Fahrenheit which requires the compressors to cycle even when it is not necessary.

- Have the ability to monitor energy usage including the ability to meter electric, gas, water, steam, hot water, chilled water, and fuel oil services.
- In conjunction with the appropriate mechanical system set-up should offer economizing based on enthalpy calculations and/or CO2 set point control.
- Have such DDC control algorithms as reset schedules for heating plants, static pressure control, and other systems where energy savings can be realized through these predictive programs.
- Offer load shedding when power companies are at peak demand and need business and industry to cut back on power usage to prevent brown outs. Building automation systems allow the owner to cycle various things off like water heaters or drinking fountains where use of these things will not be noticed even though they are off.
- Offer the ability to send alarms via email, pager, or telephone to alert building managers and/or technicians of developing problems and system failures. At your base you may have a stand-by cell phone that receives these alarms.
- Have DDC set up to bill tenants for energy usage.
- Have the communications abilities to be integrated with other building automation control systems and TCP/IP. BACnet compatible or other open source communication protocol is a plus.

Basic DDC control loop

To understand DDC, we must understand the basic control loop. Even the most adept HVAC controls technicians benefit in their work from going back to the basic control loop to solve problems or break down and understand complex DDC control algorithms. For basic DDC control or building automation control loop, we need three things:

1. Input from a sensor or device.
2. A DDC or building automation controller to process information and which holds the logic or programming.
3. Controlled device.

Inputs

This can be analog or digital. In this step, we are measuring temperature, or any other variables, and collecting data. DDC building automation inputs basically measure a medium or monitor the HVAC systems such as smoke detectors and high/low limit switches. DDC inputs measure temperature, humidity, pressure, current, wattage, and air and water flow among other things.

Process information

In this step, the DDC or building automation controller is processing the information from the input device(s) and based on the algorithm, possibly sending an output signal to a device to take appropriate action if necessary. The input device(s) does not need to be hard wired to the local equipment controller nor does an output response from the local equipment DDC building automation controller going to affect the DDC building automation controller’s local equipment. Over a communication trunk the DDC or building automation controller can receive input signals from distant automation controllers and issue output commands to those same or other distant building automation or DDC automation controllers. It really depends on the program and set-up of the entire system in the algorithms of the building automation system as a whole.

Controlled device

The actual device being controlled based on what the input is feeding to the DDC controls controller. In this step the controlled device is taking action to maintain the program based on program variables. Output devices can be damper actuators, valve actuators, relays, variable frequency or speed drives, compressors, blowers, and pumps.

DDC control responses

Knowing the different control response types will help you match them to the appropriate application. Let’s look at the types of control responses.

On-off

A two-position control response is either “on” or “off.” There may be no “in between” from on to off.

Floating

Floating control methods give a little me leeway from “on” to “off.” In addition to either fully on or off, floating control travels at a predetermined rate to compensate for variable changes between on and off. Do not confuse this with a proportional control. A floating control effort is not reciprocal to its load.

Proportional control

Often control systems are designed using proportional (P) control. In this control method, the control system acts in a way that the control effort is proportional to the load. The control effort is proportional to the load in a conditioned area, and that's what makes it proportional. If it doesn't have that property, it isn't a proportional control system.

Proportional plus integral

Proportional *plus* integral (PI) controllers use mathematical equations in an attempt to predict future performance from past conditions. This method forces the controller to find set point quicker. Since the controller responds to past values, it will tend to overshoot, even though it may be at set point.

Proportional plus integral plus derivative

The proportional plus integral plus derivative (PID) controller combines proportional control with two additional adjustments, which helps the unit automatically and closely compensate for changes in the system. These adjustments, integral and derivative, work together. Integral was described above. Derivative acts as a braking action to let the controller stop at set point so there is virtually no overshoot. The proportional, integral and derivative terms must be individually adjusted or “tuned” to a particular system using trial and error. It provides the most accurate and stable control of the five controller types, and is best used in systems which have a relatively small mass, those which react quickly to changes in the energy added to the process. It is recommended in systems where the load changes often and the controller is expected to compensate automatically due to frequent changes in set point, the amount of energy available, or the mass to be controlled. See figure 3–29.

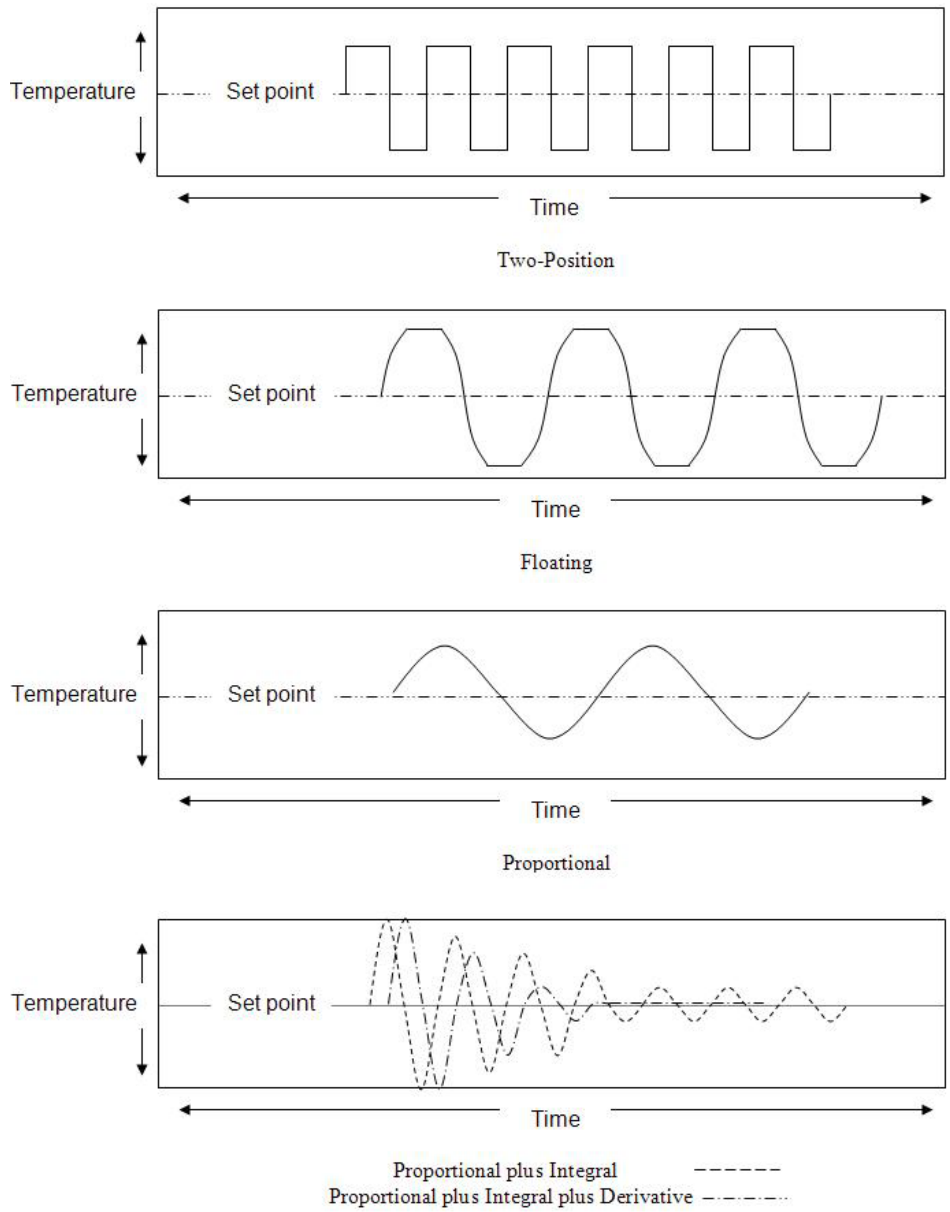


Figure 3–29. Comparison of DDC control modes.

432. Technical aspects of direct digital control

Explanations of analog, and digital, and digital inputs and outputs

DDC uses digital or analog signals as inputs or outputs to control a system. Below are the four basic methods of control:

1. Digital outputs.
2. Analog outputs.
3. Digital inputs.
4. Analog inputs.

Digital (binary) outputs

Digital and binary are the same. It simply means either ON or OFF, 0 or 1. With DDC control, these are either dry contacts or triacs (an electronically controlled switch). With our compressor start/stop above, we simply use DDCs to energize a relay that starts or stops the compressor starter. These contacts are typically rated for 24 volts but may also use 120 volts depending on the manufacturer and the ratings of the dry contacts and/or triacs. With the variable frequency drives (VFD), we are simply energizing a relay that starts and/or stops the drive(s). These (digital or binary) contacts can also be used for pulse width modulation (PWM) control.

Analog outputs

This is simply a modulating signal from DDC to a particular device or piece of equipment. Our drives, depending on how they are set up in their local parameter programming, will need a signal to tell it how fast to go. We can send three different typical signals to these drives from DDC. These are a 4 to 20-milliamp signal, a 0 to 10-volt DC signal, or a 2 to 10-volt DC signal. To keep it simple, we will set both drives and DDC up for a 0 to 10-volt DC signal. This is an output signal from DDC and an input signal to the drive. If we send 0 volts to the drive, it will run at minimum, if we send 10 volts to the drive, it will run at maximum. If we send it 5 volts, it will run at half speed and so on and so forth depending on what the program calls for the output to send to the drive. These analog outputs can also be used to control silicon controlled rectifiers (SCR) for resistive heating loads.

Digital (binary) inputs

Some DDC manufacturers use binary and some use digital when they describe their inputs and outputs. This is where DDC monitors some dry contacts like the smoke detector. These contacts are normally closed and when the detector detects smoke, the contacts open. DDC sees this, stops all blowers, and sends alarms to the appropriate sources. (**NOTE**: We don't necessarily rely on DDC to stop all the blowers. There should be a hard-wired interlock that will stop all blowers if the smoke detector trips.) The supply fan and compressor status inputs can come from contacts either on a contactor or from auxiliary contacts on the appropriate starters. Depending on how the program is set up, DDC simply wants to see an open or closed position from these sources.

Analog inputs

Input to DDC from a device or piece of equipment can be an analog signal. Temperature sensors are usually thermistors. Depending on the temperature, the resistance of a thermistor will change. DDC sends a small amount of current through the thermistor circuit. DDC takes the input current coming back through the thermistor circuit and translates it into a temperature. This is done in the program through tables in the database, which are matched up to the rated resistance/ temperature of the thermistor.

DDC/BAS wiring standards

A good DDC installation crew uses wiring installation standards to make sure all wire used meets appropriate codes and everything has consistency. In mechanical rooms, all wire will be in raceways or conduit. Above ceiling plenum, installers use plenum rated wire and tie wraps to secure the wire in a high location. Securing wiring in a high location is important to prevent someone from haphazardly cutting the wire or snagging it and pulling it loose from the controller or device. Additionally, above ceiling plenum wiring should never be tied off to other trades piping or hangers.

Where consistency really counts in wiring standards is what color is wired, and where. An example of this is communication wiring. Communication wiring is generally 24-gauge, 18-2 conductor shielded wire. The two conductors, generally one is white and one is black, should be terminated consistently throughout the project such as white is positive and black is negative or vice versa (terminations at the controllers on a network). It is important that every technician responsible for terminating completely understands these wiring standards and what color is used as positive and what is used as negative. This will save lots of headaches and communication troubleshooting in the future.

DDC controls VAV and economizers

VAV systems are the best way to zone especially in large buildings. A VAV system with the proper controls and set-up will help the building owner realize large savings in energy usage. There are many VAV systems out there set up in different ways. Of course, the most common set-up (for DDC) is usually the cheapest to install. They have an air handler, direct-expansion (DX) or chilled water, which supplies the VAV boxes with a fixed pressure and temperature of conditioned air. The VAV boxes have electric reheat which heats the air if that particular zone calls for heat. (**NOTE**: It is not uncommon to also find VAV boxes that have hot water reheat although this usually cost more to install but can save in energy costs.) The three main types of VAV boxes available are the following:

1. Series (fan powered).
2. Parallel (fan powered).
3. VAV (without a fan).

Either type of box can offer zone comfort and energy savings if the proper controls are installed. They have the appropriate programming for sequence of operation, and the system is properly balanced and calibrated. All that being assumed, let's look at a sequence of operation for a DDC controlled VAV box. We start at the thermostat, which is reading the zone temperature. If the zone temperature is too cold, the DDC backs down on the damper which allows air from the primary source, VAV air handling unit (AHU), to feed the zone. Depending if the box is parallel or series then the blower fan kicks on. This allows air from the plenum (or above ceiling) to be redistributed into the zone (this air is usually warmer than the primary air supply). If the zone temp continues to drop, then DDC will close the damper to minimum position not closed but an engineered rate of cubic feet per minute (CFM) minimum flow maximizing the use of warmer plenum air and activate electric or hydronic heat. Additionally, in the background, the zone controller is sending a heat request back through the network to the AHU equipment controller. As long as the equipment controllers (which is receiving input back from all the zone controllers) does not have any requests for cooling, then it should adjust the supply air temperature (SAT) set point up (with the proper programming). This prevents the compressors (or chilled water valves from opening) from cycling using unnecessary energy. As more zones call for heat and their particular dampers begin closing, the static pressure will rise. Through DDC, the variable frequency drives should slow the speed of the AHU blower allowing the static pressure to settle at a predetermined pressure. This application uses only the amount of energy necessary to keep the zones satisfied and is far better than systems which used to run 100 percent all of the time with little control. Note that some systems do not have variable frequency drives to control static pressure but use vortex dampers on the blowers.

Fan-powered VAV boxes

Additionally, there are VAV boxes that are fan powered. The main purpose of fan powered VAV boxes is to make use of the plenum air above the ceiling where the fan-powered VAV box is located. This air is usually warmer than the air supplied by the VAV air handler. So in the sequence of operation for a fan-powered VAV box, and a non-fan powered VAV box, would include closing the damper to allow minimal air from the air handler and at the same time energize the fan contactor so that the fan in the VAV box comes on and pulls warmer air from the plenum. Plenum air in most VAV box applications is also, usually, the return air for VAV air handling unit. When the fan in the fan-powered VAV kicks on, it pulls this plenum air into the VAV box where it mixes with the minimal airflow coming from the VAV air handler. Then, it either hits a reheat hot water coil or electric heat strips and is warmed further to a desired SAT set point in the DDC program if the VAV system is so equipped. There are also other set points, which the DDC program will monitor including CFMs. The analog signal coming from the DDC controller modulates the damper open and close (and everywhere in between to maintain the programmed set point) to maintain the desired CFMs in either the fan powered VAV boxes or the non-fan powered VAV boxes. Fan-powered VAV boxes are used to help increase efficiency by making use of the warmer plenum air and mixing it with the cooler air handler air. It takes less BTUs to heat 70-degree air than it does to heat 60-degree air.

Economizer systems

DDC systems in HVAC controls has taken leaps and bounds in the last few years in being user friendly, ease of designing systems, troubleshooting system problems, and increasing efficiency over the older EMCS. When discussing increasing efficiency of systems the idea of economizing always comes up. Economizers can be found in many different forms like using outside air when conditions are right to cool inside spaces, recovering heat loss from the relief air leaving the building, or making full use of the heat a boiler produces by recovering heat from the flue gases.

We have to understand that the mechanical code book requires so many changes of air per hour in commercial buildings. Many building owners rely on a manual fixed damper system to meet these requirements. Other systems have stand-alone dampers that actuate to the open position based on certain rudimentary input devices. The accuracy of these devices and the function they serve are rarely set up properly and hardly ever calibrated to ensure they function as designed. Typically, within a year of installation, they are disabled and the damper is closed off permanently in some way.

Depending on geographical location, a building can save lots of money with a properly designed and calibrated energy management system that allows the economizer to work through the HVAC DDC system. A good energy management DDC system has the ability to be monitored from a remote location over the Internet that collects trend data and proves energy savings using charts and graphs. Devices that are out of calibration or broken can be observed from the remote location and action taken to repair such devices. A good DDC energy management system will do all this and more.

To properly set up an economizer so that it works as efficiently as possible, we must have at least three input variables to control it:

1. CO2 monitoring inside the space.
2. An outside air temperature reading.
3. An outside relative humidity reading.

The CO2 will override everything else if it reaches a specified set point in the DDC program. By monitoring CO2 inside the spaces, we eliminate the need to have a minimum outside air damper position to meet the code requirements. That means that as long as the CO2 inside the spaces is below a specified amount, the unit can operate and condition the inside air without any influence from the outside air because of minimum positions on the outside air damper. That saves energy cost and safely monitors the building spaces for CO2 levels. The next thing we need to make the economizer effective is an enthalpy calculation on the outside air. To get an enthalpy reading, we must know what the temperature and relative humidity are outside. The DDC program crunches the numbers and determines the enthalpy value of the outside air. Based on a predetermined set point, the DDC program lockouts mechanical cooling and opens the outside air damper to bring in cool air for the purpose of cooling the space. This feature alone has the ability to save lots of money on energy costs.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

430. Energy monitoring control systems fundamentals

1. How does the EMCS CCU receive or send information from DDC systems around base?

2. How is the *main* computer allowed to manage and monitor HVAC/R systems throughout several locations of the base?

3. How will the DDC controller perform optimization routines when there are special requirements or to make the HVAC/R system more cost effective or efficient?

4. How are system operators notified of a problem?

431. Direct digital control/Building Automation System

1. Where do analog inputs usually come from?

2. Why must DDC systems be installed and tuned properly?

3. How can space set points efficiently be realized before building occupation?

4. How is the system information processed?

432. Technical aspects of direct digital control

1. What does it mean for an output to be *digital* or *binary*?

2. Depending on how they are set up in their local parameter programming, how will a drive determine how fast it needs to go?

3. How does the DDC take the input current coming back through the thermistor circuit and translate it into a temperature?

4. Why is it important to secure wiring in a high location?

3–6. Subsystem Control Strategies

The subsystems described in this section include on-off and safety controls, mixed-air control, coil controls, and other special subsystems controls.

433. On-off and safety controls

The starting and stopping of a central air-handling unit fan is controlled by a manual switch, a timer, or a relay controlled by an energy management and control system (EMCS). The manual switch may be a manual "start-stop" switch or "hands-off-automatic" selector switch located on or next to the magnetic starter, which serves the supply fan motor. In many systems the return-air fan and exhaust fans are interlocked (by auxiliary contacts on the supply fan starter) to follow the start or stop of the supply fan. The other fans and the automatic control system energize through auxiliary contacts on the fan starter, relays on the load-side wiring of the supply-fan motor-starter or by an airflow switch in the supply duct. The fan usually comes with firestats or smoke detectors and freezestats, which provide for emergency fan shutdown.

Wiring diagram

A typical wiring diagram is shown in figure 3–30. The return-air fan interlocks with the supply fan by means of an auxiliary contact on the supply fan. When someone pushes the “start” button, the starter holding coil (1M) is energized (subject to normally closed firestat [F8], firestat, and three normally-closed overload-heater relays [OL] being satisfied). At the same time, a “sealing contact” (1M) closes to maintain the holding circuit. As the airflow starts in the duct, an airflow switch (AFS) closes to provide airflow.

In addition, the green “running” pilot-indicating light (PILOT) illuminates. With the return-air fan selector switch in “automatic” position, when starter 1M is energized, the auxiliary contact 1M in the starter selector switch circuit closes to energize the return-air fan starter holding coil (2M), which is subject to three normally closed and overload heater relays.

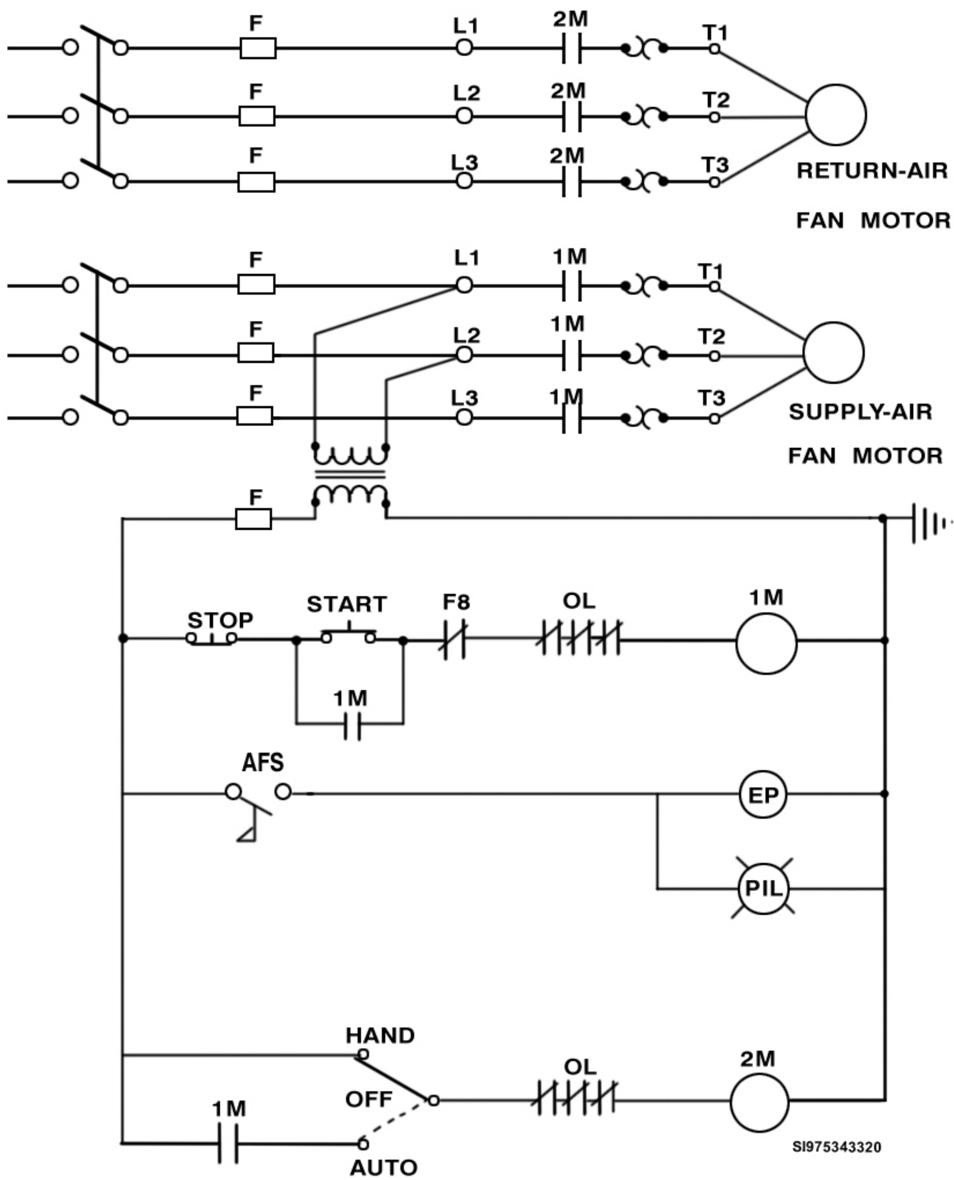


Figure 3–30. Schematic ladder diagram for an air handling unit.

Emergency fan shutdown

Another type of on-off control is the emergency fan shutdown control. The emergency fan shutdown sequence must comply with the requirements of fire codes to ensure the safety of the occupants and protection of the contents. The fire codes require that every fan have a manual emergency stop as a means of stopping the fan. This emergency stop may be the electrical disconnect for small or large systems, a separate “break-glass” station, or a tie-in with a manual fire alarm system. The emergency stops; the intention is to allow the fan to stop to prevent spreading fire and smoke through the duct system if automatic shutdown devices do not work.

Most buildings in existence today were built to comply with fire codes requiring the use of manually reset, fixed set point switches known as fire safety thermostats (FST)—or simply, firestats—in systems that move 2,000 to 15,000 cubic feet per minute. Smoke detectors are required in larger systems. The firestats, or smoke detectors, are wired to interrupt the holding coil circuit on the primary unit and, thereby, shut it down.

All interlocked units shut down by action of either an electrical interlock or through an airflow switch that interrupts control power. The firestats must be of the manual reset type to ensure that a high temperature condition receives some attention. The firestats in return air are usually set from 125°F to 135°F. Supply duct firestats are set to no more than 50°F higher than the normally expected temperature in the duct during the heating cycle. A commonly used duct smoke detector is the self-contained type. It is installed with the detector head in a cabinet outside the duct and has a sensing tube mounted across the inside of the duct or plenum to allow sampling across the entire duct width. Air aspirates into the sampling tube, through the detector head and over the ionization-type detector chambers, and out into the duct or plenum again.

Other fire and smoke devices that you may wire into the emergency fan shutdown loop include the manual fire alarm system “alarm” contacts and the automatic fire protection sprinkler system “sprinkler flow” contacts. Most systems also have freeze protection provided by a freeze safety thermostat (FZT)—or simply, freezestat. High-pressure fan systems may also have a high-pressure switch that stops the fan if duct pressures rise above the point at which damage may occur.

Smoke control in duct systems

Duct systems found in most HVAC systems are not built to perform smoke-control functions. An effective smoke-control system has an extensive set of controls, both automatic and manually positioned, to perform smoke and heat containment or smoke-removal functions. These controls are under the control of fire service personnel. Fire dampers and smoke dampers may be required to close duct air passages in an emergency and prevent the spread of fire and smoke.

In smoke-control systems, the same basic components are generally subject to individual control from a central fire-control panel. Each fan is able to restart from the fire-control panel, if there is a need to exhaust smoke from a fire zone, to supply smoke-free air to pressurize a zone, or to prevent entry of smoke and heat. In the same manner, fire-control and smoke-control dampers have individual controls so that they can be opened or closed, as necessary, to allow the fans to control pressure in the building and control smoke and fire.

NOTE: Fire or smoke dampers could fail and close when they are not supposed to. This could lead to a “no air flow” issue and is often overlooked by inexperienced technicians.

The subject of smoke control in buildings is currently undergoing extensive research and new smoke-control techniques are updating constantly. Each building has a different type of smoke-control system and a study of them must be careful to ensure that the controls are capable of operation under emergency conditions.

Filter controls

Filters may be manually changed or have an automatic changing system. Manual filter systems can include simple alarm devices to signal a high air-pressure drop across the filters. Such a condition requires a filter change.

Automatic controls for roll-feed media filters are usually based on time in service with two timing devices. One timer measures the interval between media advances while the other determines how long to run the media take-up drive motor and, thus, how much media advances during each run. Automatic controls may also be controlled by pressure-activated timer circuits that advance the media, as required, to maintain air-pressure drop within given limits.

Both filter control types may have media "runout" alarms to signal when a roll of media is coming to its end. A paper sheet rolls into the filter rack at the end of the media roll to reduce the airflow. It is important that you inspect the filter controls at each filter change to verify that they are functioning properly. A filter control that is not functioning properly could send an alarm indicating a high pressure drop situation when there is actually no high pressure drop situation. If this is the case, inspect the filters to ensure the control is faulty. Don't assume the control is bad without being thorough.

434. Mixed-air and coil controls

The basic purpose of the mixed-air control system is to control the amount of outside air brought into the HVAC system. It is important to bring in fresh air when there are people in the building; otherwise, the air gets stale and people may become ill. This outdoor air must be heated or cooled, as necessary, to keep the building comfortable. This is very expensive, particularly if the outdoor air is very hot or very cold. For example, at Sheppard AFB, the summer time temperatures are often over 100 degrees. The supply air temperature required for a building could be 55 degrees. The more 100-degree air brought into the air system, the more money it will cost to attempt to cool it to 55 degrees. For this reason, it is ordinarily important not to bring in more outside air than is necessary. During certain conditions, however, bringing in outdoor air reduces the operating costs—and dampers should be opened. These conditions occur when the outside air is moderately cool and air-conditioning is necessary to cool the building. Under these conditions, we can use the cool outside air to reduce the amount of cooling the air-conditioner must supply.

Mixed-air systems that use outdoor air to help cool the building are often called *economizer* control systems. Performance control of the mixed-air section is by the outdoor air conditions as shown in figure 3–31. If the outdoor air temperature is higher than the conditions where free cooling can be obtained, the outdoor air controller shuts the dampers.

Outdoor Air Temperature	Mixed Air Control
very hot	minimum outdoor air
mild	use outdoor air for cooling
very cold	minimum outdoor air

Figure 3–31. Mixed-air section performance.

The minimum amount of outside air required depends on many factors and is subject to health and safety regulations. Consult an engineer or your supervisor if this information is not shown on the drawings.

Coil control

The coil subsystem contains a heating coil, a cooling coil, or both. The heating coil is either hot water, steam, or electric. The cooling coil is either chilled-water or DX. There are numerous techniques for controlling coils. This lesson explains some of the typical strategies.

Discharge control

In many systems, there is a requirement to maintain a constant temperature in the air that leaves a coil. The basic control loop involves a sensor in the discharge air, a controller, and usually a valve operator.

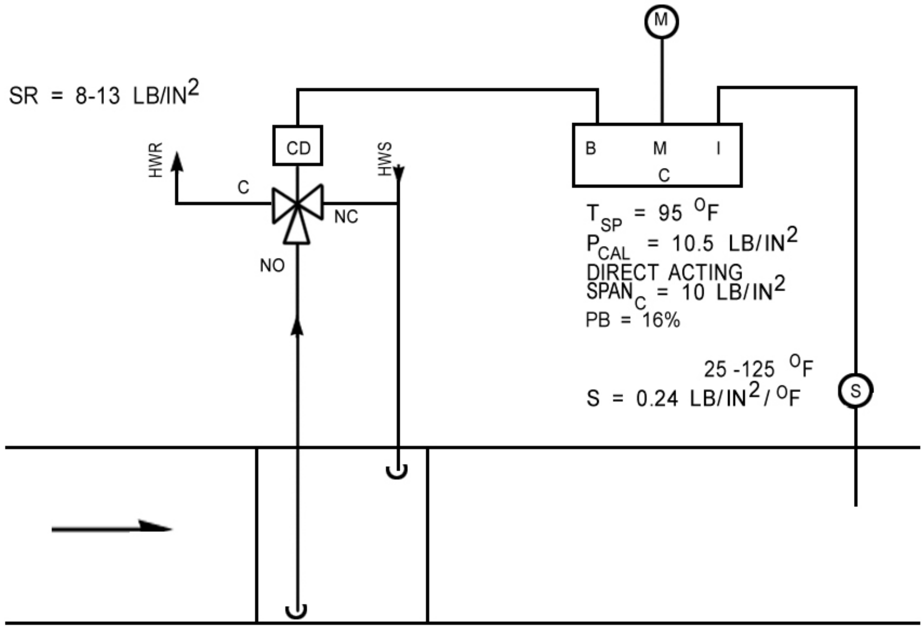


Figure 3–32. Pneumatic discharge control system.

The valve shown in figure 3–32 is a two-way equal percentage valve. The valve in this system fails to the open position, which gives a requirement for a direct-acting controller. As the temperature at the sensor becomes too warm, it is necessary to close the valve; this requires an increased signal from the controller. When the temperature goes up, the controller output goes up, a direct-acting relationship.

Space and zone control

Control of coils can also be directly from the controlled space. The control loop consists of a sensor in the space, a controller, and a controlled device that varies the capacity of the coil.

Coil control with reset

In controlling coils, it is sometimes desirable to use discharge control and reset the set point of that control loop as a function of another condition. This second condition or reset variable is usually the outdoor temperature or the space temperature.

For this system (fig. 3–32), the schedule shows that at 0°F, we want a discharge temperature of 95°F; when the outdoor-air temperature is 60°F, we want a set point of 70°F. Because the valve fails to the open position, the discharge-sensor control loop must be direct-acting. As the discharge temperature goes up, we need less heating. This requires an increasing controller output. If, as the temperature goes up, the controller output goes up, then it is direct-acting. As the outdoor-air temperature goes up, we should need less heating; this also requires an increase in the controller output. Again, the action is direct (both loops are direct-acting).

Also, looking at the reset schedule, notice that as the outside air temperature moves from 0 to 60°F, the set point for the discharge air changes from 95 to 70°F, that is, as the reset variable (outside air temperature) increases, the primary set point (discharge air temperature) goes down. This relationship is referred to as *reverse* reset (reset variable up and primary set point down).

435. Special subsystems and zone control

There are several other means of control available. This lesson explains how special subsystems and zone control work.

Reheat control

The basic reheat subsystem is common when there is a desire for humidity and temperature control. A chilled-water coil is used as a dehumidifier. As a dehumidifier, water vapor condenses out of the air by a cooling coil that lowers the water vapor content of the air. However, this air is often too cold for the conditioned space. A heating coil, sometimes hot water, is necessary to warm the air to a desired temperature. This hot-water coil or electric heat strips reheat the air that traveled from the chilled-water coil.

A typical reheat subsystem is shown in figure 3–33. The type of coil subsystem shown is called face and bypass (air either passes through the face of the coil or the bypass damper). There is constant waterflow through the coil while maintenance of the water temperature is through the chiller control. A set of dampers (CD) mixes the air that passes across the coil with the air that flows through a bypass deck. This mixed air passes through the hot-water (HW) reheat coil. The reheat coil is operated by a three-way valve that forces the hot water to bypass the coil as heating requirements decrease.

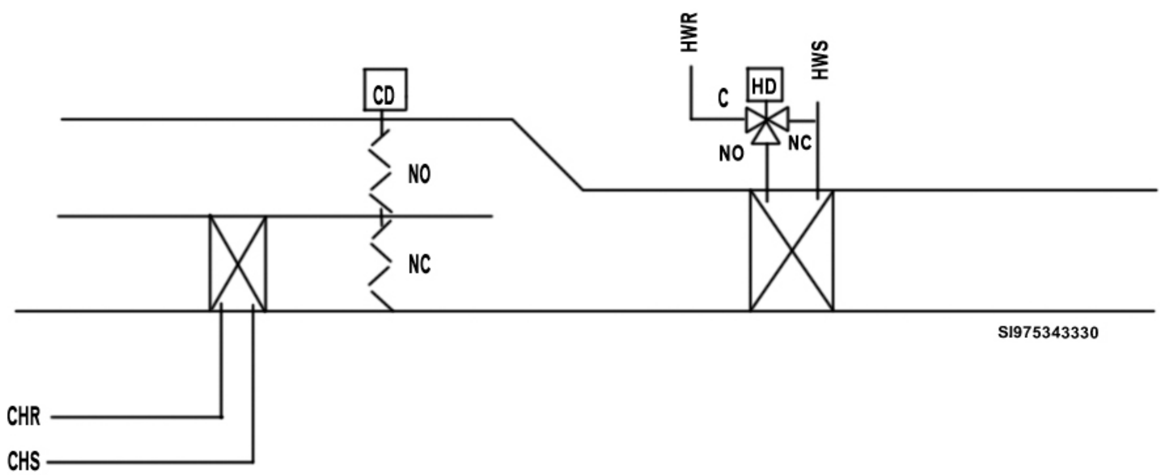


Figure 3–33. Coil arrangement for a reheat system.

The control of the reheat subsystem depends on both temperature and relative humidity of the conditioned space. In addition to cooling the air, the chilled-water coil provides dehumidification. As the relative humidity increases, more air must pass through the coil to remove moisture. To do this, the dampers (CD) must open. Since the damper for the chilled-water coil is normally closed (NC) it will now open more and the outside air dampers will close more, as needed.

The chilled-water coil can also cool the conditioned space. As the temperature in the space increases, the air needs cooling. The damper actuator has to open the damper for the chilled-water coil when the conditioned space temperature increases or the relative humidity increases.

If the space gets too cold, use of the reheat coil is necessary. As the temperature in the conditioned space decreases, the valve actuator (HD) has to move the three-way valve to allow more hot water through the coil. Since full flow through the coil is the normal position, a lower signal is required to close the valve. Thus, the temperature controller must be DA.

Not pictured are the sensors and controllers for this system. Modern systems have electronic controllers that monitor and control these functions. These controllers operate like the ones mentioned in the previous unit. There are far too many brands, models and functions to cover in this CDC. It is up to you to study the manuals for each control system you are working on.

Humidifier control

When relative humidity is too low in the conditioned space, then use of a humidifier is necessary. The humidifier is located in the air handler, downstream of the coils. Steam humidifiers are common because they can saturate the air with little increase in temperature. Control of the humidifier can be by a sensor controller that senses relative humidity in the conditioned space.

If the relative humidity in the conditioned space were to decrease, more water from the humidifier would be necessary. A signal would be sent to the humidifier allowing it to inject water from the humidifier as needed. In addition, some safety controls are necessary to help prevent damage from water.

A sensor/controller is necessary to prevent the relative humidity in the duct from rising too high. As the relative humidity in the duct increases, the humidifier has to be turned off; this is done by the controller. If there is no airflow, then the relative humidity would increase dramatically. Even if the high-limit humidity controller senses this, it may be too late. The damage has been done. An airflow indication switch can protect against putting water into the air handler or duct when no air is flowing.

Variable air volume terminal unit control

Several different types of VAV units are available. Let’s look at a few of them.

Bypass VAV

These types of terminal units have been used for many retrofit applications, primarily where better temperature control is required in a large single-zone system. The bypass VAV (fig. 3–34) gives a good temperature control but no fan savings. As the air supplied to the space is throttled, the bypass damper opens to the return air so that the total volume of air supplied by the fan remains constant.

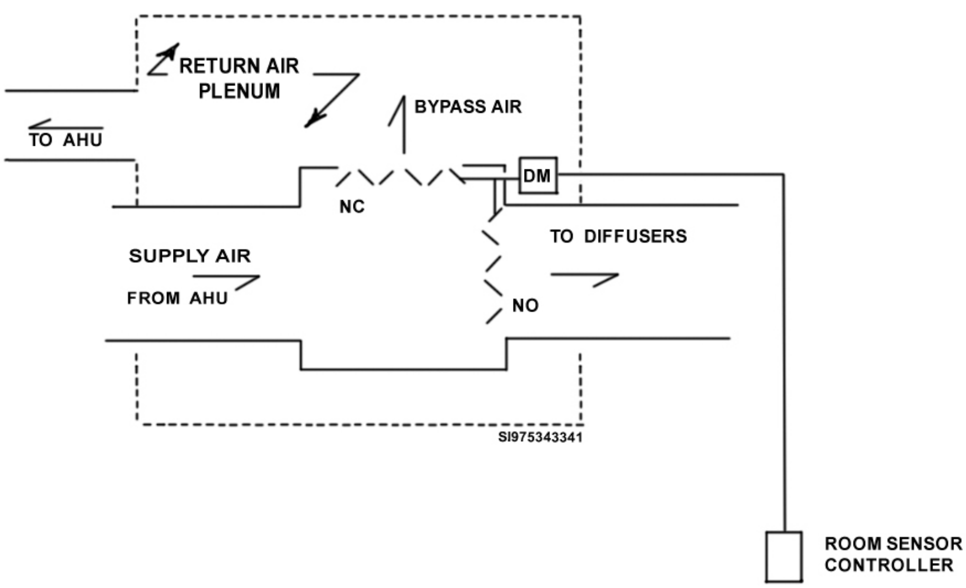


Figure 3–34. Bypass VAV.

Induction VAV

Induction units (fig. 3–35) operate to deliver a constant volume of air to the space, yet save on operating (fan) costs. They do this by running the supply air through a nozzle. The static pressure reduces through the nozzle so the pressure downstream lowers. With this lowered pressure in the VAV box, air from the ceiling plenum is induced to ensure a more constant volume of air that delivers to the space. Some brands of induction boxes use a small fan to ensure that enough air is induced.

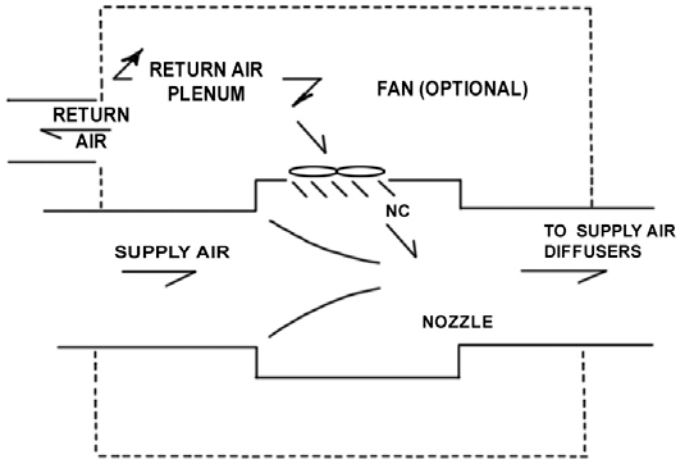


Figure 3–35. Induction VAV.

Two disadvantages of this terminal unit are higher operating costs and more noise. Both are due to the induction fan. The biggest advantage is in room comfort. The constant supply of air ensures proper mixing and more uniform temperatures in the space.

Shutoff VAV

Probably the simplest of all terminal units, this type of VAV (fig. 3–36) consists of a damper to modulate the amount of cool air delivered to the space. Warm space temperatures cause the controller to open the damper so more air is delivered to handle the load.

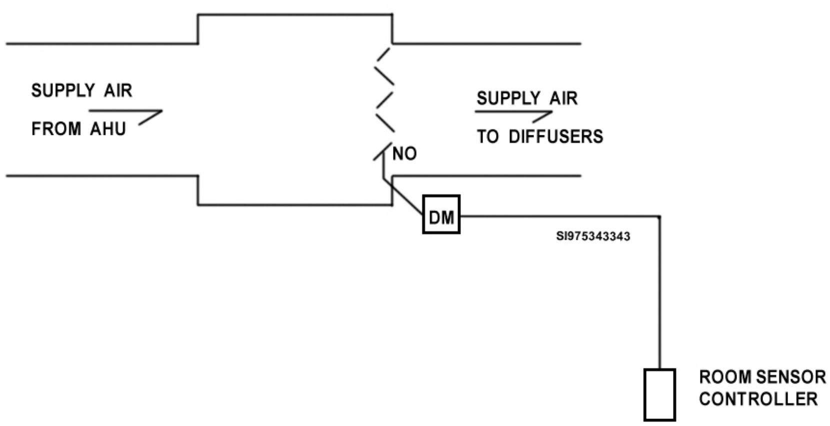


Figure 3–36. Shutoff VAV.

VAV with reheat

If there is not a separate heating system to handle the building heat loss, we can add a reheat coil at the VAV box. The room controller operates the reheat coil in sequence with the volume damper (valve actuator for hot-water coil, relay for electric resistance or strip heating).

With all the terminal units, the amount of air delivered is affected by the static pressure in the supply duct. High static pressure tends to force more air through the VAV box. Because of this, many manufacturers make “pressure-independent” VAV boxes that compensate for the various pressures behind the box and deliver the correct air volume. This usually happens through a pressure sensor (pitot tube) immediately upstream of the damper that sends a signal to the controller to reset the position of the damper. The source of energy used to operate VAV boxes is generally electricity.

Single-zone and multiple zone controls

Once you understand the operation of the subsystems, it should be easy to analyze the operation of an HVAC control system by simply dividing the control system into its smaller subsystems. The following paragraphs cover some of the more common control strategies used for single-zone; single-path, multiple-zone; and multi-zone systems.

Single-zone controls

The single-zone HVAC system can operate properly with the most basic types of control hardware. It is the least expensive to design and install. If installed properly, it is the easiest to maintain. As a result, most HVAC systems are of the single-zone or single-air-path system.

Single-zone systems are typically used where space conditions can be properly controlled with one sensor (temperature or humidity) providing the space condition information (temperature or humidity) to control the control system. For example, in a residential-type (family housing) air-conditioning and heating system, a single electronic thermostat can control the equipment for the entire house. Larger applications, such as open office spaces and small commercial spaces, can also be served by multiple sensors that “talk” to one main control or multiple sensors and multiple controllers. These systems are just like residential systems except they are bigger.

While still the same, larger applications that must be served by built-up equipment typically use PI or PID controls. These controls allow for stable, energy-efficient operation of larger systems and permit the addition of energy-saving features such as economizers (remember, economizers use outside air for cooling). A thorough understanding of the input versus output characteristics of these controls can make these systems easy to troubleshoot.

Multiple-zone

Multiple-zone (multi-zone) systems use one central air-handling unit to satisfy the individual heating and cooling loads of many different rooms or zones. A drawing of a simple multi-zone air handler is shown in figure 3–37. Note that there is one mixed-air section and one supply fan. Air leaving the supply fan splits into two paths. One path goes through a heating coil into a section commonly called a *hot deck*. The other path goes through the cooling coil into the cold deck. Air from the hot and cold decks is mixed by zone mixing dampers to meet the heating or cooling requirements of the individual zones.

There is an independently controlled set of mixing dampers provided for each zone, thus each zone can draw as much hot or cold air as it requires. Note that there is only one heating coil and one cooling coil. This means that the coil discharge temperatures must be hot or cold enough to satisfy all the zones. The basic control strategy for a multi-zone system is to select the coil discharge temperatures based on the worst-case zones; that is, the zones which have the largest heating and cooling loads.

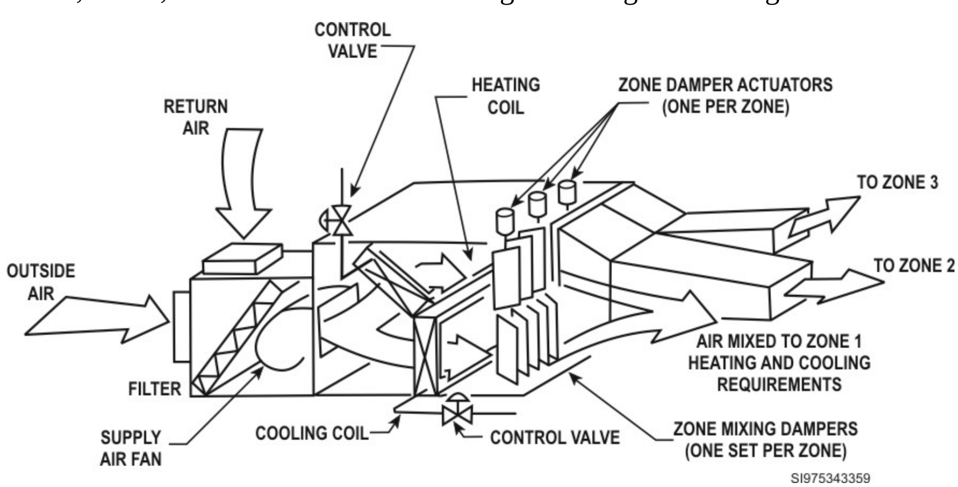


Figure 3–37. Typical multi-zone, air-handling unit.

Multi-zone systems are not very efficient because they mix hot and cold air. The design of most multi-zone control systems is to minimize the amount of mixing and to reduce operating costs. The amount of mixing required is determined by the temperature of the hot and cold decks. Ideally, the hot-deck temperature is no warmer than is required to satisfy the zone with the greatest demand for heating. The zone dampers for this zone should be fully open on the hot-deck side. Similarly, the cold deck need only be cold enough to satisfy the zone with the greatest demand for cooling.

If these conditions occur, the two worst-case zones do not require any mixing at all; the other zones only require some mixing. If the hot deck is warmer than needed, or if the cold deck is cooler than needed, all zones have to mix hot and cold air. This can be very inefficient. A hot deck only 10°F warmer than needed can easily increase the operating costs by 30 percent. The inefficiency caused by the mixing is less severe if the heating coil is turned off in the summer and the cooling is turned off in the winter, but it is still important to reduce the amount of mixing. The control system consists of four totally independent control subsystems:

1. Mixed-air control.
2. Hot-deck control.
3. Cold-deck control.
4. Zone-damper control.

The hot-deck control must keep the hot deck warm enough to keep the coldest zones comfortable on the coldest day of the winter. Since it is a single-input controller with a fixed set point, it maintains this temperature throughout the rest of the year. Similarly, the cold deck must be cold enough to keep the warmest zone comfortable on the hottest day of the summer. Obviously, because there is a great deal of mixing required during milder weather, the system is not very efficient. More efficient control schemes use a discriminator to pick the worst zones and allow these zone controllers to control the coils.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

433. On-off and safety controls

1. What switch should close once airflow starts in the duct system of an air handling unit?

2. What is the reason for the emergency stop function on an air handling unit fan?

3. How are the firestats and smoke detectors wired in duct systems?

4. What condition would be caused if the fire or smoke dampers in an HVAC system failed and closed?

5. In an HVAC system, what could a faulty filter pressure control cause?

434. Mixed-air and coil controls

1. Why is it important to bring in fresh air when there are people in the building?

2. What is a *positive* effect of bringing in outside air?

3. If the discharge-sensor control loop is direct acting, then what position will the valve fail to?

435. Special subsystems and zone control

1. When there is a desire for humidity and temperature control, how can the chilled-water coil be used?

2. How does the chilled-water coil dehumidify?

3. If the air that travels from the chilled water coil is cooled too far for the conditioned space, how is the air brought to its desired temperature?

4. How is the air that travels from the chilled-water coil reheated?

5. Where are steam humidifiers located in the air handler?

6. What type of HVAC system can serve a residential home and open office spaces?

7. How can proportional systems be easy to troubleshoot even though they are more complicated than single-zone systems?

8. In a multiple zone system, what temperatures must the coil discharges be?

9. Why are multi-zone systems *inefficient*?

10. How are most multi-zone control systems designed?

11. In multi-zone systems, how cold does the cold deck need to be?

Answers to Self-Test Questions

419

1. In applications that cannot tolerate lubricants getting downstream from the compressor.
2. It ends up degraded and oxidized by the heat of compression.
3. It forms a sludge that can gum up components of the air line.
4. Clearances between the screws.

420

1. Ensure they are in place.
2. Leaks.
3. By pulling up on the ring on top of the valve until you hear the rush of air.
4. Drain out condensation.

421

1. It increases.
2. When pressure is transmitted through the capillary tube to the bellows, the pressure then flexes the bellows.
3. The resistance to current flow usually increases with an increase in temperature and decreases with a decrease in temperature.
4. The thermistor, which has a negative coefficient of resistance, resistance to current flow decreases on a temperature rise and increases on a temperature drop.

422

1. Sensor, controller, and controlled device.
2. The controlled device reacts to the signal received from the controller to change the condition of the controlled medium; for example, air or water.
3. The sensor talks to the controller and let it know that it is hot.
4. The controller, the brain, makes a decision and tells the controlled device what to do.
5. The change in the measured variable needed to cause the controlled device to move from fully open to fully closed or vice versa.

423

1. The sensing element on the controller measures some variable (such as outside temperature) other than the controlled variable (such as inside temperature) and causes the control system to operate.
2. Timed on-off control gives shorter cycles with smoother control than does the basic on-off control.
3. By artificially heating the bimetal element in a thermostat, whenever the thermostat is calling for heat.
4. Controller then moves the actuator in the proper direction to bring the variable back within the limits of the controller differential.
5. In a neutral area.
6. By slowly adjusting the controller output up or down as needed to eliminate the offset.
7. Based on its current value and how fast or slow it is changing.

424

1. The magnetic field “pulls” the contact against the fixed contact with a positive snap.
2. The bimetal soon develops enough force to overcome the magnetic field and the movable contact breaks away with a positive snap
3. The actuator will move the valves and dampers through their complete range of motion.
4. So that the mechanical linkage doesn't bind.
5. Establishing the stroke (starting and stopping point) of the actuator.
6. De-energize the actuator and repeat the first two steps.

425

1. By making a definite movement.

2. It moves to a position proportional to the amount that the controlled variable has moved from the set point.
3. There is one, and only one, position of the final control element for each value of the controlled variable within the throttling range.
4. The coil valve must open farther and stay in that position as long as the increased load exists.

426

1. Because they perform the function of turning AC into DC.
2. When voltage reaches a designed level.
3. Flow is similar to the diode and travels from the cathode to the anode.
4. The triac operates much the same way as an SCR, but it allows current to flow in both directions.

427

1. They decrease their resistance as the temperature increases.
2. They tend to drift out of calibration with time.
3. Carefully and check their calibration frequently.
4. On the principle of the capacitance change in a 1-µm thin polymer film as it absorbs water vapor, translating to the capacitance change into a proportional electronic signal.

428

1. Individual dry bulb temperature sensors and separate wet bulb or relative humidity sensors provide inputs, and the controller calculates the enthalpy.
2. By using a varying control signal.
3. It adds or subtracts a specified voltage to or from an input signal and the output is the resulting modified signal.
4. 9 to 6 VDC.

429

1. Modifies it.
2. It is changed with a converter to DC voltage.
3. The brains of the VFD, microprocessors, select the proper output signal and convert the DC back to AC.
4. When it is de-energized.

430

1. It must be hardwired (networked) to the DDC systems in your mechanical rooms.
2. Special software.
3. By being programmed to do so.
4. DDC systems send a notification to system operators to notify them of a problem.

431

1. Typically a voltage or current measurement from a variable (temperature, humidity, velocity, or pressure) sensing device.
2. For building automation systems to be effective.
3. Optimal start is allowing the equipment to be brought on in an ordered and sequential manner automatically on a schedule.
4. A DDC or building automation controller.

432

1. Digital and binary are the same. It simply means either on or off, 0 or 1.
2. It needs a signal to tell it how fast to go.
3. This is done in the program through tables in the database which are matched up to the rated resistance/ temperature of the thermistor.
4. To prevents someone from haphazardly cutting the wire or snagging it and pulling it loose from the controller or device.

433

1. Airflow switch.
2. It allows the fan to stop to prevent spreading fire and smoke through the duct system if automatic shutdown devices do not work.
3. To interrupt the holding coil circuit on the primary unit and, thereby, shut it down.
4. It would lead to a “no air flow”.
5. It could send an alarm indicating a high pressure drop when there is actually no high pressure drop situation.

434

1. The air gets stale and people may become ill.
2. During certain conditions, bringing in outdoor air reduces the operating costs—and dampers should be opened.
3. Open.

435

1. As a dehumidifier.
2. Water vapor condenses out of the air by a cooling coil that lowers the water vapor content of the air.
3. A heating coil.
4. Reheat coil or electric heat strips.
5. Downstream of the coils.
6. Single zone system.
7. By having a thorough understanding of the input versus output characteristics of proportional.
8. Hot or cold enough to satisfy all the zones.
9. Because they mix hot and cold air.
10. To minimize the amount of mixing and to reduce operating costs.
11. Cold enough to satisfy the zone with the greatest demand for cooling.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

62. (419) If an air compressor runs for an extended period of time, the oil in it will
    a. cool down and vaporize.
    b. heat up and liquefy.
    c. cool down and sludge.
    d. heat up and turn into a vapor.

63. (419) When oil from an air compressor carbonizes and solidifies, what problems, if any, can it cause downstream?
    a. None.
    b. Line voltage issues.
    c. Too large of an increase in airflow.
    d. Valves and air tools to malfunction.

64. (420) When you push the test button on the automatic drain of an air compressor, there should be a blast of air and
    a. no moisture.
    b. a little moisture.
    c. 3 pounds of moisture.
    d. 5 pounds of moisture.

65. (421) What happens to the vapor pressure inside a sensing bulb when the surrounding air temperature increases?
    a. It leaves the bulb and capillary.
    b. It explodes.
    c. It decreases.
    d. It increases.

66. (422) What could occur if the system throttling range is too small?
    a. Operator hunting.
    b. Controller sensitivity will be adjusted.
    c. Complete loss of control of the system.
    d. Very efficient control of the system.

67. (423) In a timed on-off control, when does the heating anticipator cause the system to turn off?
    a. After the space temperature reaches set point.
    b. Early before the space can overheat.
    c. Two degrees above set point.
    d. Ten degrees below set point.

68. (423) In proportional control, if the room is very cold, how much heat will the system provide?
    a. One hundred percent heat every time.
    b. A minimum of 35 percent heat.
    c. An amount in proportion to the need.
    d. An amount in proportion plus 25 percent integral action.

69. (423) What is added to proportional control to correct its poor control and energy usage?
   a. Timed on-off control.
   b. Floating control.
   c. Integral action.
   d. On-off control.

70. (424) How do valves and dampers move through their complete range of motion?
   a. By on-off control.
   b. By loosening the linkages.
   c. By free flowing linkages.
   d. By an actuator that drives them.

71. (425) In timed on-off control, what is the result of the controller *not* having to wait until it can detect change in the control variable?
   a. A 25-percent increase in lag.
   b. A 75-percent increase in lag.
   c. The system is constantly lagging.
   d. Control system lags have no significant effect.

72. (425) In floating control, how does the controller move in relation to the deviation of the controlled variable?
   a. Its movement corresponds to the direction of deviation of the controlled device.
   b. Its movement is the inverse to the direction of deviation of the controlled device.
   c. There is very minimal relation between the controller and the controlled variable.
   d. Its movement floats the controller.

73. (426) What does a microprocessor do after it accepts inputs and stores them?
   a. Creates its own creative output.
   b. Creates a pre-programmed output.
   c. Holds on to them for up to 45 years.
   d. Creates an output for the sensor.

74. (427) What causes the temperature changes sensed by an averaging bulb?
   a. Stratification.
   b. Motor efficiency.
   c. External static pressure.
   d. Pre-programmed output.

75. (428) What does a minimum position selector use to select its output?
   a. Motor amperage.
   b. Compressor amperage.
   c. System control points.
   d. The minimum output selected for that controller.

76. (428) Where does an electronic actuator receive its direct current (DC) voltage?
   a. From the sensor.
   b. From a controller.
   c. From the controlled device.
   d. From the motor controller.

77. (429) What gives the engineers flexibility when creating customer comfort?
   a. Air handling equipment or pumps.
   b. Minimum output controllers.
   c. Variable frequency drives (VFD).
   d. Dampers.

78. (429) Where does the variable frequency drive (VFD) receive its feedback control?
    a. From the refrigerant gauges.
    b. From the controlled device.
    c. Internally or externally.
    d. Internally *only*.

79. (430) What is required for the energy monitoring control systems (EMCS) and direct digital control (DDC) components to communicate?
    a. A modem from your shop.
    b. A modem at the DDC.
    c. A modem at EMCS.
    d. A modem at both locations.

80. (430) Where can a technician make changes to a direct digital control (DDC) system?
    a. From a computer in the shop or laptop in mechanical rooms.
    b. From a government computer at your house.
    c. Only in mechanical rooms.
    d. By setting linkages.

81. (430) What should be the state of outdoor air dampers during preoccupancy warm-up periods for optimum start?
    a. Inactive.
    b. Active.
    c. 100 percent open.
    d. 75 percent open.

82. (430) What air source does early morning purge use to precool a building?
    a. Mixed air.
    b. Return air.
    c. Outdoor air.
    d. Supply air.

83. (431) What will a direct digital control (DDC) processor probably do after it receives its input and processes the information?
    a. Produce its own input.
    b. Produce an output.
    c. Control the sensor output.
    d. Control the sensor input.

84. (431) What proportional plus integral plus derivative (PID) action acts as a brake to stop the controller at set point and prevent overshoot?
    a. Derivative action.
    b. Floating control.
    c. On-off control.
    d. Integral control.

85. (432) What is a modulating signal from a direct digital control (DDC) to a particular device?
    a. Digital output.
    b. Analog output.
    c. Digital input.
    d. Analog input.

86. (432) When the direct digital control (DDC) sends a small amount of current through the thermistor circuit, what does it then do to the input current coming back from the thermistor?
    a. Performs a derivative action.
    b. Translates it into a temperature.
    c. Discards it to the floating control.
    d. Translates it to a signal back to the sensor.

87. (432) Why would you choose to install electric reheat over reheat water coils?
    a. Electric reheat is more expensive to install but more efficient to operate.
    b. Reheat coils are less expensive to install but more costly to operate.
    c. Electric reheat is the industry standard.
    d. Electric reheat is cheaper to install.

88. (433) On a central air-handling unit, which components turns **on** with the fan and also provides an emergency shutdown feature?
    a. Firestats and freezestats.
    b. Closed oil pressure switches.
    c. Freezestats and closed oil pressure switches.
    d. Firestats, smoke detectors, and airflow switches.

89. (433) How many degrees Fahrenheit (F) above the normally expected temperature are supply duct firestats set?
    a. 10.
    b. 30.
    c. 50.
    d. 150.

90. (433) Roll-feed media filters may be *automatically* controlled by
    a. the variable air volume (VAV) temperature.
    b. pressure-activated timer circuit.
    c. temperature-activated timer circuit.
    d. the technician removing the filter.

91. (434) In a mixed-air system, if outdoor air temperature is higher than the conditions where free cooling can be obtained, what will the outdoor air controller do?
    a. Shut the damper.
    b. Open the damper 50 percent.
    c. Open the damper 25 percent.
    d. Shut the damper 60 percent.

92. (434) For space and zone control, where can the control of a coil come from?
    a. Dampers.
    b. Valve actuators.
    c. The controlled device.
    d. The controlled space.

93. (434) What type of relationship occurs if the reset variable increases and the primary set point goes down?
    a. Observed.
    b. Reverse.
    c. Offset.
    d. Inverted.

94. (435) What two things does a reheat subsystem control depend on?
   a. Wet bulb temperature.
   b. Specific and relative humidity.
   c. Temperature and relative humidity.
   d. Temperature and specific humidity.

95. (435) Besides cooling the air, what other function does the chilled-water coil do?
   a. Heat.
   b. Humidify.
   c. Dehumidify.
   d. Increase grains of moisture.

96. (435) What must be used as the result of low relative humidity in the conditioned space?
   a. Chilled water cooling and dehumidifying.
   b. Steam coils to reheat air.
   c. Dehumidifier.
   d. Humidifier.

97. (435) What can be used to prevent relative humidity in the duct from rising too high?
   a. Actuators.
   b. Dampers.
   c. Sensor/controller.
   d. Controlled device.

98. (435) In a multiple-zone system, how can each zone draw as much hot or cold air as it requires?
   a. By using a dependently controlled set of mixing dampers provided for each zone.
   b. By using an independently controlled set of mixing dampers provided for each zone.
   c. By using the set of mixing dampers provided for all zones.
   d. By using bypass zoning.

99. (435) In a multiple-zone system, the coil discharge temperatures are based on the
   a. return air temperature of one zone.
   b. average building temperature.
   c. worst case zones (the largest heating and cooling loads).
   d. best case zones (the smallest heating and cooling loads).

100. (435) By what percent can a hot deck increase operating cost if it was 10 degrees Fahrenheit warmer than needed?
   a. 30.
   b. 40.
   c. 50.
   d. 60.

Glossary of Abbreviations and Acronyms

Δ	delta
µm	micrometer
1ø	single-phase
3ø	three-phase
AC	alternating current
AFI	Air Force instruction
AFS	airflow switch
AHU	air handling unit
Amb	ambient
Amp	amperes
amps	amperes
AWG	American Wire Gage
BACnet	Building Automation Control Network
BCE	base civil engineer
BTU	British thermal unit
C	Celsius
CAB	cellulose acetate butyrate
CCU	central computer
CD	dampers
CFM	cubic feet per minute
COND	condenser
CR	coil
CRC	contact
CTR	controller throttling range
DA	direct action
DC	direct current
DDC	direct digital control
DX	direct-expansion
ECU	environmental control unit
EMCS	energy management and control system
EMF	electromotive force
F	Fahrenheit
FLA	full load amperage
FST	fire safety thermostats
FZT	freeze safety thermostat
GFCI	ground fault circuit interrupter
GFCI	ground fault circuit interrupter
HC	holding coil
HD	valve actuator
HOA	hand-off auto

hp	horsepower
HVAC/R	heating, ventilation, air conditioning and refrigeration
HW	hot water
Hz	Hertz
I/O	input/output
LAN	local area network
LCL	load, control, load
NC	normally closed
NCO	noncommissioned officer
NEC	National Electrical Code
NO	normally open
O.L.	infinity
P	proportional
PI	proportional integral proportional plus integral
PID	proportional integral derivative proportional plus integral derivative
PWM	pulse width modulation
RA	reverse action
RAM	random access memory
RF	radio frequency
RH	relative humility
rpm	revolutions per minute
SAT	supply air temperture
SCR	silicon controlled rectifiers
$Sens_c$	controller sensitivity
$span_c$	voltage span corresponding to the controller throttling range
SPDT	single-pole, double-throw
SPST	single-pole, single-throw
TMC	thermostatic motor control
TR_c	controller throttling range
TS	temperature switch
T_{sp}	controller set point
VA	volt-amp
VAC	volts alternating current
VAV	variable air volume
V_{cal}	calibration voltage corresponding to the controller set point
VDC	volts direct current
VFD	variable frequency drive

Student Notes

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