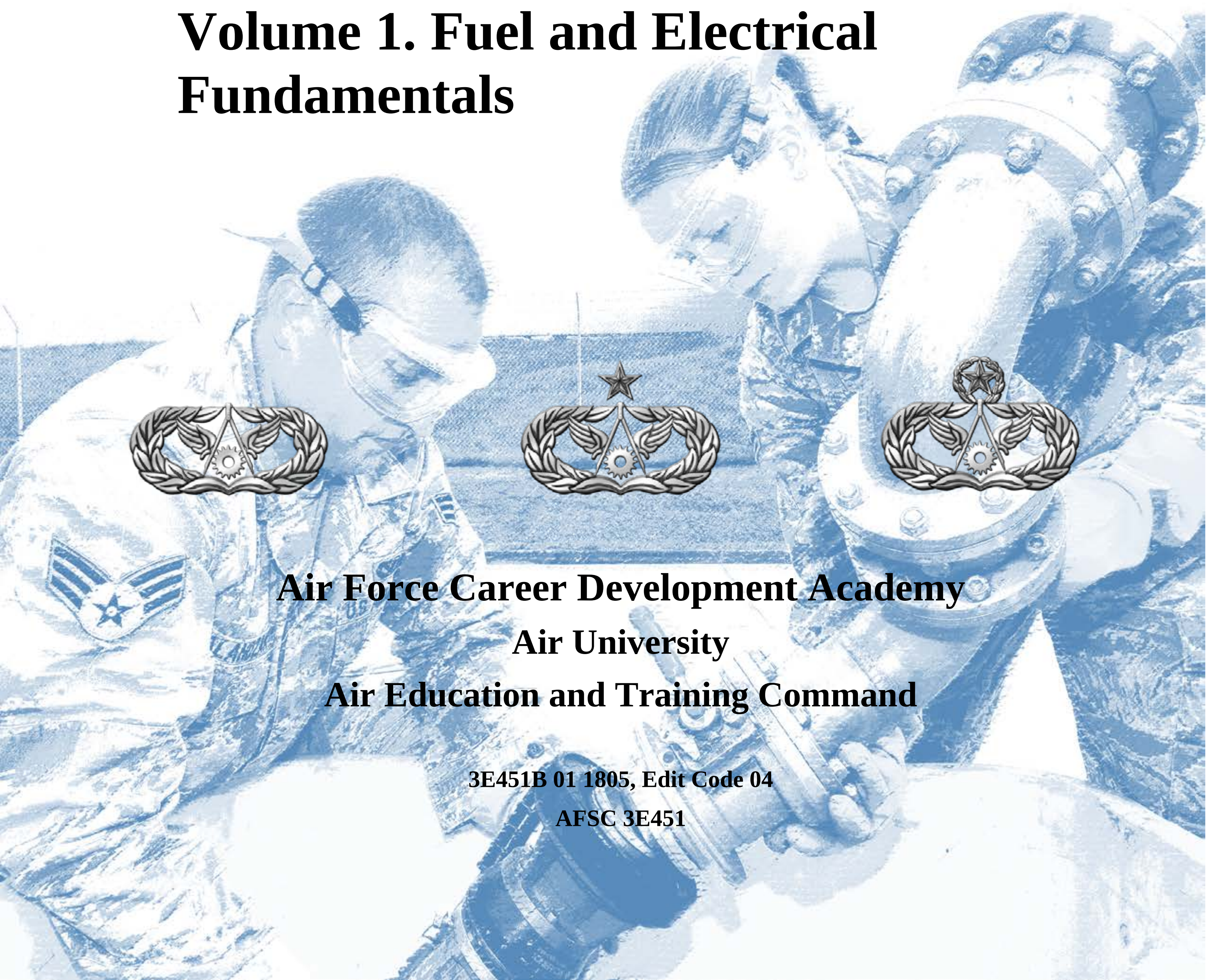
CDC 3E451B

Water and Fuel Systems Maintenance Journeyman

Volume 1. Fuel and Electrical Fundamentals



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OUR GOAL IN CDC 3E451B, *Water and Fuel Systems Maintenance Journeyman*, is to provide you with the knowledge about tank construction and tank entry as well as how to maintain the equipment normally found in fuel-related mechanical systems. Many of these components are also found at the bulk storage areas and in the immediate storage area of the hydrant systems.

This course contains four volumes. Volume 1 contains five units. Unit 1 covers fuel safety, with an emphasis on the characteristics and hazards of fuel and safety programs. In unit 2, we discuss fuel-related environmental compliance along with contract monitoring. In unit 3, we discuss the principles of mechanics and hydraulics. Unit 4 gives you information pertaining to electrical fundementals and circuit testing, and in unit 5, we discuss motors and controls.

Volume 2 gives you information on fuel tanks, filtration equipment, meters and gauges, loading/offloading facilities, and automotive dispensing systems.

Volume 3 covers the operation and maintenance of hydrant systems and components.

Volume 4 covers contingency operations.

As you complete this course, you'll gain the knowledge that if applied with on the job training will give you the skills required to advance beyond the apprentice level. Read and study each lesson, do the self-test questions and complete the mentioned training qualification packages, and you will master the contents of this course.

I recommend that you develop some study habits in order to enhance comprehension and retention of the content of this CDC.

A glossary is included for your use.

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This volume is valued at hours 15 and 5 points.

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.

Page

Unit 1. Fuel Safety

AS YOU COMPLETE your training as a Water and Fuel Systems Maintenance (WFSM) Journeyman, you are becoming a skilled worker. The trademarks of a skilled worker are visible in the efficiency of how the work is done and quality of the finished product. Those trademarks are intertwined with the safety procedures the worker uses.

This unit covers the dangers of the fuel work environment and the safety methods to keep from injury and complete the mission.

1–1. Fuel Characteristics and Hazards

FIRE! FIRE! FIRE! Those words should strike fear in your mind, but imagine the destruction possible when the words are heard in and around a fuel system. One glowing ash from a cigarette, a static discharge, or maybe a backfire from a work vehicle at the wrong time or place, and your world could turn into a blazing inferno.

This section covers the characteristics of fuel and its hazards. If you learn it well, you could have a long career and life. If not, you may become part of someone's frightful story.

001. Petroleum product characteristics

Petroleum products have certain characteristics important to all fuel handlers. A thorough knowledge of each characteristic is essential to your safety and to the safety of your fellow workers. The commonly referenced characteristics of liquid hydrocarbon fuels include their volatility, inflammable capability (bursting into flame), vapor pressure, flash point, freeze point, density, and conductivity.

In the following paragraphs about fuel characteristics, we will discuss the most common fuels that are available at most bases. These include automotive gasoline (MOGAS), diesel, E–85 (Ethanol blend) and JP–8 (jet propellant and jet fuel). We will also reference JP–4, which has been phased out for most aircraft assets and replaced with JP–8. As you begin to grasp these concepts, you will see why the Air Force (AF) prefers JP–8 over JP–4 from a safety standpoint. You may have to deal with other volatile fuels at your location, such as aviation gasoline (AVGAS), JP–5, or other blended fuels. It will be your responsibility to become familiar with their respective properties and safe handling instructions through material safety data sheets (MSDS) and your shop's hazard communication (HAZCOM) program.

Volatility

Volatility is the ease or tendency with which a liquid changes into a vapor state (vaporization). You can easily understand the importance of this characteristic when you consider that flammable and combustible liquids do not burn, but that the vapor of a liquid does. Next to the liquid's chemical composition, temperature is the key factor in determining a liquid's volatility. As the temperature of a liquid increases, so does its vaporization rate. Petroleum products are divided into two groups: (1) those having low volatility and (2) those having high volatility. Highly volatile fuels vaporize (or evaporate) easily, and low-volatile fuels do not.

Low volatility

Low-volatility products (such as oil, grease, fuel oil, kerosene, JP–8, and diesel fuel) almost have to be heated before they give off enough vapors to reach its flash point. Both diesel and JP–8 are fuels composed mostly of kerosene and have very low vapor pressures.

High volatility

Products with a high volatility (such as MOGAS [unleaded], E–85, and JP–4) vaporize enough at room temperature to reach its flash point. The volatility of jet engine fuel varies over a wider range than that of AVGAS. JP–4 has both gasoline and kerosene components, and earns its hazardous reputation because it forms explosive vapors at such low temperatures that JP–8 would not even produce vapors. MOGAS would produce vapors too rich to burn. Volatility has a direct relation with most of the other characteristics outlined in this section.

Burning and explosive characteristic (flammability)

Fire is one of your most dangerous enemies. It constantly stalks every action in a fuel area, waiting to pounce. Thousands of gallons (gal.) of gasoline in a well-built tank are comparatively safe. However, 1 gal. spilled can be very dangerous. Since some fuels vaporize much faster than other substances at lower temperatures, they are not only a fire hazard but an explosive hazard as well.

The lowest to the highest percentages of fuel mixed with air (by volume) able to be ignited, is called the *explosive range*. Mixtures of vapor and air below the lower explosive limit (LEL) are said to be too lean to burn (too much air/not enough vapors), and mixtures above the upper explosive limit (UEL) are said to be too rich to burn (too much vapors, not enough air). The explosive limits for unleaded gasoline range from 1.4 to 7.4 percent by volume, depending on the octane rating of the fuel. The range for JP–8 is 0.7 to 5.0 percent per volume. Figure 1–1 shows the explosive range of JP–8 fuel. The vapor concentration just above the fuel is more than 5.0 percent; therefore, it is too rich to burn. However, as these vapors rise and mix with air, the vapor percentage reaches the 0.7 to 5.0 percent concentration by volume. If there is a source of ignition, it will flash, burn, or explode.

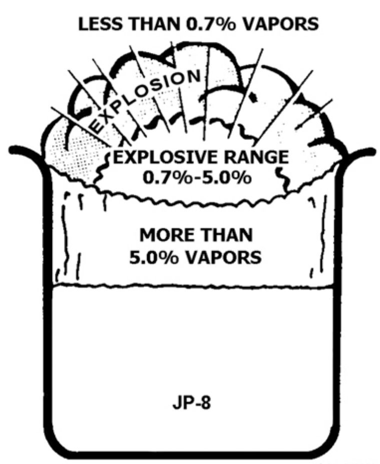

Figure 1–1. JP–8 explosive range.

LEL EXPLAINED			
FUEL	**BELOW LEL**		**ABOVE UEL**
JP–8	0<——> 0.6%	0.7 <—————————— ——> 5.0%	5.1%+ ————>
	TOO LEAN	EXPLOSIVE RANGE	TOO RICH
Diesel	0<——> 0.6%	0.7 <—————————— ——> 5.0%	5.1%+ ————>
	TOO LEAN	EXPLOSIVE RANGE	TOO RICH
MOGAS	0<——> 1.3%	1.4 <—————————— ——> 7.4%	7.5%+ ————>
	TOO LEAN	EXPLOSIVE RANGE	TOO RICH
JP–4	0<——> 1.2%	1.3 <—————————— ——> 8.0%	8.1%+ ————>
	TOO LEAN	EXPLOSIVE RANGE	TOO RICH
E–85	0<——-> 1.3%	1.4 < —————————— ——-> 7.6%	7.7%+ ————- >
	TOO LEAN	EXPLOSIVE RANGE	TOO RICH
	↑ ↑ ↑ ‖<–0 to 100%->‖ of LEL	When 100% of the LEL is reached, ← the lowest limit of the EXPLOSIVE RANGE has been also reached.	
All figures are vapor concentrations in air by volume.			

While the explosive range percentages for the various fuels are very similar, as shown in the table above, it is the temperature ranges that each fuel is able to evaporate enough vapor (becomes volatile) to reach their respective explosive range that makes one fuel more dangerous to work with than another. The next section shows the relationship between a fuel's volatility and explosive range to its vapor pressure.

Vapor pressure

The vapor pressure of a liquid is its most important characteristic from the standpoint of fire and explosion. Vapor pressure is the outward pressure generated by the vapors at a certain temperature. The "Reid" method standardized the calculation of vapor pressures for fuel products expressed in pounds per square inch (psi) at various standardized temperatures (at 68 degrees [°] Fahrenheit [F] or 100°F) in a closed container. Understanding the vapor pressure of different fuels enables you to understand why JP–4 is more dangerous than other fuels.

Depending on the ambient temperature, the vapor pressure of MOGAS ranges from 8 to 14 psi. This means that it creates pressure above its surface in a closed container. If you have ever removed a gas cap and heard the release of pressure from the gas tank, you know this to be true. At a fuel storage facility, when the gasoline temperature inside a tank is moderate (around 72°F), the area around the tank components (vents, gauging hatch, etc.) where vapors can escape, there is a flammable mixture. But because of its high vapor pressure and high volatility, if an ignition source started a fire at the tank components, it is unlikely to enter the tank because the vapor/air mixture within the tank is too rich to burn.

In this case, its characteristics in moderate to high temperatures create a non-explosive environment within its container. But when the MOGAS temperature in the tank is between –40° and 20°F, it is a different story. Between these temperatures, the vapor/air mixture above the liquid surface is within the explosion range, and the whole tank becomes a potential bomb. Under these conditions, great care must be taken not to generate sparks or other ignition sources.

The vapor pressure of JP–4 is approximately 3 psi at 100°F. This fuel's chemical composition, high volatility, and especially its low vapor pressure are what made this fuel the most dangerous of all the fuels to handle. What is significant is JP–4's high volatility when the fuel's temperature is between 10°F and 80°F. Within this temperature range, JP–4 is vaporizing just enough to maintain an explosive mixture above its surface in moderate temperatures.

The vapor pressures of JP–8 and diesel is very low, 3.3 psi and >1 psi respectively. These low vapor pressures coupled with their low volatility at moderate temperature, makes them both a much safer fuel than JP–4 or MOGAS.

Flash point

Fuel is any substance that burns in the presence of oxygen and a source of ignition. Liquid fuels (for our purposes) are hydrocarbon compounds produced at oil refineries and classified as flammable or combustible, depending upon their flash points. These classes and subclasses are defined in the table below.

Classifications of Flammable and Combustible Liquids		
Flammable		
Class	**Subclass**	**Definition**
I		Liquids having a closed cup flash point below 100°F (37.8° Celsius [C]) and having a vapor pressure not exceeding 40 pounds per square inch absolute (psia) (2,068 millimeters of mercury [mm Hg]) at 100°F (37.8°C).
	IA	Liquids having a flash point below 73°F and a boiling point (when a liquid actively begins to vaporize), below 100°F.
	IB	Liquids having a flash point below 73°F and a boiling point at or above 100°F.
	IC	Liquids having a flash point at or above 73°F and a boiling point below 100°F.
Combustible		
Class	**Subclass**	**Definition**
II		Liquids with flash points at or above 100°F and below 140°F.
III		Liquids with flash points at or above 140°F.
	IIIA	Liquids with flash points at or above 140°F and below 200°F.
	IIIB	Liquids with flash points at or above 200°F.

The flash point is the lowest temperature at which a liquid gives off sufficient vapors to ignite (momentarily flash) when mixed with air and a flame or source of ignition is applied. As you can see from the table above, flammable liquids have a flash point below 100°F and combustible liquids have a flash point at or higher than 100°F.

JP–8 has a flash point of 100°F, diesel has a flash point of <120°F, JP–4 has a flash point of 0°F, and MOGAS has a flash point of –40°F. When working with fuel, it's important that you always treat it with the respect the flash point demands. Notably, you must take great care not to get careless when working in cold environments, because some fuel flash points are in their explosive ranges in freezing temperatures. Becoming careless and rushing your work around fuel systems in this environment is a recipe for disaster. You must *always* take your time to do your work safely.

Freeze point

A product has reached its freeze point temperature when ice crystals start to form in it. For jet fuels, this characteristic does not usually create a problem for WFSM, but it is a great concern for pilots because ice crystals can clog fuel line filters, blocking the fuel's path to the aircraft engines. The freeze point for JP–8 is –58°F, while for JP–5, its –51°F.

Diesel fuel contains 6 to 8 percent wax which can form wax crystals at low temperatures (20°F to –24°F), called its cloud point. These wax crystals can then clog equipment and fuel dispensers. This is the most common fuel problem seen in low temperatures. If this happens, the fuel must be warmed enough to melt the wax crystals with a flameless or non-spark producing heat source.

Density

The density of a liquid is its mass per unit volume. When we talk of a fuel's density, we are using mass as an identifying characteristic. Closely related to density is *specific gravity*. The specific gravity of a liquid is the ratio of the density of a liquid at 60°F to the density of an equal amount of distilled water:

Specific gravity = mass of liquid/mass of equal volume of distilled water

Specific gravity is expressed as a number that tells how many times heavier or lighter a product is to water. Take a look at the following chart to see the specific gravity of some liquids.

Liquid	Weight	Specific Gravity
Water	8.34 pounds (lb.)/gal.	1.0
Diesel	About 6.8 lb./gal.	0.82
JP–8	About 6.7 lb./gal.	0.81
E–85	About 6.6 lb./gal.	0.80
Gasoline	About 6.0 lb./gal.	0.72

Because the specific gravity of most fuel is less than that of water, fuel floats on water. This is important because we can use this knowledge as a control. If we know the specific gravity of a fuel, mechanical floats, used to determine water levels in tanks and filter separators (F/S), can be designed to float in water but not in fuel. This idea is used in F/Ss and allows accumulated water to be dumped. Water drains on tanks are connected to sumps that are lower than the tank floor. The water collects in the sump and the weight of the fuel floating on top will push the water out when a valve is opened. One more important point—because of fuel's specific gravity, you cannot swim in it. Should you ever fall in a tank or try to swim across a dike full of fuel to close a leaking valve, you will sink like a stone and your chances of surviving are slim to none.

Conductivity

Conductivity is the ability of a material to transmit or conduct electricity. Fuel has low conductivity; however, it can produce its own static charge—a fact that makes it even more dangerous. Whenever any substance, such as a hydrocarbon liquid (like jet fuel) flows with enough velocity, a static charge will be generated. The fuel and anything it is in contact with will retain the static charge until enough time passes for the fuel to "relax" or dissipate the charge.

Some fuels, especially jet fuels, have a static dissipating additive (SDA) mixed into the fuel. This additive decreases the electrostatic relaxation time by increasing the conductivity of the fuel. However, the use of SDAs does not reduce or eliminate the need for you to follow proper grounding/bonding procedures.

002. Petroleum product hazards

The poisonous effect that a fuel product has on the human body is known as the product's toxicity. All fuels have the effect of poison due to their aromatic components and additives, such as benzene, tetraethyl lead (TEL), fuel system icing inhibitors (FSII), and corrosion inhibitors (CI). Poisoning from fuels occurs in three ways: inhaling the vapors, swallowing the fuel, and absorption through the skin. Let's look at each.

Inhalation of vapors/fumes

Always be sure that you are standing upwind of the fumes when working outdoors. A valve pit, hydrant pit or lateral control pit are likely places for fuel vapors to build up. While working indoors, make sure proper ventilation is provided when exposed to fuel vapors. A concentration as low as 0.1 percent vapor by volume is bad. While a low concentration of vapors won't burn, it is dangerous for you to breathe. Breathing low concentrations of fuel vapors can dull your senses, causing slight dizziness; this can irritate your eyes, nose, and throat and can lead to signs of intoxication. The lining of your lungs is also irritated by vapor inhalation. This is why proper ventilation in a fuel work area is a must. The following table shows the human response to fuel vapor at relatively small concentrations in parts per minute (ppm) and exposure times.

Human Responses to Gasoline Vapors Distilling Below 230°F		
Concentration, ppm	**Exposure time**	**Response**
550	1 hour	No effect.
900	1 hour	Slight dizziness and irritation of eyes, nose, and throat.
2,000	1 hour	Dizziness, mucous membrane irritation, and numbness.
10,000	2 minutes	Nose and throat irritation.
10,000	4 minutes	Dizziness.
10,000	10 minutes	Intoxication.

Always use vapor-monitoring equipment to determine vapor concentration instead of relying on your sense of smell. The olfactory receptors in your nose that tell your brain what you smell can become de-sensitized after a period of time around fuel vapors. In other words, you will not smell the fuel. This can lead to a longer exposure time, causing you and your coworkers harm.

Swallowing of a fuel

Fuel is very irritating when accidentally ingested, but the internal toxicity is much more serious. MOGAS is poisonous enough, but when fuel contains TEL or benzene, the poisonous effect is compounded. Throat, lung, and mucous membrane irritation may also be evident. Fuel sucked into your lungs can permanently injure them or even cause death. As a result, your lungs produce mucous to form a protective barrier. The production of too much mucous in your lungs may cause death by "dry-land drowning."

Here's something to think about—most people will stop to clean off their hands after a day of yard work, yet those same people will eat, drink, or smoke after getting fuel, solvents, or other petroleum products on their hands without properly washing them. This can lead to an accidental ingestion of these harmful chemicals. Be smart and take the time to decontaminate yourself of these hazards after exposure.

Absorption through the skin

If you spill fuel on your skin, several bad things can happen. Hydrocarbon fuels remove protective oils from your skin and can cause your skin to dry, chap, or crack. Severe burns may also result when fuel stays in contact with your skin. Fuel is absorbed through your pores, cuts, or scratches that could lead to blood poisoning. TEL and benzene are known to be in fuels that are still used today (i.e., AVGAS and JP–8) and can cause lead poisoning and cancer. If enough fuel containing either of these additives is absorbed through your skin, it can cause irreparable damage to your brain functions and internal organs. Always wash your hands immediately after getting fuel on them to prevent further absorption. If you get fuel in your eyes, go to the nearest eye wash station and flush your eyes for at least two minutes—then seek medical attention.

Sensitivity to petroleum products will vary from person to person. Some individuals can experience severe rashes, nausea, or headaches in response to a mild exposure. Always protect yourself from exposure to fuel products by wearing the proper personal protective equipment (PPE) for the job.

Self-Test Questions

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

001. Petroleum product characteristics

1. What is the definition of a Class I, flammable liquid?

2. What is the definition of a Class II, combustible liquid?

3. What is the definition of a Class III, combustible liquid?

4. What are the flash points of JP–8, MOGAS, diesel, E–85 and JP–4?

5. Match the definition in column A with the product characteristic in column B. Items in column B may be used only once each.

	Column A	*Column B*
____	(1) The ability of a material to transmit or conduct electricity.	a. Flash point.
____	(2) The outward pressure generated by the vapors at a certain temperature.	b. Freeze point.
____	(3) The ease or tendency with which a liquid changes into a vapor state.	c. Density.
____	(4) The lowest temperature at which a liquid gives off sufficient vapors to ignite when mixed with air and a flame or source of ignition is applied.	d. Volatility.
____	(5) The mass per unit volume.	e. Vapor pressure.
____	(6) The lowest and highest percentages of fuel mixed with air (by volume) able to be ignited.	f. Explosive range.
____	(7) The specific gravity of a liquid is the ratio of the density of a liquid at 60° F to the density of an equal amount of distilled water.	g. Specific gravity.
____	(8) The temperature at which ice crystals form in a substance.	h. Conductivity.

002. Petroleum product hazards

1. What are the three ways fuels can enter and poison the body?

2. What must always be used to determine vapor concentrations?

3. Match the effect in column A with its hazard in column B. Items in column B are used only once each.

Column A	*Column B*
____ (1) Leads to signs of intoxication.	a. Swallowing.
____ (2) Can result in death the same way as drowning.	b. Inhalation.
____ (3) Can cause severe burns on skin.	c. Absorption.

1–2. Fuel System Safety and Fire Prevention

Throughout the remainder of this volume and within the other volumes in this set, safety issues and guidelines will be discussed. Make no mistake, the handling of fuel and working on and around fuel systems is a job not to be taken lightly. Upon entering a new location by a permanent change of station (PCS) or temporary duty (TDY) assignment, you will be briefed on all safety concerns as part of that shop's HAZCOM program.

003. Fuels operation safety

You must observe numerous safety precautions and practices while performing maintenance on any fuel system because most accidents don't just happen; they are caused! To perform accident-free maintenance, strict compliance with safety instructions is a *must*. By following all safety protocols to the letter, you not only protect yourself and others, but also avoid damage to United States Air Force (USAF) property.

Work safety begins with the workers. As WFSM journeymen, we need to know how to operate and inspect our systems in order to do a system check once maintenance is completed. Technical order (TO) 37–1–1, *General Operation and Inspection of Installed Fuel Storage and Dispensing Systems,* provides safety requirements for the operation and inspection of these systems. Among these safety requirements is the "two-person policy," used for most fuel-handling operations. In addition to the operation and inspection aspects of this requirement, WFSM personnel will use the two-person (minimum) policy to perform work that will open a fuel system, repair a leaking fuel system, or put them in contact with fuel. This is due to the inherent hazardous nature of petroleum products. Having more than one safety-minded individual on the job makes for a safer work environment. Both individuals have to be familiar with fuel characteristics and hazards, equipment and system hazards, and emergency procedures in order for this two-person policy to be effective.

Accumulation and dissipation of static electricity in fueling systems

If you are to fully understand the dangers evolving from the accumulation of static electricity (also known as electrostatic charges), you must know its source and how to reduce and control the charge. Static electricity is the primary potential source of fires. Of all possible sources of static build-up that occur in and around fuel systems, the movement of the fuel itself is the largest generator of electrostatic charges. As such, you can see why it can be extremely dangerous to work around fuel products. Electrostatic charges are being generated within the petroleum products themselves and could possibly discharge in the presence of petroleum vapors. The turbulent flow of fuel causes electrostatic charge generation, such as through valves, piping, hoses, nozzles, and even air. Of all the fuels we work around, JP–4 and MOGAS fuels pose the greatest hazard. Besides generating static electricity, like all fuels, they have low vapor pressures. Because of their low vapor pressures, the vapors are usually in the explosive range in moderate temperatures.

As we know, flowing fuel generates static charges; however, when fuel comes in contact with different materials, the static charge generation is compounded. So, it is no surprise that tests have shown that a normal flow of fuel through an F/S produces sufficient static electricity to make a spark. This is a result of the F/S containing several different materials. The vessel itself is made of steel; the filter elements inside the vessel are made of plastic, cloth, and fibrous materials; and there are stainless steel components such as a float and tubing. All of these components provide a tremendous amount of surface area upon which charge generation can take place in a relatively short period of time. This is why the refilling of an empty F/S must be a slow process. If fuel flows too fast into an empty F/S, the static charge build-up will cause a flash or fire inside the F/S.

Petroleum products conduct electricity poorly and do not bleed off static charges very rapidly. Contaminants picked up during fuel transfer can enhance the buildup of static charges and increase the chance of sparks. Particles suspended in air or vapor can create a difference of potential with liquid fuel. The normal humidity of the atmosphere (moisture in air) provides a path to dissipate the static charge safely. However, in dry areas the charge dissipates slowly, and dangerous accumulation of static builds up.

Fuel is not our only concern. Another producer of static electricity is the movement, contact, or separation of two dissimilar materials. People and clothing (wool, rayon, and synthetic materials) also accumulate static charges. You are a producer of static electricity. If you walk across a carpet and touch another person or conductive material, an electrostatic discharge will occur and you get shocked. Similarly, when you walk across a fuel yard in cold, dry weather, friction occurs with the wind, your body, and clothing, which will generate a static charge. These charges can discharge through the clothing, skin, tools, and equipment as they come in contact with fuel system components. If fuel vapors are present when this happens, it can spell disaster. Nylon clothing and materials can generate up to 600 volts (V) potential. For this reason, nylon is not to be worn or used around fuel systems.

Prevention of static charges

Since the mid–1950s, hundreds of fires and explosions attributed to static discharges were recorded during aircraft refueling/defueling and tank truck loading/unloading operations. In almost every case, it is human error that caused the release of static discharges in the presence of fuel vapors. With fuel flow creating static charges day in and day out, 365 days a year, you would think that anything containing fuel is a disaster waiting to happen. This is only partly true.

While the complete elimination of static electricity is impossible, certain precautions can reduce the charge's strength and the release of electrostatic sparks or arcing. First, operating instructions (OI) and safety guidelines are developed to prevent workers from creating hazardous conditions. Next, electrical grounds and bonding wires are attached to portions of the fuel system (i.e., tanks, F/Ss, and truck fillstands). Grounding directs and dissipates any build-up of electrostatic charges literally into the ground, and bonding equalizes the electrical potential of separate components carrying a charge. Grounding and bonding will be discussed further in a later volume.

As we have said, contaminants in fuel enhance the build-up of static charge within fuels. For this reason, contaminants are removed from the fuel before it enters a tank. Avoid agitating the surface of the fuel in a tank. The fuel tank inlet or receiving lines are designed to enter horizontally or vertically close to the tank bottom to reduce turbulent flow or fuel freefall that would build up excessive amounts of static charges. When there is fuel in a tank, surface agitation is normally not an issue when adding more fuel to a tank. But when a tank is empty, precautions must be taken. Normal flow of fuel through a pipeline is 7–12 feet per second (fps). When you are filling an empty floating roof tank or cone roof with floating pan tank, the flow rate through the receiving line must be reduced to 3 fps until the roof or pan is floating. The flow rate through the receiving lines of an underground or cone roof tank is the same except that the 3 fps is maintained until the receiving line is completely submerged in fuel. This is done to reduce surface agitation, which can create electrostatic charges. The insertion of any object (such as a tape-and-bob) in a storage tank or the climbing of an aboveground tank's stairs are prohibited for at least 30 minutes after receiving fuel into the tank. This time lapse permits dissipation of any static charges.

All personnel working on or around fueling equipment and operations should wear clothing made of 100 percent cotton or combination blends of 50 percent cotton and 50 percent polyester as outer garments. The 50–50 blend produces less charging than the 100 percent cotton; therefore, it is the preferred clothing. Civilian or military clothing made of wool, silk, or nylon materials or blends of wool, silk, or nylon generates far greater electrostatic charges and constitutes an unacceptable hazard potential. You can, however, wear wool socks, glove inserts, and underwear of nylon, silk, or polyester as long as the material is not exposed or you do not remove them around open fuel systems.

Ground yourself frequently by touching static grounds in areas where fuel is stored, handled, or issued. A static ground will be an exposed piece of metal or braided wire that is not painted or does not have an insulated covering. Static grounds will be connected to a ground rod so that after touching it with your bare hand, any static charge your body has will also go to ground. Ground yourself to the storage tank or piece of equipment before opening any access covers, gauging hatches, or components that contain fuel. There will be designated static grounds at aboveground tanks, pump houses, truck fillstands, or fuel off-loading areas.

004. Fire prevention practices

Fire prevention is especially important around fuel systems to protect both personnel and AF assets. In this lesson we discuss the elements of fire and the practices we employ to prevent fires from starting.

Elements of fire

Figure 1–2 shows two simple triangles—not harmful looking at all, but they represent one of our greatest fears. On one side of the first triangle is air, which is all around us. Another side of this triangle is fuel, which can be anything that burns; but in our job, petroleum products come to mind first. Both the air and fuel sides of the triangle are touching because we can rarely alter their existence around us. The bottom of this triangle is a source of ignition—some type of heat. When all sides of this triangle come together and touch (as shown in the triangle on the right) fire occurs. Our job is to try to eliminate, as much as possible, any heat sources and to keep fuel vapors to a minimum while performing our work.

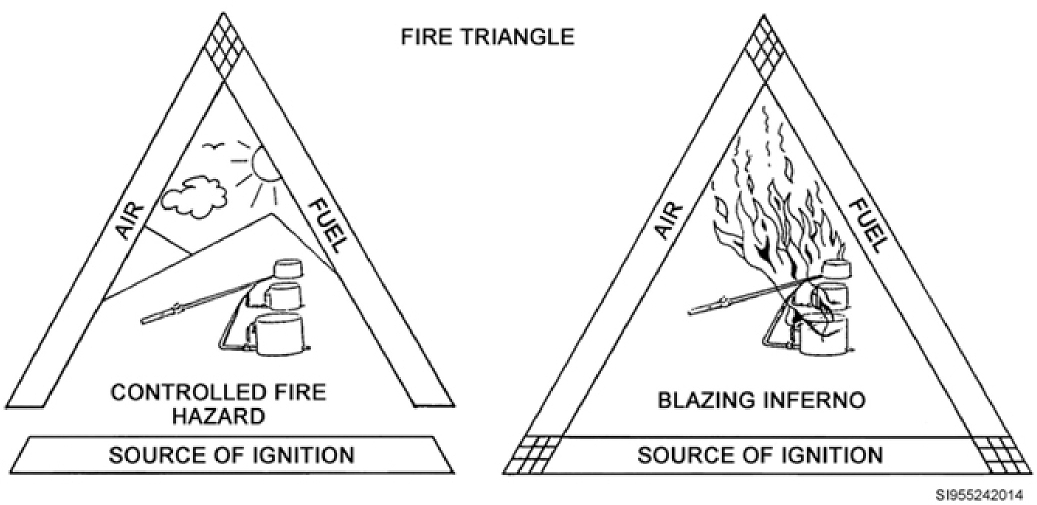

Figure 1–2. Fire triangle.

Fires can be prevented by eliminating any one of the three factors of the fire triangle—air, fuel, or source of ignition (heat). Heat is the single factor you must eliminate at all times around fuel systems by being aware of your surroundings and possible heat sources.

REMINDER: Static discharges are the most common heat source around fuel systems, so closely follow the prevention practices in the last section.

Minimizing vapors

Since air is all around us and we need it to breathe, it cannot be eliminated. Fuel is in and around some of the systems we work with, so you can't eliminate it either, but you can try to control the source of vapors. By minimizing the amount of vapors in the work environment, you can keep them out of the explosive range, preventing a fire.

Figure 1–3. Self-closing metal container.

Eliminating fuel vapors is not easy and sometimes impossible, but there are a few methods you can use. First, try to avoid spills. When working on the fuel system, drain as much fuel as possible back into the tank and/or pump the fuel into drums or contain it in drip pans and remove it from the area. If you are using rags to clean or soak up excess fuel, put them in a self-closing metal container immediately (fig. 1–3) instead of laying them on the floor.

Second, when working in an enclosed area, use an exhaust fan. An exhaust fan helps keep vapors from accumulating and keeps the vapors in a "too-lean-to-burn" state. Since vapors are heavier than air and settle in low places, an exhaust fan is necessary in pits more than 6-feet deep and in enclosed pump houses. If mission requirements permit, postpone work in a vapor saturated area to let the installed or portable exhaust fans do their job.

Third, never leave a pipe open after removing a component. Fuel may not leak out after you have drained the pipe, but vapors probably will. Always plan and equip yourself to cap, plug, or blind-flange the ends of open pipes.

Fourth, always approach and perform fuels-related work from upwind of the vapors so you won't become the source of ignition or be overcome by the vapors. Always check the wind direction and the area downwind before opening the fuel system or removing a component to prevent vapors from blowing towards a possible source of ignition (fig. 1–4). It is important to remember that heavier than air vapors travel low to the ground and drift with the wind for long distances where flashbacks can occur.

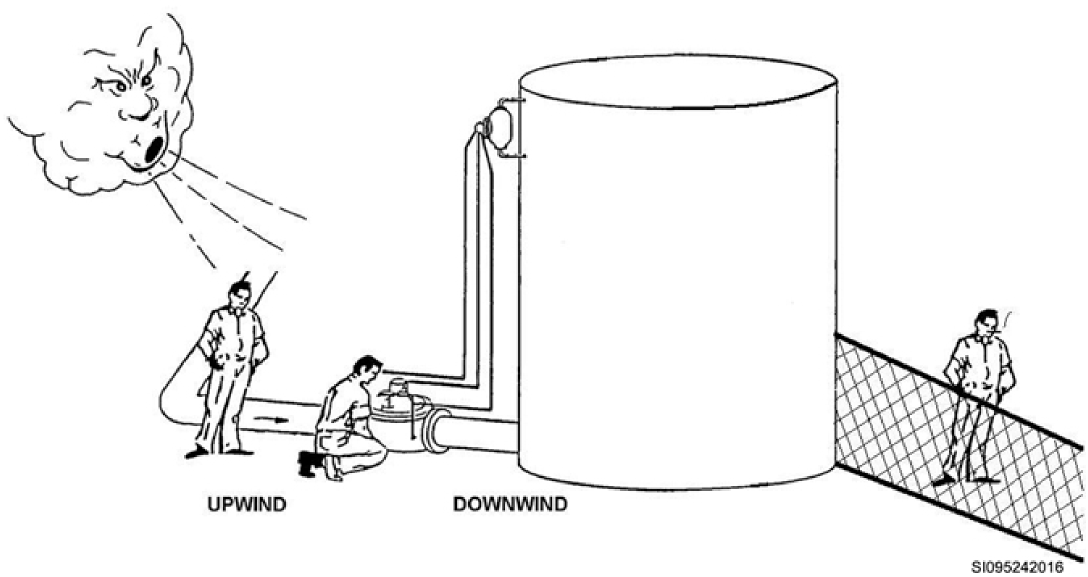

Figure 1–4. Work upwind.

Eliminating heat sources

What can you do to eliminate sources of heat that might trigger a fire or explosion? First, never allow open flames, including smoking, near a fuel storage area or fueling operation. Next, make sure that correct grounding and bonding connections are made to prevent dangerous electrostatic discharges—which also includes you. ALWAYS ground yourself.

Don't bang metal objects together in an area where vapors are present. In the fuels environment, if a piece of equipment that is powered by a fuel-driven motor is used, be certain that flame arrestors are on each exhaust pipe. If electrically powered tools and equipment are used, make sure they are rated for Class I, Division I, Group C and D environments.

Become very familiar with every aspect of your fuel systems so that you can recognize their own potential ignition sources. Before performing any maintenance on the fuel system, always shut off all electrical equipment, and lock the switch open and tag it. If the system uses cathodic protection, it must be turned off before you remove any component under its protection

Self-Test Questions

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

003. Fuels operation safety

1. When would you use the two-person policy?

2. What is the largest generator of electrostatic charges in fuel systems?

3. Of all the fuels you work with, why does JP–4, E–85, and MOGAS pose the greatest hazards?

4. What can enhance the static charge build-up in fuel?

5. What type of material is not to be used around fuel systems?

6. How does grounding and bonding affect electrostatic charges?

7. Describe the methods used to fill an empty underground tank.

8. How long must you wait after a tank has been filled before inserting any object in to it? Why?

9. What type of clothing produces the least amount of static electricity?

10. List the civilian and military types of clothing that are considered unacceptable hazard potential.

004. Fire prevention practices

1. Where should oil-soaked rags be kept?

2. What should be used in enclosed areas to prevent fuel vapors from accumulating?

3. What must you do to a pipeline when a component has been removed and the line is opened?

4. Relative to the wind direction, where should you perform fuels-related work?

5. What can happen to vapors that are drifting with the wind?

6. When around a fuel system, what must be on the exhaust pipes of equipment powered by fuel-driven motors?

7. Before doing maintenance on the fuel system, what must you do to all electrical equipment?

8. What must you do to the cathodic protection before you remove a system component?

1–3. Fuel Facility Safety Requirements and First Aid

You must observe numerous safety precautions during any maintenance activity. These precautions are detailed in Air Force Instruction (AFI) 91–203, *Air Force Consolidated Occupational Safety Instruction.* To have accident-free operations, you must make sure of strict compliance with safety instructions. Follow these instructions to the letter to protect yourself and others and to avoid damaging USAF property.

005. Safety requirements in a fuel facility

The craftsman understands the dangers of the work environment and never takes unnecessary risks. He or she diligently studies the rules of safety and has the wisdom to apply the rules. Safety experts know that unsafe work habits eventually cause accidents. Your supervisor will not reward you if, in an effort to save a little time, you ignore the rules of safety. In simple and blunt language, the person who disregards safety rules is a *fool* and is a danger to themselves and others around them. Cultivate the smart habit of observing and obeying all safety rules. Those rules were developed primarily for the protection of you and your coworkers, and secondarily for the protection of AF assets.

Guidance

A master of the trade rarely gets hurt, knows the tools and equipment of the career field, and keeps them in good working condition. Always operate your equipment and perform your work according to the applicable AFIs, TOs, OIs, and safety guidelines. If there are no TOs for the equipment, follow the manufacturer's operations and maintenance (O&M) instructions. If there are no organizational OIs or guidance, use the principles of operational risk management (ORM) to develop a shop OI with the help of your supervisor and the base safety office.

Signs and markings

It is most important to plainly display signs and markings in all fuel areas and around special activities to inform personnel of a hazardous environment. These signs are prefaced with the attention words "CAUTION," "WARNING," or "DANGER." For example, when you are cleaning a fuel storage tank, you must rope off the area and display a sign stating:

CAUTION!

DO NOT ENTER

TANK CLEANING IN PROGRESS

Danger signs for fuel storage areas are worded as follows:

DANGER!

NO OPEN FLAMES OR

IGNITION SOURCES BEYOND THIS POINT

Where appropriate, you must display other signs within the fuel system area such as:

NO SMOKING WITHIN 50 (or 100) FEET

DANGER - HIGH VOLTAGE

AUTHORIZED PERSONNEL ONLY

Place these signs on the security fence surrounding the area. In those instances where security fences are not provided, post signs 50 feet from all approachable sides of diked areas and fuel vents of underground storage tanks, as well as area entry walkways and roads. The number and location of these signs is determined by the base civil engineer (CE) in consultation with base safety.

Pipeline markings

Markings on fuel piping and tanks must also be properly displayed (fig. 1–5). Identify all pipelines and tanks as to product service by color coding, banding, product names, North Atlantic Treaty Organization (NATO) designation, and directions of flow according to Military Standard (MIL–STD)–161, *Identification Methods for Bulk Petroleum Products Systems*, to aid in identifying the type of fuel in the pipe or tank. As a minimum, use yellow as a primary warning for all flammable gases and liquids. Use yellow stripes or bands to indicate the type of fuel. White letters on a black background describes the exact type of fuel.

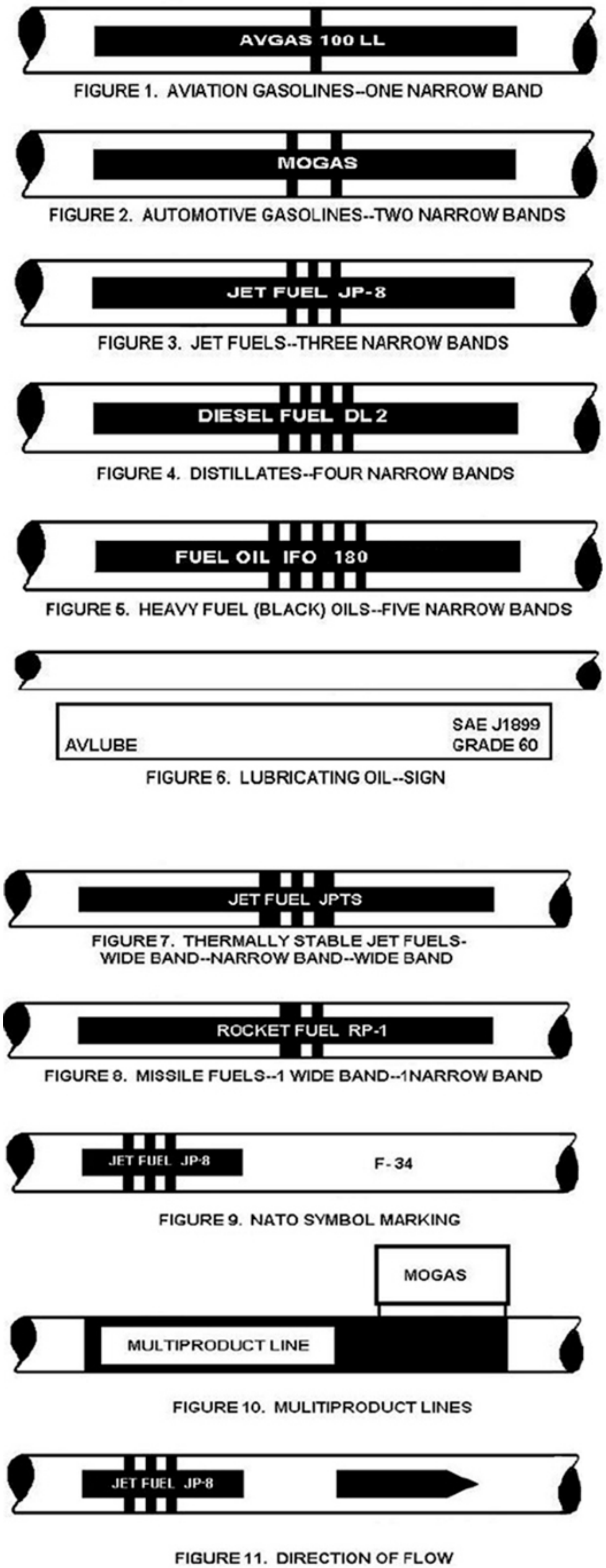

Figure 1–5. Fuel piping markings.

For instance, one narrow yellow stripe or band indicates aviation fuel, and white letters of "AVGAS 100/130" on a black background indicates a specific type of aviation fuel. MOGAS has two narrow bands; jet fuel has three narrow bands; diesel has four narrow bands; and heavy oils, such as fuel oils used in power production plants, have five narrow bands. Multi-product pipelines have one broad yellow band that encircles the product name being used in the pipeline. Bases where NATO aircraft could land and be serviced must use the NATO symbols listed in the table below.

Ground Fuels		Jet Fuels	
Grade	**NATO symbol**	**Grade**	**NATO Symbol**
Diesel Fuel	F–54	JP–4	F–40
Unleaded Automotive Gasoline	F–57	JP–5	F–44
Ethanol	E–85	JP–8	F–34

The NATO symbol and the broken line around it are yellow in color against a contrasting background.

Lubricating oil lines

Because of the infrequency of their use, bands are not assigned to lubricating oil lines. A flag or sign may be employed, and each flag or sign must have a yellow border of at least $^{3}/_{4}$ inch in width.

Multi-product lines

Where a single pipeline is used for transporting more than one product, but not simultaneously, a flag or sign identifying the product in the line at time of transfer may be used in lieu of or as a supplement to the wide yellow band that is at least 36 inches wide.

Concrete valve and refueling pits

In concrete pits and locations with similar conditions where space does not permit banding and stenciling of the pipe, vertical bands are painted on the wall adjacent to the pipe to represent the product group. The title is stenciled horizontally across the bands in white on black. Where pit covers are installed, the marking may be applied to the pit cover top.

Use of arrows

Yellow arrows are used to show the direction of the flow of fuel in pipelines. These arrows are affixed adjacent to the title and bands or where the direction of flow changes.

Night-time lighting

Provide adequate lighting to illuminate petroleum areas for safe and secured night operations (1-foot candlepower in general areas; 2-foot candlepower on tank catwalks). Use explosion-proof lighting fixtures and wiring in all fuel areas as outlined in the *National Electric Code (NEC)*.

Emergency shutoff switches

Make sure all fuel systems are equipped with an emergency shutoff switch capable of stopping all fuel pumps in the event of a fire or other mishaps. The emergency shutoff switch will be properly identified (usually painted red and written on the switch box or attached sign), and all personnel will be familiar with its location. Locate the switch no closer than 25 feet to a truck fillstand. The emergency shutoff switches at service stations is located no closer than 25 feet and no farther than 100 feet away. Operationally inspect these safety devices once every quarter.

Emergency showers/eye wash stations

Emergency showers are usually located in or around pump houses or centrally located in bulk storage yards and truck fillstand areas. If you are ever soaked by fuel, go immediately to the nearest emergency shower. When soaked with fuel, you become a walking torch looking for a light. Waste no time; get under the shower and drench yourself completely with your clothes on; then, and only then, remove your clothes. After your clothes are off, drench yourself again. Fuel facilities that have water supplied to it should, in addition to emergency showers, have emergency eye wash stations. In case you need it, you should test the shower and eye wash station *before* starting work to ensure it operates properly. At a remote fuels location where there is no supplied water, know the location of the nearest water supply or carry a portable eye wash bottle or station in your vehicle.

Fire equipment

Operational and fire-reporting telephones are provided for all fuel storage distribution and dispensing facilities. Fire-reporting telephones should be located within 300 feet of all fixed-fueling points and within 500 feet of other aircraft parking and operational servicing points.

Fire protection water mains, hydrants, valves, and application devices are provided to permit control of brush and grass fires and cooling of storage tanks in the event of a fire. A minimum of two hydrants is required, and they must be located within 300 feet of the storage tank.

006. Fuels-related first aid

As you know, first aid refers to the treatment given the sick and injured before trained individuals from your local emergency medical service (EMS) can administer more advanced medical treatment. You can become skilled at providing first aid in the field and at your work center by learning, practicing, reviewing, and remembering the procedures outlined in this lesson and in the first aid classes provided as part of your contingency training. In an emergency, you may have to depend upon your own knowledge of first aid. The good first aid provider deals with the whole situation—the person as well as the injury. When giving first aid, a person who lacks sufficient knowledge could possibly cause even further injury to an injured person. Anyone trying first aid must use care and skill. In practicing first aid, your primary duty is to know what to do and what not to do in a given situation. You must keep calm, use appropriate first aid measures, and seek medical help as soon as possible. Never try a treatment that is beyond your skill, and never move an injured person unless it is absolutely necessary.

You should learn as much as you can about first aid measures for sickness and injury resulting from the various toxic substances you could come in contact with in the performance of your work. Some of the most common first aid procedures you should know are how to perform cardiopulmonary resuscitation (CPR) and assuring breathing and how to prevent and treat traumatic shock, electrical shock, drowning, unconsciousness, and the effects and treatment of overexposure in hot and cold environments.

Because fuel presents a number of potentially hazardous situations, always be prepared for emergencies. Know what to do if someone inhales vapors, swallows fuel, is splashed with fuel, is shocked or burned, or suffers effects of heat or cold.

First Aid for Handling Fuels-Related Incidents	
Danger	**Description/What to Do**
Asphyxiation	If someone is exposed to excessive fuel vapors, get that person out of the area and into fresh air as quickly as you can. If the victim is not breathing, or is breathing irregularly, have someone call your EMS immediately. Administer mouth-to-mouth resuscitation until the EMS arrives. To reduce the danger of fuel vapor asphyxiation in low lying areas and confined spaces, two people must work together (the two-person concept). Check all confined spaces and suspect areas for vapors before entering them. While one person enters the area, the other will remain outside and observe the entrant very closely. If the person in the confined space or suspect area shows any sign of being affected by vapors, the observer will follow the emergency steps outlined in the shop's Master Entry Plan (MEP).
Swallowing Fuel	If someone swallows fuel, *do not induce vomiting*. Call EMS at once. If the person is

First Aid for Handling Fuels-Related Incidents	
Danger	**Description/What to Do**
	conscious, have the person sit up and give the individual four or five glasses of water to dilute the fuel. If unconscious, *do not* try to give liquids; the individual may choke to death. Lay the person on his or her side in case of vomiting, and monitor until EMS arrives.
Skin Irritation	Remove fuel by washing with soap and water as soon as possible after contact. If a person becomes soaked in fuel, he or she must shower immediately before removing soaked clothing, shoes, or gloves, and avoid exposure to any source of ignition. If you get fuel in your eyes, flush them with large amounts of water, and see a doctor promptly.
Traumatic Shock	Shock is a depressed condition of some of the body functions. It results when not enough blood circulates through the body. Shock can be caused by burns, injury, or mental trauma. In shock, the person's skin is cold and clammy, the face is pale, and the person can be confused or unresponsive. The pupils of the eyes are contracted. Breathing is shallow or irregular. Handle shock victims carefully, especially those with injuries to prevent further damage. To treat a victim for shock, keep the person lying down. This position allows a greater flow of blood to the chest, where it is needed most. Next, elevate the feet, unless there is a head injury, and keep the victim covered to prevent loss of body heat. Give sips of non-alcoholic liquids if the victim is able to swallow and has not sustained and abdominal injury. Shock is always serious. Seek medical attention immediately.
Burns and scalds	Burns are classified according to depth or degree. In first-degree burns, the skin is reddened. Second-degree burns cause blisters in addition to redness. Until medical help arrives, immerse 1st and 2nd degree burned areas in tap or cool water or apply clean, cool, moist towels. Do not use ice because it may cause further damage to the burned area. Avoid breaking any blisters that may appear. Do not use ointments, greases, or powders. The worst are 3rd degree and chemical burns, which will cook, char, or eat away the skin. First aid for these more severe burns consists of treating for shock, making the person as comfortable as possible and preventing contamination of the burns to prevent infection. Seek medical attention immediately.

By the nature of your work in maintenance, the majority of your time is spent outdoors. During the summer, the heat can cause serious problems if you don't take precautions. You can avoid many of the ill effects of heat by staying hydrated and having a sufficient salt intake. Heat cramps, heat exhaustion, and heatstroke (sunstroke) are common problems encountered by fuels personnel in hot weather. Learn how to identify the symptoms and apply the proper first aid techniques.

Heat Effects	
Danger	**Description/What to Do**
Sunburn	Sunburn is the most common ailment from overexposure to ultraviolet radiation from the sun. Covering your skin with clothing or sunscreens is your best protection against sunburn. If sunburned, a variety of over the counter products can treat minor sunburns. Major sunburns cause severe pain and blistering which may need medical attention. Repeated overexposures can lead to skin cancer.
Heat cramps	Heat cramps occur when a person sweats a great deal and has not stayed hydrated and/or has lost too many bodily salts. He or she will experience muscle cramps, especially of the intestines, abdominal wall, or limbs. Frequently, the person vomits and becomes weak. Give large amounts of water to a person suffering from heat cramps.
Heat exhaustion	Heat exhaustion results from excessive loss of water and salt by the body. This condition follows heavy sweating. Paleness, dizziness, and faintness are symptoms. Victims often faint but usually regain consciousness in a few minutes. For first aid, move the victim to shade, loosen clothing, and give salt water if conscious. If a person passes out because of heat: • Carry the victim to a cool, shady place and remove the clothing.

Heat Effects	
Danger	**Description/What to Do**
	• Sprinkle the victim with lots of cool water. • Fan the victim with an article of clothing. When the victim becomes conscious, give cool salt water (2 tablets or ¼ teaspoon of salt in a canteen of water). The victim should drink 3 to 5 canteens full of water in the 12 hours afterwards. Get medical help.
Heatstroke (sunstroke)	Heatstroke, a serious condition with a high death rate, is characterized by high body temperature, dry/flushed skin (no sweating), and delirium or unconsciousness. Treat the victim by lowering the body temperature. Follow the first aid rules we listed above for heat exhaustion. *Do not administer stimulants*, and get medical help immediately.

Excessive exposure to cold environments affects individuals who are inadequately dressed or who remain outside for an extended period of time. Since we can be called upon to maintain and repair WFSM systems regardless of the time of year, working in freezing temperatures can be hazardous without taking the proper precautions.

Cold Effects	
Danger	**Description/What to Do**
Frostbite	Frostbite occurs under very cold conditions when tissues actually freeze, meaning that ice crystals form within the cells, causing them to rupture. Frostbitten skin appears white or grayish-yellow and becomes unusually firm or waxy and numb. Frostbite most often affects the nose, ears, cheeks, chin, fingers, and toes. Dressing appropriately to cover and insulate these body parts is your best defense against frostbite. Treatment includes getting into a warm room as soon as possible and immersing affected areas in warm (not hot) water. Do not rub affected area because this can cause more damage. Do not use a heat source that produces hot temperatures because numb areas can easily be burned. Seek immediate medical attention.
Hypothermia	Hypothermia usually occurs at very cold temperatures but can occur at cool temperatures if a person becomes chilled from rain, sweat, or submersion in cold water, or if exposure occurs during cold, windy conditions. The warning signs of hypothermia include shivering, confusion, memory loss, drowsiness, exhaustion, fumbling hands, and slurred speech. If the body temperature of someone with these signs is less than 95°F, medical attention should be sought immediately. Dressing in layers under a tightly woven outer garment and retreating to a warm area during the rest period of the work/rest cycle is your best defense against hypothermia. Treat hypothermia by removing the person to a warm area and slowly warming him or her while seeking medical attention.

Self-Test Questions

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

005. Safety requirements in a fuel facility

1. How are danger signs in fuel storage areas worded?

2. What publication specifies the color-code system for pipelines?

3. Describe a typical pipeline marking for JP–8 jet fuel.

4. What type of nighttime lighting in fuel areas is required by the *National Electric Code*?

5. Where should the emergency shutoff switch be located for truck fillstands?

6. What should you do if you are soaked by fuel in a pump house?

7. How close should the fire-reporting telephone be located from all fixed-fueling points?

006. Fuels-related first aid

1. What must you do if your co-worker develops breathing problems while the two of you are inspecting an enclosed pump house?

2. What must you do if your coworker accidentally swallowed fuel?

3. During a fueling operation in the bulk storage area, your hands and arms are soaked with fuel when a gasket blows. What should you do?

4. How do you treat for shock?

5. How do you treat 1st and 2nd degree burns?

6. How do you treat heatstroke?

1–4. Safety Programs

There are two main safety programs directly related to working in a fuels environment: confined space and respiratory protection. Although we will cover the confined space program in a later volume when we discuss tank cleaning, in this section we will consider respiratory protection and proper equipment use and care.

007. Respiratory protection program

The purpose of a respiratory protection program (RPP) is to make sure that all Air Force personnel are properly protected from respiratory hazards. The Air Force publication that governs the wear of respirators is AFI 48–137, *Respiratory Protection Program*, which implements the Occupational

Safety and Health Administration (OSHA) Standard 29, Code of Federal Regulations (CFR) 1910.134, *Respiratory Protection.* All respirators used by AF personnel must be National Institute of Occupational Safety and Health (NIOSH)-certified. The respirator shall be used in compliance with the condition of its certification.

Responsibilities

AFI 48–137 outlines specific and detailed responsibilities. Bioenvironmental engineering (BE) is the office of primary responsibility for the base RPP and is responsible for conducting respirator fit-testing according to provisions in AFI 48–137. Unit commanders, directors, and functional managers will make sure that an active RPP (when required) is implemented within their organization.

Workplace supervisors have a direct responsibility for protecting their workers by doing the following:

- Developing, maintaining, and enforcing a workplace written RPP to include an OI according to the guidelines in AFI 48–137 and other applicable directives.
- Ensuring all shop personnel receive initial and annual respirator training as required by the base BE and document such training on AF Form 55, Employee Safety and Health Record (or its electronic equivalent).
- Following the additional responsibilities as outlined in AFI 48–137.

Requirements and usage

Only government-provided respirators shall be used, and no employee may wear a respirator not approved or recommended by BE. The initial and annual respirator training and fit-testing will be provided by BE with additional annual workplace specific training provided by the workplace supervision.

The workplace supervisor shall provide respirators when such equipment is necessary to protect the health of the employee. They are to be used only where (1) engineering controls of respiratory hazards are not feasible, (2) while controls are being installed, or (3) in emergencies.

The elements of a RPP include workplace exposure monitoring and surveillance; selection criteria; training and fit-testing procedures; written OIs; use, maintenance and care procedures; administrative procedures; guidelines for emergency use of respirators; medical surveillance; and procedures for program evaluation. These elements shall be addressed in the base regulation required by AFI 48–137 and shop OIs.

Respirators come in many different type of systems for different levels of protection. There are dust respirators, air purifying respirators (APR), supplied air respirators (SAR), and self-contained breathing apparatus (SCBA) respirators. The two most common respirators that WFSM personnel use are the APRs (used in oxygen-enriched atmospheres) and SARs (used in oxygen-deficient or vapor-saturated atmospheres). As stated above, you will receive training for the respirator system needed at your location.

Program evaluation

Supervisors are responsible for conducting evaluations of the workplace as necessary to make sure that the provisions of the current written program are being effectively implemented and that it continues to be effective. They will regularly consult employees required to use respirators to assess the employees’ inputs on program effectiveness and to identify any problems.

Supervisors will notify BE of any problems or mishaps that occur while respirators are in use and notify BE whenever workplace operations change to the extent that a new evaluation of respiratory protection is needed. Examples would include, but are not limited to, addition or deletion of chemical usage, procedural changes such as addition or deletion of automated equipment, or modifications to existing controls. BE will also be notified when personnel in the RPP are assigned to or depart the workplace.

008. Respirator use, maintenance, care, and cleaning

Since we deal with fuel vapors and other toxic gasses, the use of respirators is necessary to protect ourselves. In order for the respirators to provide protection, they must be the correct type, fit the wearer, and be properly maintained.

Use of respirators

All employees faced with respiratory hazards should be familiar with the standard operating procedures of the RPP. Only respirators approved by NIOSH shall be used, as previously mentioned. Respirators are selected according to the hazards to which the worker will be exposed. Respirator selection involves the review of each operation to determine what hazards may be present and to select the type or class of respirator that offers adequate protection.

APRs have an air-purifying filter, cartridge, or canister that removes specific air contaminants by passing ambient air through the air-purifying element. For work done in a fuels environment, organic vapor filters are used. The SAR respirators are a full-face mask connected to breathing air bottles with air lines.

The concentration of the air contaminants can be established by different methods of air monitoring, dependent upon whether the contaminants are gases, vapors, dusts, or mists. Once this is determined, three other factors need to be considered—how long workers are exposed, how well the area is ventilated, and whether it is an open area or confined space.

For WFSM purposes, respirators used in immediately dangerous to life and health (IDLH) atmospheres shall include a full-face protective mask connected to a pressure-demand SAR system with auxiliary self-contained air supply for egress. If the respirator is to be used in a confined space, refer to AFI 91–203 for respirator selection.

The supervisor will make sure of the following:

- For all IDLH atmospheres, one standby person (or more when needed) is located outside the IDLH atmosphere.
- Visual, voice, or single-line communications is maintained between the workers in the IDLH atmosphere and the workers outside the IDLH atmosphere.
- Standby personnel are trained and equipped to provide effective emergency rescue.
- He or she is notified before standby personnel enter the IDLH atmosphere to provide emergency rescue.
- Standby personnel are equipped with approved SAR with an SCBA escape bottle.
- Appropriate retrieval equipment is available for removing worker form the IDLH atmosphere.
- Respirator masks requiring a tight-fitting face seal shall not be worn by employees who have facial hair, facial features or any condition that interferes with the face-to-mask seal or the inhalation/exhalation valve function of the mask.

Maintenance and care of respirators

The supervisor must provide each respirator user with a respirator that is clean, sanitary, and in good working order. The supervisor must make sure that respirators are cleaned and disinfected using the procedures in this section or procedures recommended by the respirator manufacturer, provided that such procedures are of equivalent effectiveness. Respirators must be cleaned and disinfected after each use.

All respirators must be stored to protect them from damage, contamination, dust, sunlight, extreme temperatures, excessive moisture, and damaging chemicals. Respirators must not be stored in locations that can cause any deformity, such as in the bottom of a personal locker where other objects could be place on top of it. Storing respirators in their original boxes or respirator kit cases is preferred.

All respirators used in routine situations must be inspected before each use. The supervisor must make sure that respirator inspections include a check of respirator function, tightness of connections, and the condition of the various parts—face shield, face seal, head straps, valves, connecting tube, cartridges, canisters or filters, elastomer parts, and so forth. Air and oxygen cylinders must be maintained in a fully charged state and must be recharged when the pressure falls to 90 percent of the manufacturer's recommended pressure level when not in use. The supervisor must determine that the regulator and warning devices function properly.

If, during a respirator inspection, you find damage of a defect, report it to your supervisor so that he or she can remove the respirator from service to be discarded, repaired, or adjusted in accordance with the following procedures:

- Respirators damaged beyond repair must be immediately discarded.
- Respirators in need of repair or adjustment must have a Department of Defense (DD) Form 1577–2, Unserviceable (Repairable) Tag, filled out and attached immediately to the respirator until repair *and* testing is completed. Once successful testing is performed by BE, the DD Form 1577–2 can be removed and the respirator returned to service.
- Repairs or adjustments to respirators are to be made only by persons certified to repair that specific respirator and shall use only the manufacturer's NIOSH-approved parts designed for the respirator. A person certified to repair one manufacturer's respirators is not qualified to repair another manufacturer's respirators.
- Repairs must be made according to the manufacturer's recommendations and specifications for the type and extent of repairs to be performed.
- Reducing and admission valves, regulators, and alarms must be repaired only by the manufacturer or a technician trained by the manufacturer.

The supervisor must provide employees using atmosphere-supplying respirators (SAR and SCBA for egress) with breathing gases of high purity and tested according to TO 42B–1–22, *Quality Control of Compressed and Liquid Breathing Air*, and attachment 16 in AFI 48–137. Compressed breathing air must meet at least the requirements for Type 1-Grade D breathing air described in the American National Standard Institute (ANSI)/Compressed Gas Association Commodity Specification for Air.

Responsibilities of the individual user

As an individual user, you must maintain a sanitary condition by making sure that your respirator is washed after each workday use and before you turn it over to another worker. Inspect the respirator before each use in accordance with the information above and the equipment manufacturer's guidelines. Store the respirator in a clean and safe environment designated by the workplace supervisor. Properly wear and use the respirator in accordance with the equipment manufacture's guidelines and any training received.

Notify the supervisor of any damage to the respirator, and/or any change in your medical status that may impact your ability to safely wear the respirator, such as changes in weight by more than 20 pounds, extensive dental work, or facial cosmetic surgery, scarring, or disfigurement. If you are male, you must be clean shaven around all areas that come in contact with the sealing areas of the tight-fitting respirator.

Before starting any hazardous operation, make sure the respirator functions properly as described in the referenced directives and OIs. Do not perform any potentially hazardous duties that require respiratory protection unless you are medically qualified, properly trained, and fit-tested with the appropriate equipment.

Before each use of an approved respirator, check all parts of the respirator for wear and defects. Inspect the air line, compressor, and respirator to make sure the NIOSH certification is still valid in accordance with the equipment manufacturer's literature and any training received. Change the filter in accordance with manufacturer's instructions (if required). Make sure air line hoses used for SARs do not exceed 300 feet. Make sure that the compressor is located outside of any contaminated area. Inspect escape bottle for audible air leaks.

Training requirements

All workers in the RPP must receive initial training and fit-testing by BE before assuming duties that require the use of respirators. In addition, these workers will receive annual fit-testing and training also conducted by BE.

All supervisors must be trained by BE in accordance with AFI 48–137 on the proper implementation of the RPP in their workplace.

BE may direct other requirements based on substance-specific OSHA standards or other factors such as manufacturer recall.

Respirator cleaning procedures

Use manufacturer's cleaning procedures when available. Here are some general procedures.

Remove filters, cartridges, or canisters. Disassemble mask by removing speaking diaphragms, demand and pressure-demand valve assemblies, hoses, or any components recommended by the manufacturer. Discard or repair any defective parts.

Wash components in warm water (43°C [110°F] maximum) with a mild detergent or with a cleaner recommended by the manufacturer. A stiff bristle (not wire) brush may be used to facilitate the removal of dirt. Rinse components thoroughly in clean, warm, preferably running water. Then be sure to let the water completely drain from all the components.

When the cleaner used does not contain a disinfecting agent, respirator components should be immersed for two minutes in one of the following:

- Hypochlorite solution (50 ppm of chlorine) made by adding approximately one milliliter of laundry bleach to one liter of water at 43°C (110°F).
- Aqueous solution of iodine (50 ppm iodine) made by adding approximately 0.8 milliliters of tincture of iodine (6–8 grams ammonium and/or potassium iodide/100 cubic centimeters [cc] of 45 percent alcohol) to one liter of water at 43°C (110°F).
- Other commercially available cleansers of equivalent disinfectant quality when used as directed, if their use is recommended or approved by the respirator manufacturer.

Rinse components thoroughly in clean, warm (43°C [110°F] maximum), preferably running water, and then drain them. The importance of thorough rinsing cannot be overemphasized. Detergents or disinfectants that dry on masks may result in dermatitis of the skin. In addition, some disinfectants may cause deterioration of rubber or corrosion of metal parts if not completely removed. Hand-dry components with a clean, lint-free cloth or air-dry them. Reassemble the mask, replacing filters, cartridges, and canisters where necessary. Test the respirator to make sure that all components work properly.

Safety is our greatest concern as we accomplish our mission in and around WFSM systems. The guidance you have received here in this unit and will receive throughout the rest of this career development course (CDC) set is very important, but it is not all-inclusive. The additional training you will receive at your current and next assignment is equally important because it will be tailored to the tasks specific to that duty location. So keep your eyes and ears open and your wits sharp to absorb and retain the information needed to get the job done right the first time while protecting the lives and health of yourself and your coworkers.

Self-Test Questions

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

007. Respiratory protection program

1. What AF publication governs the wear of respirators?

2. Which agency's certification is required on all respirators used by AF personnel?

3. Who will provide initial and annual respirator training and fit-testing?

4. What are the two common respirator types WFSM uses?

008. Respirator use, maintenance, care, and cleaning

1. How often are respirators used in routine situations inspected?

2. What should you do if you find respirator damage or defect?

3. Why is the thorough rinsing of a respirator important?

Answers to Self-Test Questions

001

1. Liquids having a closed cup flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 40 psia (2,068 mm Hg) at 100°F (37.8°C).
2. Liquids with flash points at or above 100°F and below 140°F.
3. Liquids with flash points at or above 140°F.
4. JP–8 is 100°F, MOGAS is –40°F, diesel is <120°F, and JP–4 is 0°F.
5. (1) h.
   (2) e.
   (3) d.
   (4) a.
   (5) c.
   (6) f.
   (7) g.
   (8) b.

002

1. (1) Inhaling the vapors, (2) swallowing the fuel, and (3) absorption through the skin.
2. Vapor-monitoring equipment.
3. (1) b.
   (2) a.
   (3) c.

003

1. Fuel system operation and inspection, work that will open a fuel system, repair a leaking fuel system, or put them in contact with fuel.
2. The movement of the fuel itself.
3. Because of their low vapor pressures, the vapors are usually in the explosive range in moderate temperatures.
4. Contaminants.
5. Nylon.
6. Grounding directs and dissipates any build-up of electrostatic charges literally into the ground; bonding equalizes the electrical potential of electrostatic charges between separate components.
7. Fill at a flow rate of 3 fps until the inlet fill pipe is completely submerged in fuel.
8. At least 30 minutes; permits dissipation of any static charges.
9. A 50–50 blend of cotton and polyester.
10. Exposed clothing made of wool, silk, or nylon materials, or blends of wool, silk or nylon.

004

1. Self-closing metal containers.
2. An exhaust fan.
3. Always cap, plug, or blind-flange the open ends.
4. From upwind of the vapors.
5. A flashback can occur if the vapors reach an ignition source.
6. Flame arrestors.
7. Shut it off, lock the switch open and tag it.
8. Turn it off.

005

1. Danger! No Open Flames or Ignition Source Beyond This Point.
2. MIL-STD–161.
3. Three yellow stripes or bands, and “Jet Fuel JP–8” in white letters against a black background.
4. Explosion-proof lighting fixtures and wiring will be used in all fuel areas as outlined in the *NEC*.
5. No closer than 25 feet to a fillstand.
6. Go immediately to the nearest emergency shower, drench completely before removing any clothing, and drench again after clothes are off.
7. Within 300 feet.

006

1. Take the person out of the pump house into the fresh air, administer artificial respiration if necessary, and send for help.
2. Call EMS at once. Do not induce vomiting. If that person is conscious, give four or five glasses of water to dilute fuel.
3. Wash affected areas using plenty of soap and water as soon as possible and if necessary seek medical attention.

4. Seek medical attention immediately, keep person lying down, raise the feet unless there is a head injury, cover and keep victim warm. Give sips of non-alcoholic liquids if able to swallow and has not sustained an abdominal injury.
5. Immerse burned areas in tap or cool water or apply clean, cool moist towels until medical attention arrives. Do not use ice and avoid breaking any blisters that may appear.
6. Lower the body temperature. Follow the first aid rules listed for heat exhaustion. *Do not administer stimulants*, and get medical help immediately.

007

1. AFI 48–137.
2. NIOSH.
3. BE.
4. (1) Air purifying and (2) supplied air respirators.

008

1. Before each use.
2. Report it to your supervisor so that he or she can remove the respirator from service to be discarded, repaired, or adjusted.
3. Detergents or disinfectants that dry on masks may result in dermatitis. In addition, some disinfectants may cause deterioration of rubber or corrosion of metal parts if not completely removed.

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. (001) Which properties make JP–4 the *most* dangerous of all the fuels?
   a. High density and low vaporization.
   b. Low density and high-specific gravity.
   c. High-vapor pressure and low volatility.
   d. Low-vapor pressure and high volatility.

2. (001) What term describes the temperature at which a liquid actively starts to vaporize?
   a. Boiling point.
   b. Flash point.
   c. Fire point.
   d. Volatility.

3. (001) What is the flash point of JP–8 jet fuel?
   a. –20 degrees Fahrenheit (° F).
   b. –40° F.
   c. 100° F.
   d. 140° F.

4. (001) Because of their specific gravity, what reaction will *most* liquid petroleum products have in water?
   a. Sink in water.
   b. Float on water.
   c. Produce an electrostatic discharge.
   d. Mix with water and become a solution.

5. (001) Static dissipating additive (SDA) is added to JP–8 to
   a. increase conductivity of the fuel.
   b. decrease conductivity of the fuel.
   c. eliminate the need for grounding.
   d. reduce the need for grounding.

6. (002) Dry-land drowning results from
   a. inhaling vapors.
   b. absorbing fuel through the skin.
   c. too much mucus produced in the lungs.
   d. drinking water to dilute fuel in stomach.

7. (003) The “two-person policy” is required for fuel handling and maintenance operations
   a. to ensure proper work/rest cycles are maintained.
   b. because petroleum products are inherently dangerous.
   c. to ensure all tools and equipment are put away properly.
   d. because some equipment requires more than one person to operate.

8. (003) How many feet per second (fps) is considered normal flow through a pipeline?
   a. 3.
   b. 5.
   c. 7–12.
   d. 12–15.

9. (003) To reduce the risk of static charges, what type of outer garments are preferred when working around fueling operations?
   a. 100 percent nylon.
   b. 100 percent cotton.
   c. Combination blends of 50 percent cotton and 50 percent wool.
   d. Combination blends of 50 percent cotton and 50 percent polyester.

10. (004) What single element of the fire triangle *must* we try to eliminate?
   a. Air.
   b. Fuel.
   c. Heat.
   d. Vapors.

11. (004) After using fuel-soaked rags, where should you place them?
   a. Hazardous waste storage areas.
   b. Self-closing metal containers.
   c. Containers filled with water.
   d. Solid-waste disposal pits.

12. (005) How many feet from an underground fuel storage tank vent *must* you post danger signs?
   a. 50.
   b. 100.
   c. 150.
   d. 200.

13. (005) Fuel pipeline markings will be color coded according to
   a. Air Force Manual (AFMAN) 85–16.
   b. Air Force Instruction (AFI) 36–2903.
   c. Operating Instruction (OI) 86–4.
   d. Military Standard (MIL-STD)–161.

14. (005) How many yellow bands will be displayed on an 8-inch JP–8 pipeline?
   a. 2.
   b. 3.
   c. 4.
   d. 5.

15. (005) What North Atlantic Treaty Organization (NATO) symbol is used on an unleaded automotive gasoline (AVGAS) pipeline?
   a. F–34.
   b. F–40.
   c. F–50.
   d. F–57.

16. (005) How far *must* an emergency shut-off switch be located from a diesel fuel truck fillstand?
   a. No closer than 25 feet.
   b. No closer than 50 feet.
   c. No farther than 25 feet.
   d. No farther than 50 feet.

17. (005) What should you do *first* if you get soaked with fuel?
   a. Find the nearest emergency shower, remove your clothes, and then drench yourself.
   b. Find the nearest emergency shower and drench yourself with your clothes on.
   c. Return to the shop and take a shower.
   d. Go home and take a shower.

18. (005) Fire protection water hydrants *must* be located within how many feet of a fuel storage tank?
    a. 150.
    b. 300.
    c. 450.
    d. 600.

19. (006) With a second-degree burn, the skin is *best* described as
    a. reddened.
    b. blistered.
    c. charred.
    d. cooked.

20. (006) What should you do for a person suffering from heat cramps?
    a. Induce vomiting.
    b. Move the victim to shade.
    c. Remove the victim’s clothes.
    d. Give the victim large amounts of water.

21. (007) What Air Force (AF) publication governs you wearing respirators?
    a. Air Force Instruction (AFI) 48–137.
    b. Air Force Manual (AFMAN) 36–2903.
    c. Military Standard (MIL-STD)–32–1275.
    d. Air Force Occupational Safety and Health (AFOSH) standard (STD) 91–25.

22. (007) Who approves respirators worn by Air Force (AF) employees?
    a. Bioenvironmental engineer (BE).
    b. Base civil engineer (CE).
    c. Wing safety.
    d. Supervisor.

23. (008) How often *must* employees receive respirator training?
    a. Monthly.
    b. Quarterly.
    c. Semi-annually.
    d. Annually.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Fuel-Related Environment Compliance

AS YOU LEARNED in previous volumes, guidance is the cornerstone to performing any type of task. In this unit, we will focus on the directives and organizations that guide the fuel maintenance side of our career field.

2–1. Contract Monitoring

Fuel is big business in the United States (US) and around the world. It is also a major requirement for all Department of Defense (DOD) activities. It takes the coordination of several entities within the AF, the DOD, and private enterprise (contractors) to ensure we have the fuel, facilities, and equipment necessary to keep our aircraft and vehicles moving. Even though fuel systems are built to last, work has to be completed to maintain, upgrade, or replace these systems. All of these entities will play a part in this process either through funding, planning, designing, constructing, or maintaining. WFSM personnel have a responsibility to make sure the work is getting done right from start to finish, even when we are not the ones performing the work.

009. Role of the contract monitor

Contractors are on the base to do a specific job, and that job is detailed in a contract's "statement of work." As a WFSM shop supervisor or skilled worker, you may become involved in contract work as a subject matter expert (SME). During contract negotiations with the contractor, a SME from the shop should attend to discuss the work to be performed. During these discussions, the SME will provide input on procedures, equipment, and safety, especially when dealing with fuel projects.

Someone from the base will be appointed as the contract monitor to oversee the project to make sure the work is performed according to the contract agreement. Before and during contract work, the SME will perform inspections on equipment and observe the contractor performing their work to ensure safety practices are followed and he or she adheres to the contract agreements. At the contract monitor's request, the SME will provide updates and attend meetings until the project is completed.

On occasion, you may happen upon a base contractor doing something you consider wrong. Unless the contractor is performing an unsafe act that could cause someone bodily harm or might damage AF property, you cannot stop his or her work. You must contact the contract monitor to voice your concerns. Read the following two scenarios to avoid the mistakes others have made in the past.

Scenario 1: If you tell the contractor to stop work for a reason that is not safety related, you may have cost the AF money, and it may come out of your pocket. For contractors, "time is money." If a contractor stops working because you told him to do so, he will add the work stoppage fee to his contract as a deviation to the contract for which someone will have to pay.

Scenario 2: If you instruct or even suggest to the contractor to do something a different way, the contractor may perceive you as a "base authority in uniform" and that you are making a change in the contract. Again, the result is the same; you could end up paying for your suggestion.

Do not be afraid to point out unsafe equipment or shoddy construction. Just do it the proper way through the contract monitor, who is trained in how to notify the contractor of discrepancies and how to negotiate desired changes.

After the contractor has completed his work, you and the contract monitor will need to perform an acceptance inspection. This consists of a thorough check of the completed project to make notes of everything you feel is wrong. The contract monitor will be able to determine if the work was included in the contract specifications and, if necessary, will direct the contractor to make fixes. This is why the initial project specification is so important. If the work was not included in the original contract, the contactor does not have to perform it, even if the system will not work without it!

Communication with agencies and offices both on and off base is key to completing a project from "cradle to grave." Once the project reaches your base, communication throughout the project with the contractor and contract monitor ensures the AF gets what it paid for.

Self-Test Questions

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

009. Role of the contract monitoring

1. For what reasons can you stop a contractor's work?

2. Who is authorized to negotiate changes with a contractor?

3. As a contract monitor, what do you do after a contractor finishes a project?

2–2. Environmental Compliance

Since the start of man's industrial age, up to the beginning of the twentieth century, most people, companies, and governments never considered the consequences of their polluting actions on the earth. People were complacent and did not realize the toll that contaminates take on nature and the environment in which we live. It has been only in the past 50 years that our government and those around the world have passed meaningful laws to curb or eliminate the pollutants that endanger the environment and our lives.

010. Governing authorities

It is all of our responsibility to follow the regulations and guidelines in order to be good stewards of the environment. In this lesson, we cover the organizations and guidance that make and enforce environmental rules as it relates to the fuels maintenance portion of your job.

Code of Federal Regulations

The CFR is the collection of the general and permanent rules published in the Federal Register by the executive departments and agencies of the federal government. These rules implement the laws passed by Congress and enforced by executive branch agencies and departments. The CFR is divided into 50 titles that represent broad areas subject to federal regulation. The titles that most concern us are Title 29—Labor, Title 40—Protection of Environment, and Title 49—Transportation.

Title 29—Labor

29 CFR, Chapter 17, Part 1910, covers occupational safety and health standards. Subpart H deals with the requirements when working with different types of hazardous chemicals. Section 1910.106 covers requirements for flammable and combustible storage and handling, including liquid fuels. It covers

requirements for construction and placement of storage tanks, placement and requirements for other facilities, such as tank truck loading and offloading racks, requirements for service stations, and standards for flammable liquid-handling equipment.

Subpart S of 29 CFR Chapter 17 Part 1910 deals with electrical regulations. Section 1910.307 classifies hazardous locations with respect to flammables and electrical wiring.

Title 40—Protection of Environment

As you learned previously, the National Environmental Policy Act (NEPA) is our basic national charter for protection of the environment and the development of the Environmental Protection Agency (EPA). NEPA establishes EPA policy, sets goals, and provides the means for carrying out the policy. It also contains “action-forcing” provisions to make sure that federal agencies act according to the letter and spirit of the Act. NEPA regulations are found in the 40 CFR: *Protection of Environment,* Chapter V. The purpose of the regulations is to tell federal agencies what they must do to comply with the procedures and achieve the goals of the Act. The president, federal agencies, and the courts share responsibility for enforcing the Act to achieve the substantive requirements of the regulations. The supervisor has a responsibility as well as yourself to comply with these regulations.

40 CFR Chapter 1, Part 260, covers hazardous waste management. Parts 280 through 282 cover underground storage tanks.

Title 49—Transportation

While 40 CFR contains rules protecting the environment from hazardous materials and waste, Title 49 contains rules covering the movement of hazardous materials and waste. Of particular interest to us in WFSM are rules covering hazardous liquid pipelines in 49 CFR Chapter 1 Part 195, *Transportation of hazardous liquids by pipeline.*

Civil engineering environmental element

The CE environmental engineering (CEI) is the section in charge of the environmental protection mission of the base and our information resource when dealing with hazardous substances that can affect the environment. When it comes to fuel, they monitor how we store and transport usable fuel as well as how we collect, segregate, store, and transport fuel waste. Additionally, they develop base emergency plans to prepare, contain, and clean up catastrophic fuel spills. Because of our expertise in handling fuel, individuals within the WFSM shop may be tasked, as a part of the base emergency plan, to lead and/or participate as a member of the base spill team. The base spill team is called upon to handle spills of various sizes to prevent environmental contamination. Civil engineering environmental and infrastructure engineering (CEIE) provides funding for equipment and clean-up supplies for the base spill team.

011. Environmental awareness

During your everyday maintenance activities, you will encounter many hazardous substances that need to be disposed of properly. Some examples are used fuel filters and absorbent pads, oily/dirty rags, waste fuel, waste oil, water from tank bottoms, lead paint chips, and so forth. These substances could cause an environmental impact if not controlled or properly managed. Many of these substances are regulated by federal, state, and local regulations, and by AF regulations and policies. You must be aware of *all* regulations governing wastes produced by your maintenance activity. Air Force Policy Directive (AFPD) 90–801, *Environment, Safety, and Occupational Health Councils,* is the best place to start. You should be thoroughly familiar with this AFPD—believe me, your inspectors will be.

Environmental, safety, and occupational health compliance assessment and management program

One program that we must be compliant in is the environmental, safety, and occupational health compliance and management program (ESOHCAMP). Inspectors report findings based on the major compliance categories included in the ESOHCAMP program as listed below:

- Air emissions management.
- Hazardous materials (HAZMAT) management.
- Hazardous waste management.
- Natural and cultural resource management.
- Noise (environmental) management.
- Pesticide management.
- Petroleum, oils, and lubricants (POL) management.
- Pollution prevention management.
- Solid waste management.
- Special programs management.
  - Asbestos.
  - Poly chlorinated biphenyls (PCB).
  - Radon.
  - Installation restoration program.
  - Environmental impact analysis process.
  - A–106—environmental budgeting.
  - Lead-based paint.
- Water quality management.

Environmental Management System

Environmental Management System (EMS) is the program used by CEIE to track findings from environmental inspections during ESOHCAMP. This program provides various report and input capabilities that track environmental non-compliance findings. As you may recall from 3E451A, volume 1, a finding comes from an environmental inspection and is a report of non-compliance. You should be aware of findings so that you do no repeat errors from the past.

Regulations and inspections

It is relatively easy to research federal regulations, but sometimes more difficult to determine how state regulations supplement those same federal regulations. State and local regulations can be more stringent than federal regulations, but they cannot be less stringent. This is where CEIE will really show their expertise. They should be able to tell you specific differences in your state regulations.

After reviewing the ESOHCAMP program and checklists, schedule an appointment with CEIE to review the last ESOHCAMP inspection and to discuss any changes in regulations, shop activities, and inspection finding updates. All ESOHCAMP inspection findings must be answered in a timely manner before the next inspection.

Review shop processes

Using all the applicable regulations, annually perform a thorough review of each process in your section that produces a waste. Get someone from CEIE to help you. While discussing your shop's waste disposal procedures, also ask if the hazardous substance is really needed or whether it can be substituted with another non-toxic equivalent. This last step will save you hours of paperwork by eliminating tracking and disposal before it even starts. The key to waste reduction is source reduction.

012. Waste disposal

When performing work, there is always the possibility of generating waste. If the waste is contaminated with petroleum products, we cannot just throw them into the trash. Therefore, we must have the methods and means to dispose of it properly. The CEI flight provides us with the regulations and guidance on how to accomplish these tasks and remain within the law.

Fuel disposal

There are two options available to reduce your waste fuel waste stream quantities: (1) return good fuel to the system and (2) blend "off-spec" fuels. You must first determine which class of fuel quality you have collected. These include reclaimed, recoverable, and waste.

Reclaimed product

This class of fuel meets the original production specification (has not been contaminated) and can be returned and used in the system from which it came. Fuel drained into a "reclaimed JP–8" bowser from a pipeline falls in this class as long as the bowser is clean and does not contain any other product other than JP–8.

Recoverable product

This class of fuel does not meet the original specification (has some contaminants or is "off-spec") and cannot be used in the system from which it came. JP–8 fuel from a generator tank that has not been used in years may chemically break down and become "off-spec." This JP–8 fuel (without refining) can be blended with a large quantity of a lower grade fuel, such as diesel or fuel oil, without degrading the specifications of the lower grade fuel. Before blending, coordination with the POL section of the supply squadron is required.

Waste product

Not all recovered fuel can be blended. Either the fuel is too contaminated or "off-spec" or there is not a lower grade fuel with which to blend. This class of fuel is considered a waste product and must be put in a waste fuel tank or in a Department of Transportation (DOT) or United Nations (UN) approved containers (UN containers for overseas) to be transported off base. Drums must be labeled appropriately for shipping. The military or contractor operated HAZMAT collection site can provide you with the approved container labeling.

Waste water

It is impossible to completely separate water from fuel without a fuel sheen (residual fuel) left on top of the water's surface. In this condition, it is considered contaminated and this waste water must be disposed of properly. Water contaminated with fuel is commonly generated and collected from fuel tank bottoms, F/S, and containment dikes. This contaminated or waste water is put into an oil/water separator. Oil/water separators are generally concrete vaults that allow the residual fuel to remain on top of the water, while the water at the bottom is allowed to drain to the sanitary sewer.

You should take great care not to allow more than a fuel residual to enter an oil/water separator because the sanitary sewer empties into the sewage treatment facility. These facilities use microbes to break down the sewage. If too much fuel enters this facility, it will kill the microbes. Oil/water separators are closely monitored and usually have detailed procedures to prevent unauthorized use.

Sludge disposal

Fuel sludge is a hazardous waste product composed of impurities and dirt mixed with fuel that settles to the bottom of containers such as drums and fuel tanks. Fuel system maintainers most often deal with sludge when performing fuel tank cleanings. Fuel sludge can be wet or dry. In either form, fuel sludge is disposed of in the same manner using drums. The only difference is how the sludge gets to the drum. Dried sludge is scraped off container or tank bottoms, collected in pails, and placed in drums. Wet sludge is maintained in a slurry state and pumped into drums. Once again, only approved drums can be used as containers and for transportation.

Solid waste

In the process of maintaining a fuel system, fuel-contaminated solid waste is generated. Fuel filters or fuel-contaminated absorbent pads and rags are the most common solid waste and therefore have a hazardous waste stream profile. These common waste streams can be placed in containers located at or near your shop (also known as [a.k.a.] satellite accumulation point). Depending on the guidance from your base CEIE office, fuel-contaminated solid waste can be aired to dry and thrown in the trash, washed (rags and coveralls) at an approved laundry site and reused, or placed in drums and turned in at the base HAZMAT collection site when the drums are full. If these solid wastes are temporarily stored at your satellite location, containers must have self-closing lids (for rags and coveralls) or lids that can be tightly secured after items are placed in them.

The collection, treatment, and/or disposal of fuel-contaminated soil varies from base to base. Some state laws allow for soil remediation (the airing out of the soil) to evaporate the fuel. When the remediation is complete, the soil is reused, thus reducing disposal costs. Fuel sludge, in some cases, may qualify for soil remediation. If allowed at your base, CEIE will have a soil remediation plan.

Environmental issues are a major concern for your CE commander. Following the environmental laws and regulations for hazardous material storage, use, tracking, inspections, and waste management keeps the base commander out of trouble since he or she has the ultimate responsibility. Remember, the CE environmental flight is your point of contact for any environmental concerns.

Self-Test Questions

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

010 Governing authorities

1. Into how many titles is CFR divided and which ones are concerned with fuel?

2. What establishes EPA policy?

3. Which title contains rules covering the movement of hazardous materials and waste?

011. Environmental awareness

1. Name some wastes in the WFSM shop that could cause environmental impact if not properly managed.

2. How must all ESOHCAMP findings be answered?

3. What is the key to waste reduction?

012. Waste disposal

1. What are the two ways to avoid creating waste fuel?

2. What are the three classes of fuel quality?

3. What can happen if too much fuel is dumped into an oil/water separator?

4. Fuel sludge is most often found in the performance of what activity?

5. A satellite accumulation point for waste streams is commonly found where?

6. Hazardous solid waste containers that are temporarily stored at a satellite accumulation point must have what?

7. If state regulations permit, what does soil remediation do and what is its benefit?

Answers to Self-Test Questions

009

1. If the contractor is performing an unsafe act that could cause bodily harm or might damage AF property.
2. The contract manager.
3. You and the contracting officer perform an acceptance inspection.

010

1. 50. Title 29-Labor; Title 40-Protection of Environment; Title 49-Transportation.
2. NEPA.
3. Title 49.

011

1. Used filters, used absorbent pads, oily/dirty rags, waste fuel, waste oil, water from tank bottoms, paint chips.
2. In a timely manner and before the next inspection.
3. Source reduction.

012

1. First determine the class of fuel, return reclaimed product to the system from which it came and blend a recoverable product with a lower grade fuel.
2. (1) Reclaimed product, (2) recoverable product, and (3) waste product.
3. Too much fuel entering a sewage treatment facility will kill the microbes.
4. Fuel tank cleanings.
5. At or near your shop.

6. Self-closing lids (for rags and coveralls) or lids that can be tightly secured.
7. Soil remediation allows fuel to evaporate from the soil; reduces disposal costs.

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).

24. (009) Who is authorized to negotiate changes with the contractor?
    a. Design reviewer.
    b. Contract monitor.
    c. Subject matter expert (SME).
    d. Noncommissioned officer in charge (NCOIC).

25. (010) What area is Title 40 of the Code of Federal Regulations (CFR) concerned with?
    a. Labor.
    b. Fuel Systems.
    c. Transportation.
    d. Protection of Environment.

26. (011) Which is *not* considered a hazardous substance?
    a. Oily rags.
    b. Used fuel filters.
    c. Lead paint chips.
    d. Stagnant ditch water.

27. (011) How often does a review of each section’s waste producing process need to be performed?
    a. Semiannually.
    b. Bi-annually.
    c. Quarterly.
    d. Annually.

28. (012) What are the three classes of fuel quality?
    a. High, medium, and low.
    b. Filtered, unfiltered, and waste.
    c. Reclaimed, recoverable, and waste.
    d. Usable, unusable, and contaminated.

29. (012) When disposing of waste water from a fuel tank bottom, where do you put it?
    a. Sanitary sewer.
    b. Oil/water separator.
    c. Water treatment facility.
    d. Sewage treatment facility.

Please read the unit menu for unit 3 and continue ➔

Student Notes

Unit 3. Mechanics and Hydraulics

ALTHOUGH YOU MAY THINK that you are just a mechanic, turning wrenches to make sure WFSM systems on base can receive, store, and dispense water or fuel, you are wrong! Definitely, there is more to your job than that. You must also be a problem solver because you will be faced with many problems that require you to troubleshoot and analyze what is wrong with our systems. Before wrenches can be turned, you need to know what is wrong and which system component is causing the problem.

The purpose of this unit is to give you some principles of physics that will enable you to understand the forces that act in our systems and components. Once you have a firm grasp of these principles, you can apply them in your analyzing and troubleshooting skills. The first section deals with the principles of mechanics; the second is on hydraulics. These two subjects are very important. Our systems are actually hydraulic with mechanical components.

3–1. Principles of Mechanics

Mechanics is the study of objects and the energy used to complete a task. The principles of mechanics are being used as you read this sentence. The movement of your eyes and the muscles flexing as your fingers and arms turn pages actually follow specific laws. In this section, the laws of motion written by Sir Isaac Newton comprise your first lesson. Through these laws and with examples from our systems, you'll see how the equipment operates which can be applied to other systems and components. Your second lesson is a brief study on simple machines and how mechanical advantage (MA) is gained. Your knowledge of these principles and their application will help to make you a better mechanic.

013. Newton's laws of motion

In 1687, Sir Isaac Newton published his laws of motion to explain the movement of all things, from the rustle of leaves on the ground to the orbits of planets around the sun. The first law is sometimes referred to as the law of inertia, the second as the law of proportionality, and the third as the law of action and reaction.

First law—the law of inertia

A body continues in its state of rest or uniform motion in a straight line unless an unbalanced force acts on it. Forces are the key to this law because they either push or pull objects. You know that if you throw a baseball it will not continue in a straight line forever. Eventually it will fall to the ground and stop. Again, *forces* are the key.

Gravity and friction are the unbalanced forces acting on the ball. You can throw a greater distance on the moon, because compared to the earth, the moon has six times less gravity and the atmosphere is a vacuum; therefore, its atmosphere is less dense. The earth's gravity pulls the baseball to the ground and the density of our atmosphere pushes against the forward motion of the ball, creating drag (friction), slowing it down. Right now, because of this law (and many pre-launch calculations), there are satellites orbiting earth without power to propel them.

As an example that relates to your career field, an automatic valve remains closed until pressure (force) pushes against the diaphragm, which will then open the valve. When the pressure under the diaphragm is no longer applied, spring tension pushes and gravity pulls the valve closed again.

Second law – the law of proportionality

The acceleration of a body is directly proportional to the force exerted on the body, is inversely proportional to the mass of the body, and is in the same direction as the force. To help you better understand exactly what this second law means, let's define mass. According to the dictionary, mass is "the property of a body that is a measure of its inertia, which is commonly taken as a measure of the amount of material it contains, and causes it to have weight in a gravitational field."

It would seem that mass and weight are the same, but they are not. The mass of an object is the amount of material the object has in it. Weight of an object is really determined by the gravitational pull. Remember, we stated earlier that the earth's gravitational pull is six times stronger than the moon's. Although you would not weigh as much on the moon, you would still have the same mass.

Why, then, is mass so important in this second law? To put it simply, a one-quarter horsepower motor can easily turn a small sump pump on a product recovery system, but would not stand a chance of turning a larger 600 gallons per minute (gpm) deepwell turbine pump. Why? Because the shaft and impellers of the deepwell turbine have a greater mass than the shaft and impeller of the sump pump.

Mass also applies to moving fuel. Fuel has mass, and we usually think of its mass as specific gravity. It takes a larger pump to move JP–8 two miles through an 8-inch pipe than it would to move it 100 feet. The more fuel contained in a pipe, the more mass the fuel has.

The second law helps you understand that the larger the mass an object has, the more force required to move it. Also, the faster you want an object to move, the more force needed. Finally, when force is applied to an object, the object moves in the direction the force is moving. In other words, proper proportionality of forces will move the object at the right speed and in the right direction. Engineers factor in this information when determining the pump size needed to move liquids from point A to point B.

Third law – the law of action and reaction

Whenever one body exerts a force upon a second body, the second body exerts an equal and opposite force upon the first. For every action there is an equal and opposite reaction. First we must understand exactly what it means. A common example is a jet aircraft. Thrust from the engine propels the aircraft forward. Also, if you've ever gone fishing in a rowboat, you know that as you pull the oars you move them in the opposite direction of the boat's course. These two examples are easy to see and understand.

Let's take a closer look at this action. As the oar presses against the water, the water is actually pressing against the oar. The same pressure is felt and applied on the oar as on the water. A pressure gauge is designed with that thought in mind. The bourdon tube inside a standard pressure gauge is constructed in the shape of a question mark. As fuel pressure is exerted against the tube, the tube exerts an equal amount of pressure against the liquid. If it did not, the tube would simply straighten out and indicate no pressure.

Now, how can you apply this law to the fuel system? Pumps and pump motors must be securely bolted down because of the third law. If the motor is not secured, the torque will cause the motor housing to turn. Fuel being forced by the pump would force the pump in the opposite direction of the fuel flow.

These three laws have a definite effect on the fuel system and everything around you. Knowing these laws can assist you in determining problems with the system or things you will have to consider when making a system modification.

014. Mechanics and their advantages

The laws just discussed allow you to move things and to perform work. Work has always been work, and working with less effort has been a human quest since the beginning of time. From the development of some simple ideas, machines have been created that have allowed mountains to be moved, skyscrapers to be built, and you to travel great distances in short periods of time with less effort.

A machine is something that uses force and applies energy to do work. No machine creates energy without applying energy. To do work, the machine must receive energy from some source, and the maximum work it does cannot exceed the energy it receives. However, through five simple machines—lever, wheel and axle, pulley, inclined plane, and screw—we are able to apply a greater force than would be possible without the machine. This is called gaining MA.

Work and MA

If your boss asked you to lift a 10,000 barrel (bbl) fuel tank 2 inches off the concrete ring wall and another Airman to mop the floor of the shop, who has the most work? Well, it sounds like you would have the toughest job; however, on a closer analysis of the two tasks, you may be surprised.

Trying to lift the tank surely would take a lot of effort and energy, and although you won't be able to lift it by yourself, the energy you expend trying to lift it will make you extremely tired. But, guess what? Unless you are able to lift and move the tank some distance, you have not worked at all. Work is equal to the force times the distance an object is moved. The Airman who pushed the 1lb. mop around the shop floor would have done all the work, while you would have only used energy.

Now if you could have moved that tank using some type of machine, you would have worked with a MA. MA is defined as *the ratio of the resistance to the effort (MA = resistance/effort)*. For instance, look at figure 3–1. If you use a hand truck to move a case of filter separator elements that weigh 90 lb. (resistance), you have exerted only 30 lb. of force (effort), which is a 3 to 1 MA.

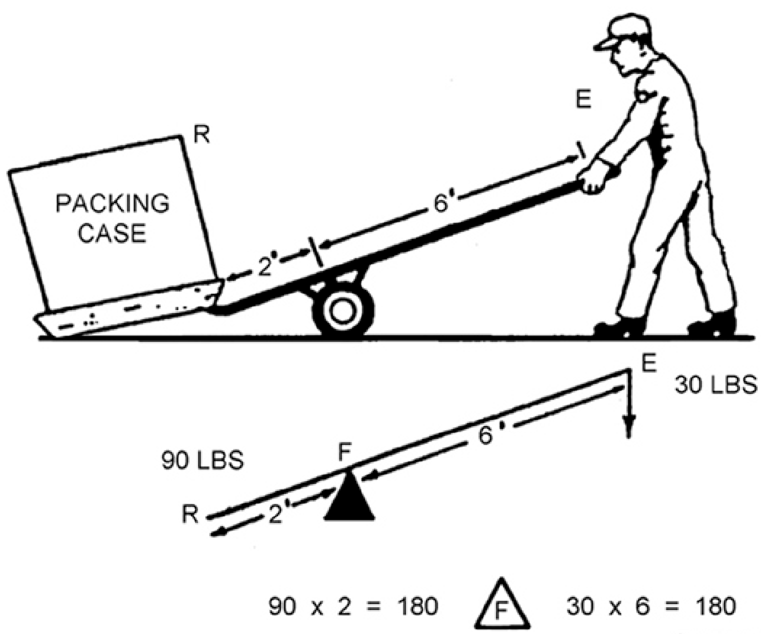

Figure 3–1. MA.

There are many ways to gain MA, but all of them stem from the five basic machines we mentioned earlier. Let's take a look at each one.

Lever

Figure 3–2 shows the three classes of levers. They differ only by where the effort is applied, the distance resistance is moved, and where the fulcrum is located. Notice that, in all cases, the effort is always in the opposite direction of the resistance—Newton's third law.

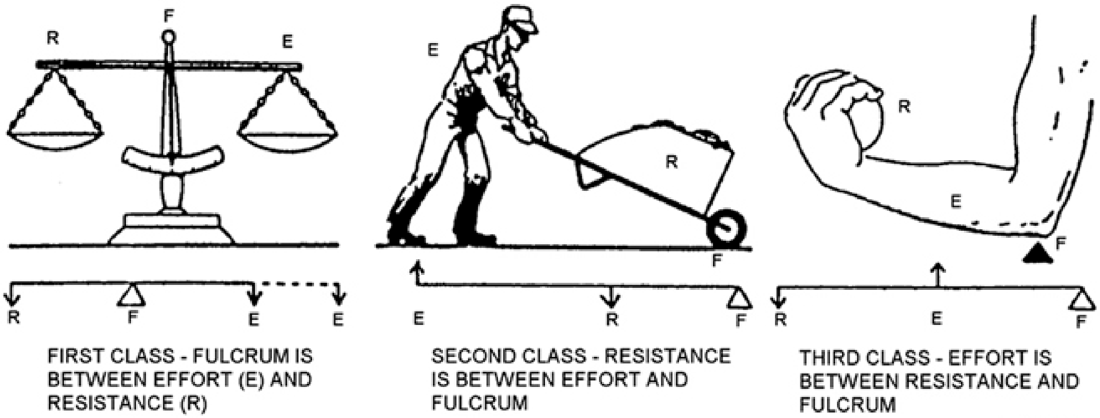

Figure 3–2. Levers.

Wheel and axle

One form of wheel and axle that is familiar to you is the crank and axle. The crank and axle are used in several ways. An automobile wrecking truck uses a winch to raise an automobile before it can be towed. The "old oak bucket" that hung in the well was raised and lowered with a winch, or windlass. What about the steering wheel of today's speedboat? It also is a winch. Figure 3–3 illustrates the winch and how to calculate the MA. If you divide the radius of the crank by the radius of the axle, your answer will be the MA of the crank.

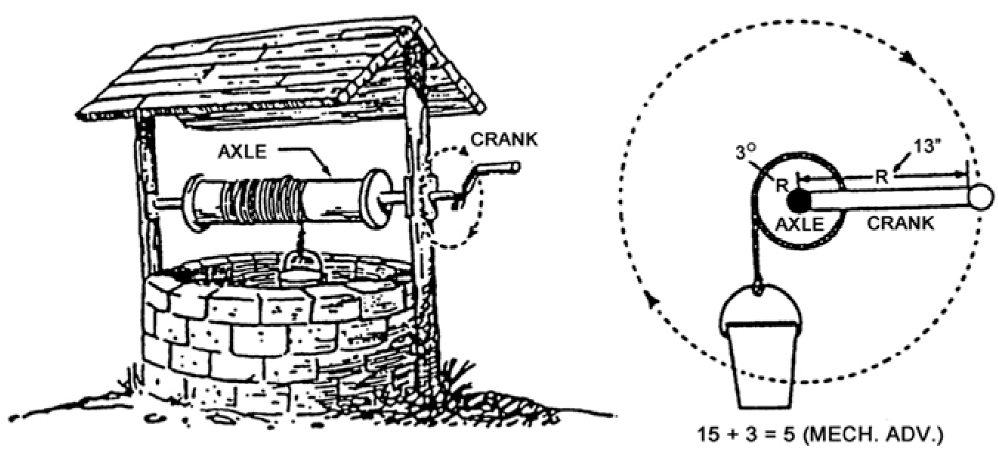

Figure 3–3. Winch.

The pulley

Pulleys are used for many purposes. They may be used to obtain different degrees of MA or to change the direction of effort being applied. Quite often, pulleys are arranged to do both at the same time. In figure 3–4, you can see a fixed pulley. When a single sheave pulley is used in this manner, it simply changes the direction of applied effort; however, it does not provide any MA.

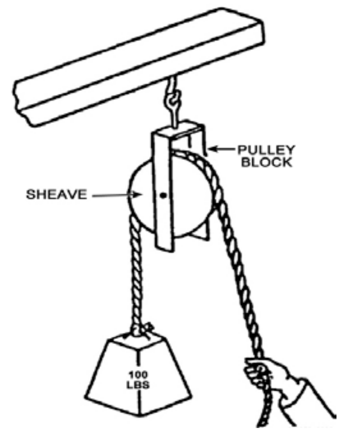

Figure 3–4. Fixed pulley.

Figure 3–5 shows two double-sheave pulleys. One pulley is fixed and the other is movable. Figuring the MA for pulleys is not nearly as difficult as the picture might lead you to believe. Referring back to figure 3–4 (the single pulley) you notice that the radius of the pulley is the same on both sides, so the MA is simply 1 to 1 (or no advantage). Examining figure 3–5 again, take note that four ropes are supporting the weight. When you raise the weight, each rope supports one-fourth of the total weight, or a MA of 4 to 1. The amount of effort you must apply, or the MA of a series of pulleys, is found by dividing the weight by the number of pulley ropes (not counting the one in your hand).

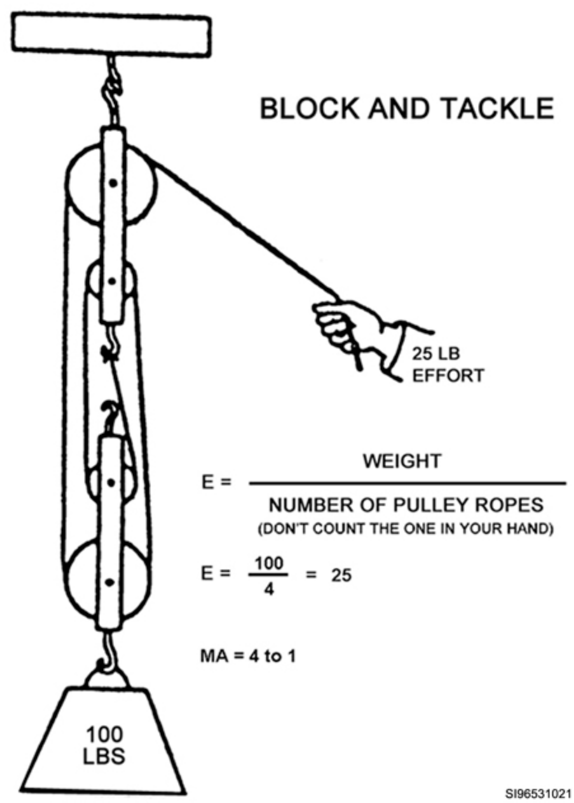

Figure 3–5. Block and tackle.

Quite often, pulley arrangements and weights are used to counterbalance movable pipe couplings or adjustable chutes. Many times, overhead garage doors are counterbalanced by a spring connected to the top of the door through fixed pulleys. There are many other examples of the use of pulleys. How many others can you think of at the moment?

The inclined plane

The inclined plane has many applications. Figure 3–6 shows an inclined plane in the form of a plank used to load fuel drums onto a truck. An inclined plane can be coupled with a pulley arrangement to move very heavy loads. Every road or street that is not level is actually an inclined plane. A perfect example of this is a switchback mountain road. The road keeps winding back and forth so that the steepness of the grade is never so great that your automobile cannot climb it easily. Finding the MA of an inclined plane is not difficult. Either part of the following formulas will give you the MA.

Resistance/effort, or length of plane/height of plane = MA

If you had a plane 10 feet long and 10 feet high, then your MA would be 1; 10/10 = 1. However, if you had a plane 40 feet long and 10 feet high, then your MA would be 4; 40/10 = 4. By this example you can see the advantage you gain by increasing the length of the inclined plane.

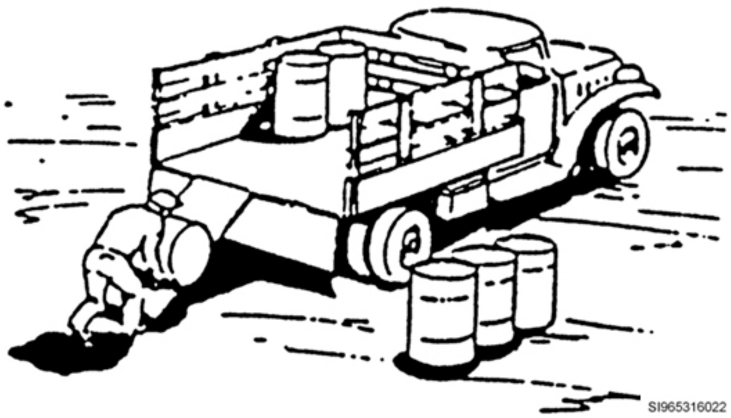

Figure 3–6. Inclined plane.

The screw

A screw may be thought of as a continuous inclined plane wound around a shaft or drum. In actual application, the screw is used as a continuous wedge, forcing its way against the load. A screw jack, for example, provides a tremendous force and can be used to move very heavy equipment or even raise houses. Figure 3–7 illustrates three common uses of the screw. Other examples of the screw are wood screws, metal screws, bolts and nuts, and precision instruments such as the micrometer.

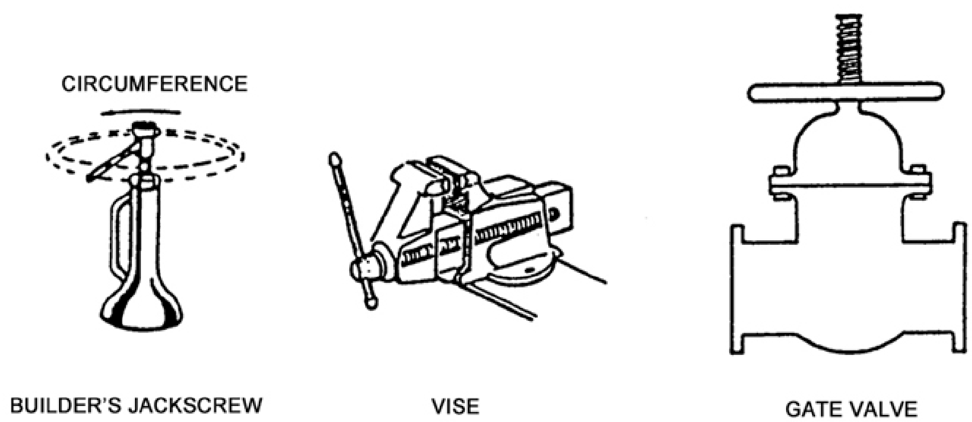

Figure 3–7. Common uses of the screw.

The MA of a screw is controlled by the distance between the threads (pitch) of the screw and the length of the handle turning the screw. If the pitch of the threads is greater, the screw will move farther along its axis for each turn of the screw (fig. 3–8). If the pitch of the threads is smaller, the screw will not move as far along its axis with each turn. The ease with which a screw can be turned is controlled by the length of the handle attached to it, or the leverage. In figure 3–7, for example, a longer handle on the vise would rotate in a wider circle, giving you a greater MA.

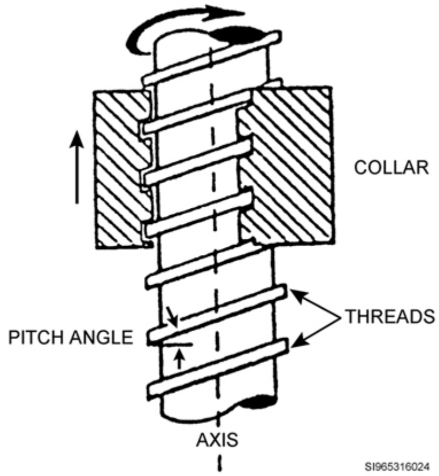

Figure 3–8. The screw.

Remember, in the case of the screw, you do not get all the MA you bargain for. Even with good lubrication on the screw threads, there is considerable friction against the threads and the material screwed. This means that more force is actually required to turn a screw than there should be if it were not for the friction. This is not altogether a disadvantage, because if it were not for the friction, the screw would turn backward as the result of vibration.

Putting simple machines to work

So far, we have stayed away from very complex examples of the use of simple machines. However, since we have discussed them, we can now see how they are combined and put to work. Every day, as you work in the shop or out in our systems, you take advantage of these simple machines. Of all the simple machines, the lever is probably the most difficult to recognize because it can be bent or shaped in such a way that it simply does not look like a lever. Figure 3–9 illustrates a float-controlled valve in its simplest form.

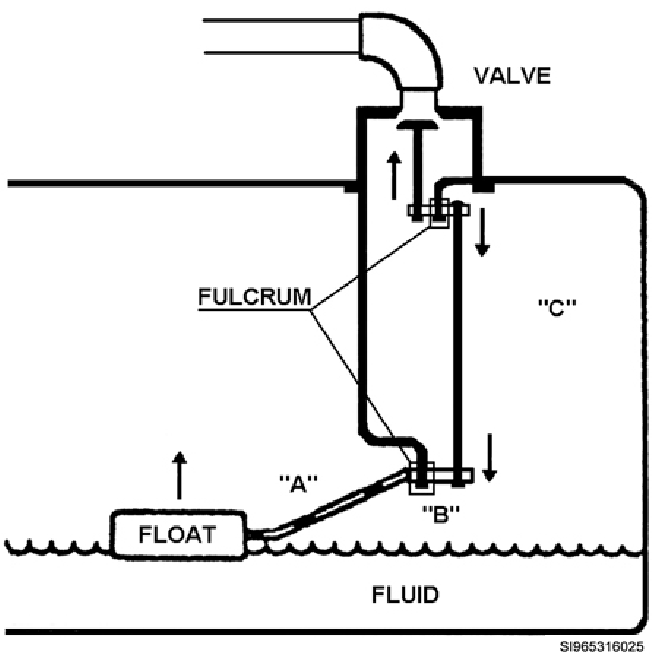

Figure 3–9. Float controlled valve.

Let us examine the figure more closely. Trace the linkage from the float to the valve. Note how the short arm (C) is necessary to move the valve in the closing direction as the fuel level rises. If we had connected the rod directly from arm B to the valve, the valve would not have closed as the tank filled. Compare the length of arms A and B on either side of the fulcrum. The float and arm A can move several inches, but the rod on the end of arm B would only move a fraction of an inch by comparison. In this case, the difference in the length of arms A and B acts as a reducer rather than a multiplier. Arm C is the same length as each side of its fulcrum or pivot, so it merely transmits motion. Air eliminators, liquidometers, both high and low-level flow control valves, and quick-closing valves all use levers in one form or another.

Examine the clamp that connects a grounding cable to an aboveground tank or fuel truck fillstand. Here, the high MA of the screw (inclined plane) has been used to force the lug against the cable and ground rod for a firm electrical connection. Many of the fillstands (pantograph type) are counterbalanced for ease in moving or handling. Quite often, a cable and counterweight are rigged through a series of pulleys. Even the hoists you use in the work center, or in the field, have a pulley arrangement, plus a winch, or wheel and axle.

The next time you are in your work center, take a few minutes to see how many different forms of the simple machines you can find. You will be surprised at the number of variations and combinations in use. Even the most complex equipment is just a combination of these simple machines.

Power

Work and power are often confused. Work (W) is the process of overcoming resistance. It is measured by multiplying the force (F) times any distance (D) through which it acts ($F \times D = W$). Power is the speed or rate of doing work. Notice that we used the word "rate." Rate implies a time element. To determine the amount of power used in moving a 50 lb. case of oil 100 feet, you must know the amount of time it took to move it.

Suppose it took 4 minutes (min) to move the case of oil. You can find the amount of power used by dividing the work performed by the time it took to do it (*power = work/time).* Therefore, if you divide 5,000 foot-pounds (50 lb. case of oil × 100 feet movement) by 4 min, you'll find that 1,250 foot-pounds force per minute (ft-lbf/min) in power was applied. It may be easier to see by using the following equation:

$$\frac{50 \text{ lb X } 100 \text{ ft}}{4 \text{ min}} = 1{,}250 \text{ ft-lbf/min}$$

If this does not help you much, let us look a little further. Horsepower is a familiar word that is the rating of our electric motors, gasoline engines, and even steam engines. One horsepower is actually the amount of work one horse can do in 1 min, as it was determined by a fellow named James Watt. Mr. Watt used a horse to pull a 150 lb. weight up a coalmine shaft to measure the distance the horse would raise the weight in 1 min. The horse raised the weight 220 feet in 1 min or 33,000 foot-pounds in 1 min. Mr. Watt called this amount of work 1 horsepower. The formulas for calculating horsepower are: horsepower = 33,000 ft-lbf/min or 550 foot-pounds force/second (ft-lbf/sec) (33,000/60). Again, it may help to look at the following equation:

$$\begin{aligned}\frac{150 \text{ lb X } 220 \text{ ft}}{1 \text{ min}} &= 33{,}000 \text{ ft-lbf/min}\\ &= 33{,}000 \text{ ft-lbf/60 sec}\\ &= 500 \text{ ft-lbf/sec}\end{aligned}$$

In summing up work and power, just remember that work is a measure of energy used in moving an object, and power is the rate of doing the work.

The transmission of power

Most shops contain an assortment of machines. These machines fall into one of two categories. They are either driving machines or driven machines. Motors and engines are the driving machines. Lathe attachments, drill bits, planers, sanders, grinding wheels, pumps, and exhaust fans are the driven machines. Each driven machine must be coupled, or connected, to a driving machine. There are many ways of transmitting power. They are all simply a different means to an end. Let's examine several methods of transmitting power, including direct drive, belt drive, gear drives, and field drives, which are also presented in figure 3–10.

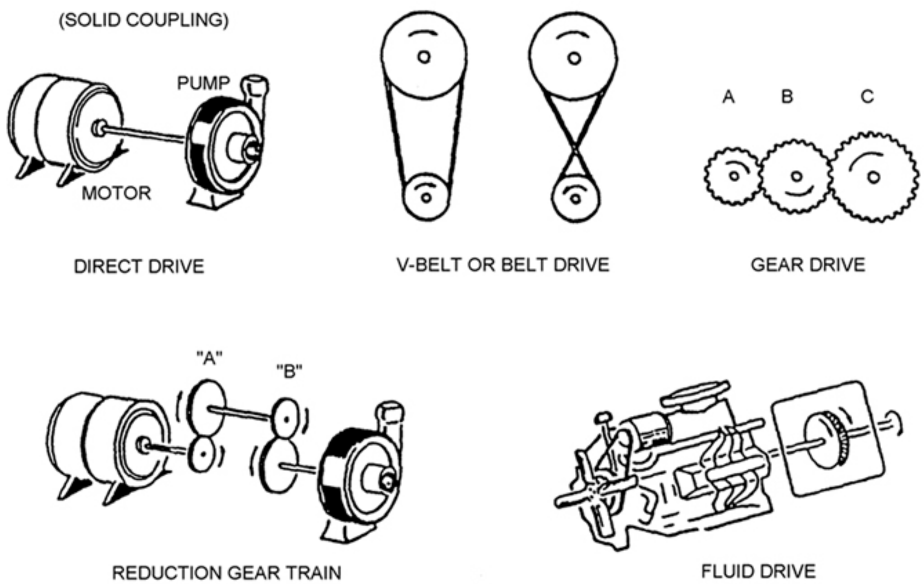

Figure 3–10. Methods of power transmission.

Direct drive

Equipment such as saws, grinders, and pumps are often driven by a solid shaft connected to the driving source (motor). The drive ratio is 1 to 1 (one turn of the driver to one turn of the equipment being driven). When a pump or similar equipment is being driven by direct-drive coupling, the drive shaft will generally contain a flexible coupling that absorbs vibration or allows for some misalignment.

Belt drive

Air-conditioner fans, ventilator fans, air compressors, and refrigeration units are examples of belt-driven machines or equipment. The fan on your automobile is another. Notice the two belt drives in figure 3–10. The one on the left illustrates how the belt is installed to turn the driven wheel the same direction as the driver. The illustration on the right shows you how you would install the belt to change the direction or rotation of the driven wheel. Most belt drives are single or multiple V-belts, depending on the load.

Gear drives

A simple gear drive is illustrated in the upper right corner of figure 3–10. The small gear is the driver, and the larger gear is the driven gear. Two things should be noted here. First, the direction of rotation changes from each gear to the mating gear. Second, the speed of rotation is different for each of the gears.

Let's assume that gear A has 50 teeth, gear B has 100 teeth, and gear C has 200 teeth. Each time gear A makes one revolution, gear B will make one-half of a revolution and gear C will turn one-fourth of a revolution compared to gear A. If gear A is turning at 2,000 revolutions per minute (rpm), how fast is gear C turning? If your answer is 500 rpm, then you are correct. Once again, an equation may help demonstrate this more effectively:

$$1 \text{ rpm} \times 200 \text{ teeth (Gear C)} = 4 \text{ rpm} \times 50 \text{ teeth (Gear A)}$$

$$\frac{1}{4} \text{ rpm} \times 200 \text{ teeth (Gear C)} = 1 \text{ rpm} \times 50 \text{ teeth (Gear A)}$$

$$2{,}000 \times \frac{1}{4} \text{ rpm} \times 200 \text{ teeth (Gear C)} = 2{,}000 \text{ rpm} \times 50 \text{ teeth (Gear A)}$$

$$500 \text{ rpm} \times 200 \text{ teeth (Gear C)} = 2{,}000 \text{ rpm} \times 50 \text{ teeth (Gear A)}$$

The rule for finding gear ratio is, "the speeds of two gears are inversely proportional to the number of teeth on them." For example, gear A had 50 teeth and gear B had 100 (twice as many); therefore, gear A would have to turn two revolutions (100 teeth) to turn gear B one revolution.

Reduction gears are shown in the lower left corner of figure 3–10. Follow the gear train by checking the direction of rotation. Now follow it through again, paying particular attention to the relative size of the gears. Is the pump going faster or slower than the motor?

Fluid drives

There are many types of fluid drives; however, they are fundamentally the same. Some have gear reduction trains in them; others may have more than one set of turbines. Examine the fluid drive in figure 3–10. Essentially, the drive is a sealed chamber containing two turbine fans facing each other. The chamber is filled with light oil. As the engine turns the driving fan, the fan blades swirl the oil in the direction of rotation of the fan. The driven fan faces the driving fan and is very close to it. The swirling action of the oil pulls at the blades in the driven fan, causing it to turn in the same direction, although somewhat slower. The power and speed of the driven shaft are generally controlled through the use of gear trains or the speed of the driving unit.

Friction

Thus far in our discussion of simple machines, work, and power, we have disregarded friction. Engineers also wish they could ignore friction, because it is a source of heat and wear. Friction tends to slow down machines and is a great power stealer. By definition, friction is the resistance that opposes every effort to slide or roll one body over another. When you slide a packing case across the floor, much of the resistance you must overcome is friction or the drag between the bottom of the case and the floor surface. You rely on friction when you are walking or running. Ice provides much less friction, and therefore running on ice is very hazardous.

You grease bearings, oil drive shafts, and polish aircraft wings to reduce friction, but, at the same time, friction does have advantages. Without it, trains and other wheeled transportation could not move. The brakes of the fuel truck would not stop the truck. Drive belts would not stay on pulleys or drive them. In fact, without friction you could not even walk. Several factors affect friction, or the lack of it. Let's examine a few of them.

The type and texture of a surface have considerable effect on the amount of friction the surface presents. Bearings, for example, are made of very hard steel that has been smoothly ground and highly polished. Even without grease, the friction is lower than on rougher surfaces. Lubrication is the key to friction reduction. Wooden drawers can be coated with paraffin or soap. Metal surfaces are generally oiled or greased. Sometimes it is not advisable to put oil or grease on a bearing surface, such as door locks, for example. In this case, use graphite as a lubricant. Graphite is a dry, powdery lubricant. Sometimes using the wrong lubricant can be worse than using none at all.

Self-Test Questions

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

013. Laws of motion

1. Match the law in column B to the appropriate definition or example in column A. Items in column B may be used once or more than once.

Column A	*Column B*
____ (1) Acceleration of a body is directly proportional to the force exerted on the body, is inversely proportional to the mass of the body, and is in the same direction as the force.	a. First law.
____ (2) A body continues in its state of rest or uniform motion in a straight line unless an unbalanced force acts on it.	b. Second law.
____ (3) Whenever one body exerts a force upon a second body, the second body exerts an equal and opposite force upon the first.	c. Third law.
____ (4) This law explains the size motor required to turn a deepwell turbine pump.	
____ (5) This law explains the movement of a jet.	

2. Explain why a thrown ball does not continue in motion but will eventually fall to the ground.

3. What is the difference between weight and mass?

4. Which law would be used to determine the force necessary to move fuel through a pipe at specific velocity?

5. Which law proves a pressure gauge bourdon tube exerts an equal amount of pressure as the liquid it contains exerts?

014. Machines and their advantages

1. Define “work.”

2. Define “mechanical advantage.”

3. How many classes of levers are there?

4. How much effort would be required to lift 50 lb. with a 5-rope pulley system?

5. Why can't you get the full MA the threads of a screw offer?

6. What formula is used to determine power?

7. Is a drill bit a driver or driven machine?

8. Name the four methods of transmitting power.

9. Define "friction."

3–2. Principles of Hydraulics

Hydraulics is a Greek word meaning water and pipe. Initially it referred to liquids in motion. *Hydrostatic*, also a Greek word, was used to define the science of liquids at rest. Over the years hydraulics came to be the sole word used for the study of fluids in motion or rest. Thus, this section is particularly important to you. Fuel and water systems contain fluids in motion and at rest. Automatic valves operate because of the principles and laws of hydraulics. Problems such as leaks and hydraulic shock exist because of the same principles and laws. This section will help you better understand the effects on system equipment.

015. Physical properties of fluids

Fluids such as water, oil, air, and so forth, are substances capable of changing their shape and flow. They are divided into two classes or states—liquids and gases. Our study is predominately about liquids. A major difference between the two is that liquids are far less compressible than gases.

Molecules

All substances are made up of molecules. Some substances have molecules that have a strong attraction to each other, and those are known as solids. The molecules of a liquid have a much weaker attraction to each other. This allows the molecules to move around and slip over each other. This is why liquids conform to the shape of any container they are poured into (fig. 3–11). For our purposes, there are four main physical properties that affect liquid molecules: weight, pressure, viscosity, and temperature.

Figure 3–11. Liquids conform to the shape of their container.

Weight

Every atom or molecule in a solid has weight; since they attract each other, the ones at the base support the combined weight of all the atoms and molecules above. This weight, of course, is transmitted to the surface the solid lies on.

Liquid molecules, as already mentioned, move constantly; therefore, it seems they cannot support the molecules above them. Yet, at any level, the molecules bear the weight of the liquid above it. This fact is possible because of the billions of collisions that pass the weight and pressure to the bottom of the container.

Pressure

The molecules of a liquid are moving constantly. Even though they are more tightly packed than gas molecules, they move at speeds of about a thousand miles per hour. It is believed this constant moving resulting in billions of collisions per second, in addition to their weight-bearing property, produces a steady and constant pressure.

Viscosity

Different molecules have different attractions to each other. Molecules that have more attraction than others offer a resistance to flow. This resistance is called viscosity. That is why oil flows slower than gasoline. Also, this attraction tries to hold the molecules together and creates a surface that solids can move on better. The lubrication effect provided by viscous liquids is possible because liquids fill and take the shape of any container or depression, making the surface smoother.

Temperature

You now know that liquid molecules are moving constantly, and this motion gives liquids weight and pressure. You also know that the relative ease with which they move determines whether a liquid has a high or low viscosity. The temperature also affects the movement of these molecules. As they heat up, they will try to move faster. The faster the molecules move, the more pressure they exert. The pressure increases because the collisions occur more often and harder, actually expanding the liquid, causing it to increase in size. Of course, as the liquid increases in size, it also increases in weight. If this doesn't seem possible, fill up your car's gas tank early in the morning. If you don't drive it and the temperature increases enough, you'll notice that gas will start to drip from the overflow vent.

An increase in temperature also affects liquids with a high viscosity. The molecules moving with greater velocity are able to slip over each other more easily, offering less resistance; therefore, they provide a better flow. The reverse is also true; diesel at colder temperatures becomes thicker, even to a point of jelly.

Pascal's principle

Pascal's principle states: ***pressure applied to a confined liquid is transmitted equally and undiminished in all directions throughout the vessel, regardless of the shape or size of the vessel***. Let's explain this with an example. A farm hand went to the well, filled a jug with water, inserted the stopper, and hit the stopper with a sharp blow. Much to his astonishment, the bottom fell out of the jug. Now look at what really happened.

Figure 3–12 represents the jug filled with water. As the cork was driven into the jug by the force of the blow, its pressure upon the confined liquid was transmitted equally in all directions. For convenience, assume the neck of the jug had an area of exactly 1 square inch (in^2) and a 10 lb. force used to drive the stopper into the jug. That means every square inch of the inside surface was subjected to a pressure of 10 lb. If the bottom of the jug had an area of 40 square inches, the total force acting upon it must have reached the total of 400 lb. The bottom of the jug was not strong enough to withstand so great a force.

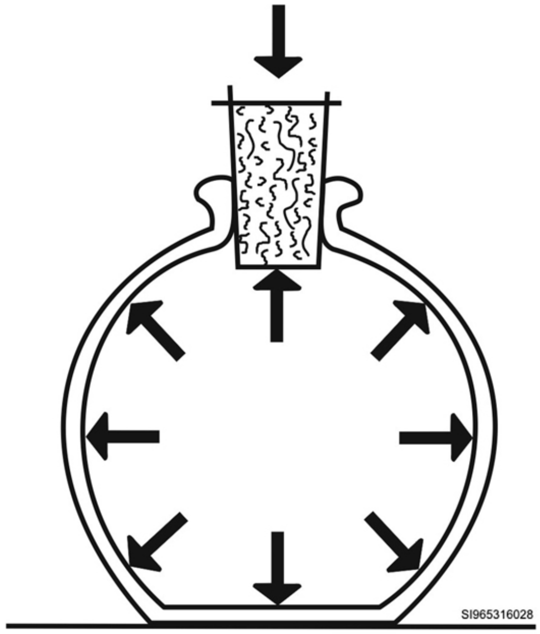

Figure 3–12. Pascal's principle.

Transmission of force

When the end of a solid column is struck, the force of the blow is carried straight through the solid in the direction of the blow only. If the end of a column of confined fluid is struck, the force is transmitted not only to the opposite end but also equally in all directions throughout the column, causing the container to literally be filled with pressure (fig. 3–13).

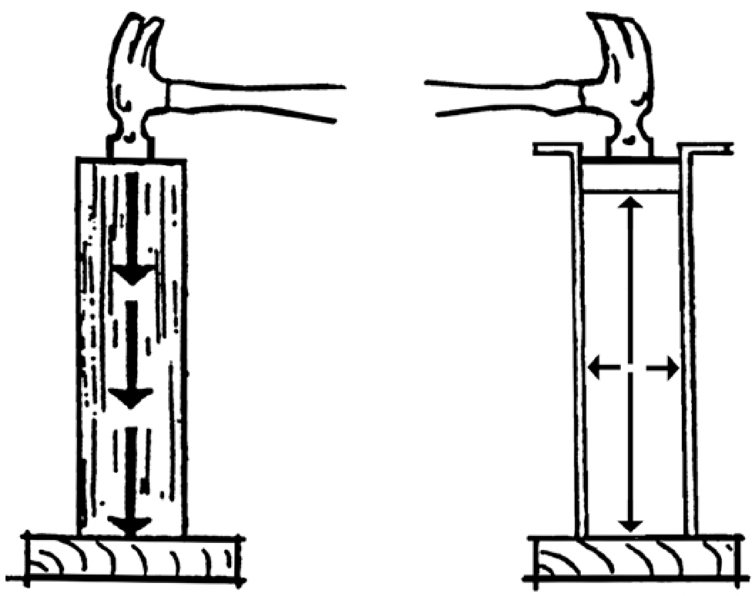

Figure 3–13. Transmission of force.

Forces can be transmitted through fluids—up or down, around corners or curves—with great efficiency (fig. 3–14). Although fluids are not rigid, the laws of fluids permit them to be used like levers. A small force can be used to balance a large force (fig. 3–15).

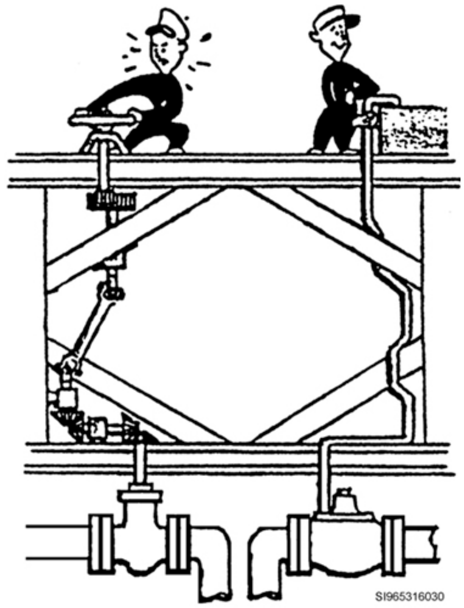

Figure 3–14. Float controlled valve.

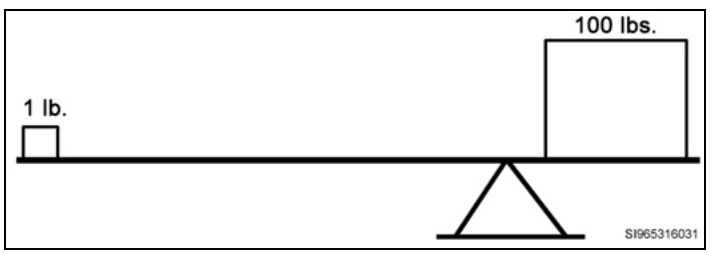

Figure 3–15. Lever.

Let us consider a hydraulic system consisting of two interconnected cylinders, one having a piston area of 1 in^2 and the other a piston area of 100 in^2, and the system filled with a liquid (fig. 3–16).

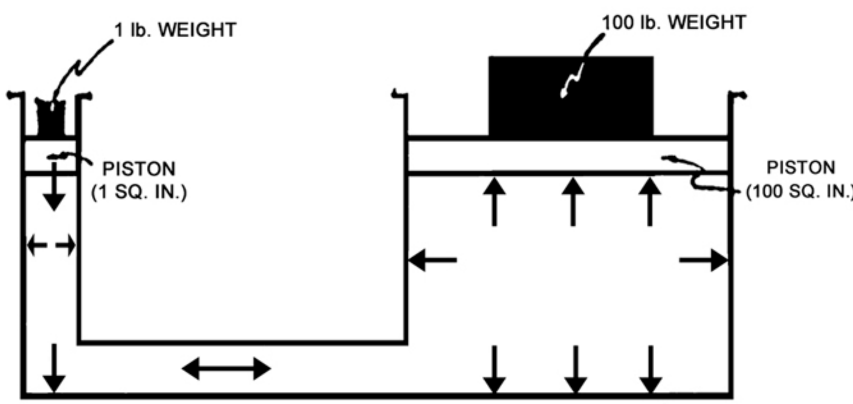

Figure 3–16. Pistons.

Disregarding friction, a downward force of 1lb. on the small piston creates a pressure of 1 psi on the liquid. This pressure is transmitted undiminished in all directions throughout the system and acts at right angles against all internal surfaces. Thus, the upward force on the 100 square inch piston will support a weight of 100 pounds (1 psi × 100 in^2).

016. Liquids at rest

Now let's discuss liquids at rest. Have you ever looked at a fuel tank and wondered what the pressure at the bottom was? There is a lot of fuel in the tank; therefore, there must be a lot of pressure. Not so fast. There is less pressure than you think at the bottom of a tank.

Static pressure

Liquids at rest are said to be *static*. Static pressure is the pressure created by a liquid over a given area. At any point in a liquid at rest, the pressure is the same in every direction. Therefore, in a liquid at rest, the pressure is the same at all points on the same level (fig. 3–17).

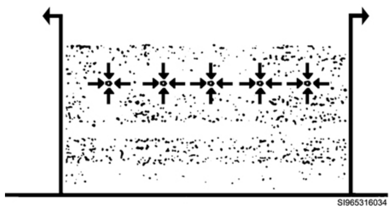

Figure 3–17. Equal pressure in all directions at the same level.

Suppose you have a wooden tank filled with water. If you bore a hole in the bottom of the tank the water will flow out, proving that fluids push downward. If you bore a hole in the side of the tank the water will flow out, proving that fluids also exert pressure in a sideways direction. If you push a piece of wood down into the water, it will rise to the surface as soon as it is released. The upward push that liquids exert upon objects submerged in them causes those objects to seem to lose weight. From these examples we must conclude that fluids exert pressure in all directions (fig. 3–18).

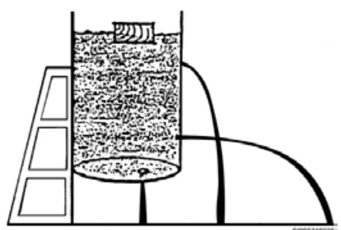

Figure 3–18. Pressure is exerted up, sideways, and down.

Liquid pressure is proportional to the depth, just as bricks lying on a table exert force or pressure upon the table proportionally to the number of bricks. When several bricks are piled upon one another, the downward pressure is increased. Likewise, every layer of liquid appears to sustain the weight of the layer or layers above it; hence, the pressure of the liquid increases in direct proportion to its depth (fig. 3–19).

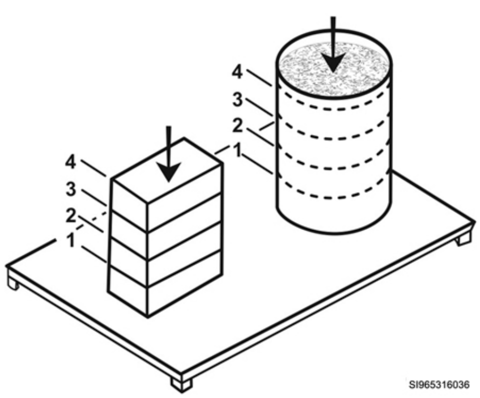

Figure 3–19. Layers of solids and liquids.

In the study of liquids, water is most commonly used for illustration. Although the density (weight per unit volume) of water varies, for the purpose of standard measurements, its weight is considered to be 62.4 pounds per cubic foot (pcf).

If the bottom area of a straight-sided container is one square foot, then water one foot deep in this container exerts a pressure of 62.4 pcf at its base, or .433 pounds per square inch/foot (psi/ft) (62.4 pcf divided by 144 in^2/ft^2 = .433 psi/ft).

Pressure exerted by any liquid is governed by its weight density as well as its depth. As a result, the pressure in psi exerted by any liquid at any depth may be determined. For example, after obtaining the depth of the liquid in feet (from the top), multiply this depth by .433 psi/ft, and then multiply the result by the specific gravity of the liquid. For example:

Depth (ft) X .433 psi/ft X specific gravity.

Using this formula, then, to find the psi exerted at the base of a column of gasoline (specific gravity 0.7) 18 feet in depth, we would perform the following action:

18 ft X .433 psi/ft = 7.794 psi

Now, let's multiply the product with the specific gravity:

0.7 X 7.794 psi = 5.4558 psi

= 5.46 psi (rounded up)

Liquid pressure and containers

Since liquid pressure is measured in unit area and is exerted equally in all directions, the shape of a container or vessel does not affect the amount of pressure exerted by the contained liquid. The depth of the liquid in containers determines the pressure exerted at any point, regardless of container shape or size. The fact that the force exerted on the bottom of a vessel is determined by the height of the liquid and not the volume is called the hydrostatic paradox, as shown in figure 3–20.

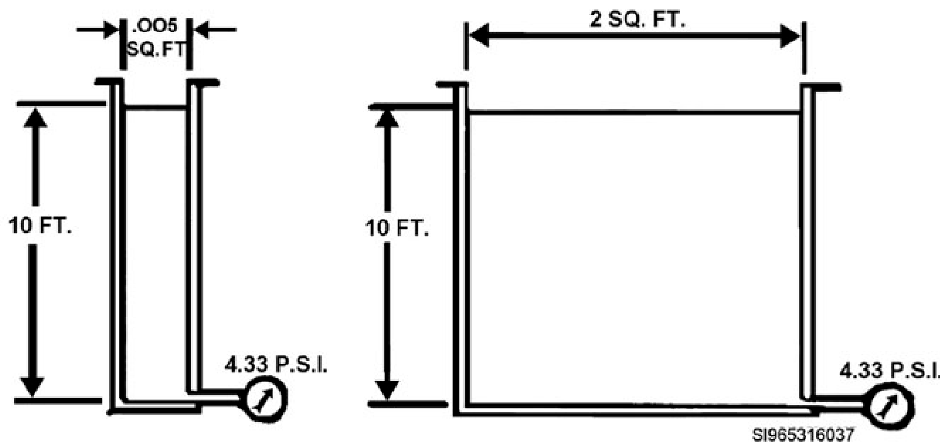

Figure 3–20. Hydrostatic paradox.

A liquid will come to rest at the same height in open vessels that are interconnected, regardless of the shape or area of these vessels. Water seeks its own level, as shown in figure 3–21.

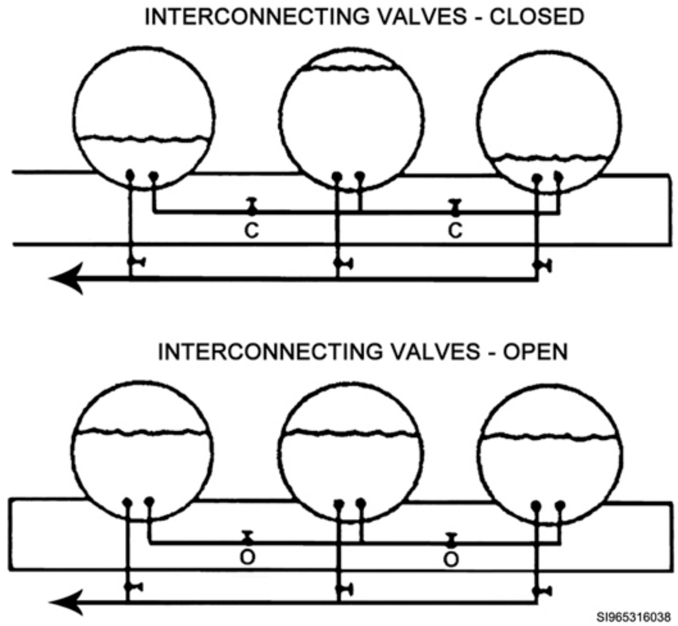

Figure 3–21. Liquids seek their own level.

Buoyancy

The lifting force of a liquid on a body immersed in it is called buoyancy. The law of buoyancy, discovered by Archimedes about 420 before Christ (BC), states that a body immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced by it. It follows, then, that when a body floats on a liquid with a portion protruding above the surface of the liquid, the weight of the liquid displaced is equal to the weight of the floating body (fig. 3–22). A float must be constructed so that the weight of its volume is less than or equal to the weight of its volume of liquid. In other words, if a float weighs 1 lb. and displaces ½ lb. of liquid, only half of the float will be submerged; but if the displaced liquid equals 1lb., then the float will be completely submerged before it starts to float. A float must be designed for the liquid in which it floats.

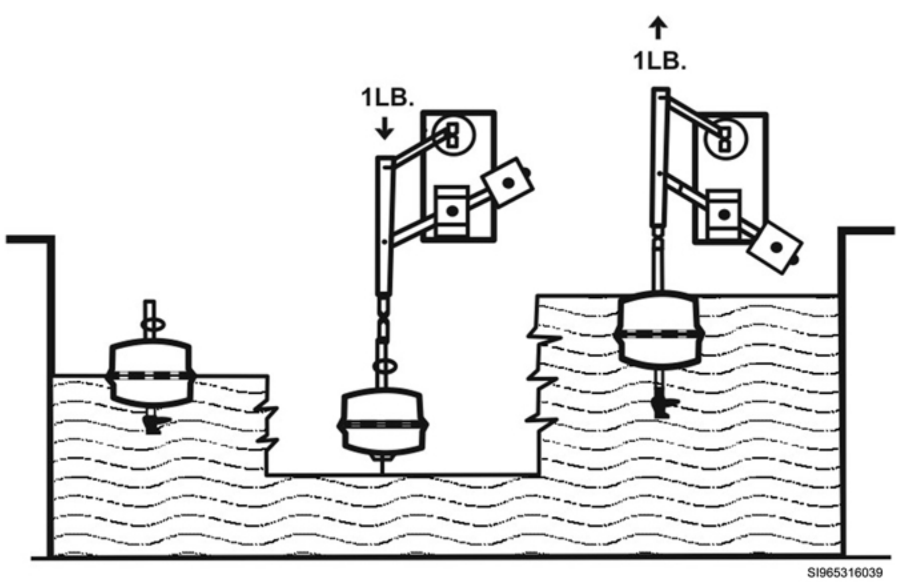

Figure 3–22. Floats.

Floats can be used to control the level of liquids in reservoirs or tanks by using mechanical and hydraulic linkage to control the opening and closing of an automatic valve (fig. 3–23).

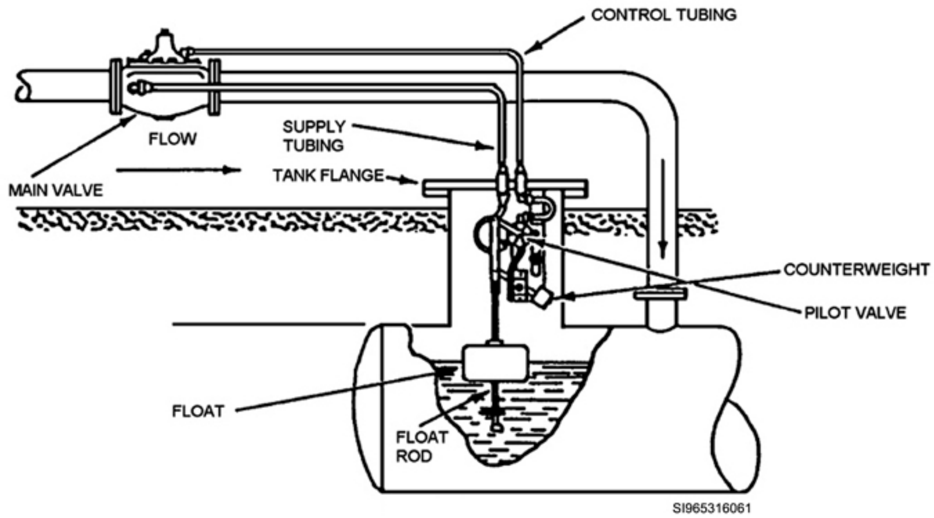

Figure 3–23. Float operated valve.

Immiscible liquids

Let's say that a quantity of gasoline (specific gravity 0.7) and water (specific gravity 1.0) is poured into a container. Even though someone might try to thoroughly mix them, when they are allowed to settle, the two liquids will quickly separate and the gasoline will float on top of the water. When completely at rest, the two liquids will be separated by a clear-cut line. In other words, the two liquids are incapable of truly being mixed and are said to be immiscible.

Whenever you work with immiscible liquids, they will not remain in solution when mixed with each other but tend to separate as oil and water do when they are mixed. The liquid that settles on top is the lighter liquid. The line of separation is called the interface, which is the division line between immiscible liquids that are contained in the same vessel. True solutions, however, will thoroughly mix, and they will not have an interface and are not immiscible. Salt water is a good example of a true solution.

A float can be constructed in such a manner that it comes to rest at the interface of two immiscible liquids, with one half of its volume above the interface and one half of its volume below the interface. With such a float, and proper mechanical and hydraulic linkage to an automatic valve, the volume of either liquid in a vessel can be controlled.

017. Liquids in motion

In order to understand hydraulic systems and flow of liquids through valves, it is necessary to become acquainted with some of the characteristics of liquids in motion.

Volume of flow

Volume of flow refers to the quantity of liquid that passes a given point in a system in a unit of time. It can be measured in many different ways—barrels per hour (bph), cubic feet per second (cfs), and gpm. Gpm is the most common unit of volume of flow.

Velocity of flow

Velocity of flow means the rate of speed of the liquid flowing. There are several units of measure for velocity. The usual method of stating velocity is in fps. Volume and velocity are interrelated since volume can be determined by multiplying the area of a pipe in^2 by the velocity in fps resulting in volume in cfs.

Steady and unsteady flow

Few hydraulic systems have steady uniform flow rates. Changes in demand and pressure are usually changing the rate of flow of most systems.

Laminar flow

Flowing liquid tends to flow in a laminar streamline manner in large-diameter pipes and at low velocities. Streamline means the particles of liquid follow each other and move alongside each other (fig. 3–24).

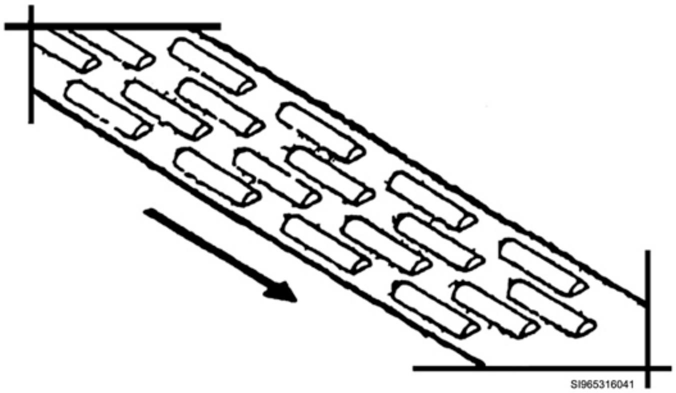

Figure 3–24. Laminar flow.

In a pipe or channel, the liquid flowing next to the pipe wall has very little velocity and is considered to have laminar flow. If you have ever seen a mountain stream, the flow comparison is similar. The flow along the banks of the stream is slower and calmer. The closer it is to the center, the greater the velocity. The more turbulent the flow is, the less difference in velocity it will be from wall to center. Velocity, when stated, is the average velocity across a cross-section of the pipe.

Turbulent flow

When flow velocities increase and/or pipe diameters become smaller, the liquid particles tend to tumble and jostle each other and flow becomes turbulent (fig. 3–25). Take the same mountain stream and you will notice that the flow in the middle of the stream is faster and creates more ripples on the surface. The same thing happens if the stream narrows at any point.

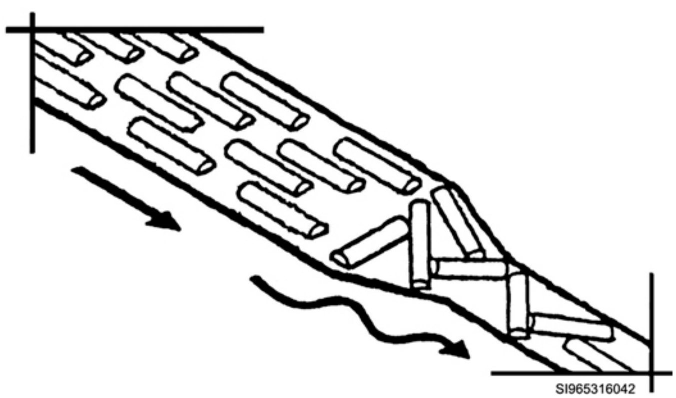

Figure 3–25. Turbulent flow.

Flow through valves is generally accepted to be turbulent. Some designs are less inclined to cause turbulence than others. Fuel systems are designed so that fuel flow will not normally exceed 12 fps. This design idea reduces static charge buildup and lessens the likelihood of stirring up pipe scale and water in fuel systems. The 12 fps does not apply when flushing a system. When flushing a system, you want maximum velocity, 20–30 fps. The turbulent flow resulting from this cleans the pipes.

Factors involved in flow

Before we discuss the behavior of liquids in motion and the factors that affect the flow of liquids, let's review the definition of inertia. Inertia essentially defines that property which is possessed by all forms of matter and that makes the matter resist being moved if it is at rest. Likewise, the matter resists any change in its rate of motion if the matter is moving (Newton's first law).

In order to overcome this tendency to resist any change in its state of rest or motion, some force that is not otherwise cancelled or balanced must act upon the object. Some unbalanced force must be applied whenever liquids are set in motion or are made to accelerate; conversely, forces are made available to do work elsewhere whenever liquids in motion are retarded or stopped.

There is a direct relationship between the magnitude of the force exerted and the inertia against which it acts. This force is dependent on two factors—the mass of the object (which is proportional to its weight) and the rate at which the velocity of the object is changed. For example, the force it takes to move water through a 4-inch pipe at 12 fps will be more than the force needed to move gasoline through the same pipe and at the same rate due to the fact that water's mass (weight) is more than that of gasoline.

Physical factors

There are five physical factors that act upon a liquid and affect its behavior: gravity, atmospheric pressure, specific applied forces, inertia, and friction. The relationships of these five factors to each other determine all of the physical actions of liquids. Their descriptions and behaviors are as follows:

- *Gravity* acts at all times upon all bodies, at rest and in motion, regardless of all other forces.
- *Atmospheric pressure* acts whenever any part of a system is exposed to the open air, which applies either at rest or in motion.
- *Specific applied forces* may or may not be present but, in any event, are entirely independent of the presence or absence of motion. An example of applied forces would be the energy supplied by thermal expansion (liquid at rest) or a booster pump (liquid in motion).
- *Inertia* comes into play whenever a body is acted upon and there is a change from rest to motion or the opposite, or whenever there is a change in direction or in rate of motion.
- *Friction* is always present whenever there is motion.

Static and dynamic factors

The first three factors—gravity, atmospheric pressure, and applied forces—apply equally to liquids at rest or in motion, while the latter two—inertia and friction—apply only to liquids in motion. The first three are the static factors, and the latter two are the dynamic factors. Static pressure is the sum of gravity, atmospheric pressure, and applied forces at any given point in time.

As we previously mentioned, Pascal's principle states that the pressure of a liquid acts equally in all directions and at right angles to containing surfaces. This covers the situation only for liquids at rest, or practically at rest, and is true only for the factors making up static head (pressure). It is for this reason that most problems involving fluids at rest disregard friction completely. Obviously, when velocity becomes a factor, it must have a direction and the force related to the velocity must also have a direction, so that Pascal's principle alone does not apply to the dynamic factors of liquid flow.

The dynamic factors of inertia and friction are related to the static factors in one sense. Velocity head and overcoming friction are obtained at the expense of static head. As you already know, force is necessary to start a body moving if it is at rest, and is present in some form when the motion of the body is stopped. In other words, whenever a liquid is given a velocity, some part of its original static head (pressure) is used to achieve velocity, which then exists as velocity head. If the velocity head again slows, at least a portion of velocity head always reverts back to static head.

Look at figure 3–26. This system consists of a chamber (A) under pressure connected by a tube (X) to chamber (B), which is also under pressure. The pressure in chamber (A) has a static pressure of 100 psi. The pressure in the connecting tube (X) is currently 90 psi. As the liquid enters chamber (B), it is slowed down; as it slows, its pressure returns to 100 psi. That is, the force (pressure) required to get the liquid moving in the first place is subtracted from the static pressure. Why? Because the force used to move the liquid is exerted only in a forward direction, while the remaining static pressure is exerted equally and undiminished in all directions. For example, if 10 lb. of the static pressure is used to move the liquid from chamber (A) to chamber (B), then only 90 lb. will be sensed in the pressure gauge at the intermediate point. The 10 lb. is not lost or eliminated. When the velocity of the liquid slows down in chamber B, the 10 lb. of pressure will return to the static pressure head.

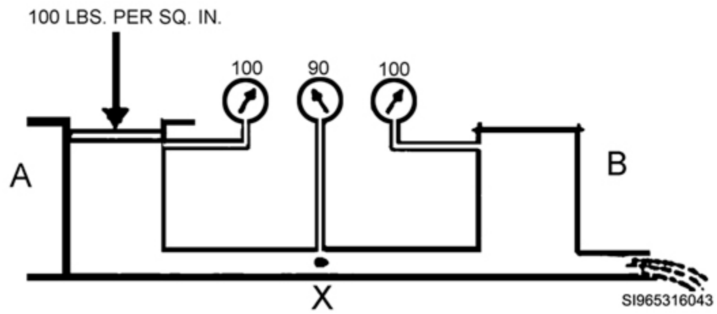

Figure 3–26. Bernoulli's thermo.

The situation described disregards friction, and would therefore not be met in actual practice. Friction also requires force or head to overcome it; however, contrary to the inertia effect, this force cannot be recovered again. Therefore, in an actual system, the pressure in chamber (B) would be less than that in chamber (A) by the amount of pressure used in overcoming friction along the way. This general truth is known as Bernoulli's Theorem, and it is the second important basic law of hydraulics which governs the relations of the static and dynamic factors.

Now consider figure 3–27. If ordinary bourdon tube pressure gauges were installed in a pipe 100 feet apart and flow was occurring through the pipe, the gauge downstream (P_2) would show a lower pressure than the upstream gauge (P_1). The amount of pressure would depend on the velocity of the flow and the amount of friction that was overcome.

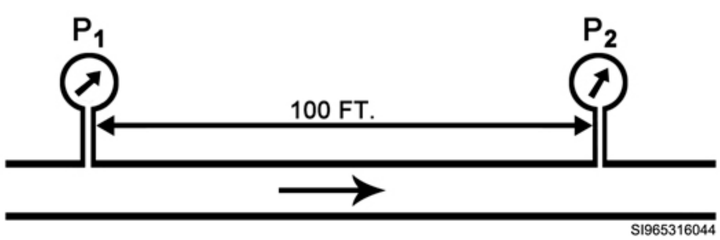

Figure 3–27. Flow through a pipe

Any obstruction in the pipe that changes the direction of the whole stream, or even part of it, will alter the characteristic flow pattern and create turbulence. This causes an energy loss greater than that normally accompanying flow in straight pipe. Because valves and fittings in a pipeline disturb the flow pattern, they produce an additional pressure drop.

Figure 3–28 shows two sections of pipeline of the same diameter and length. The upper section contains a globe valve. If the pressure losses on both pipelines were measured between the points indicated, it would show that the globe valve pipeline has a greater pressure loss than the straight pipeline would. Pressure loss through valves is normally given for a wide-open valve. Not all valves, however, are wide open during flow.

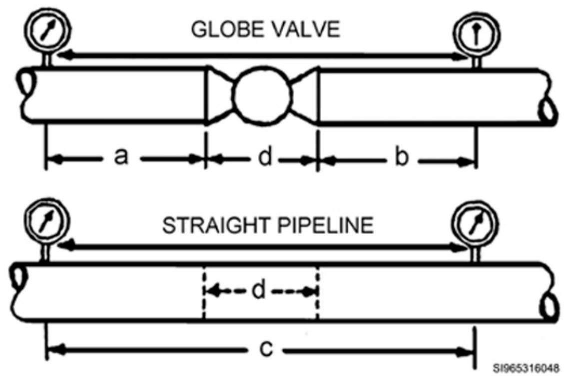

Figure 3–28. Restrictions through valves.

Using a venturi

Bernoulli's Principle states: *As the velocity of a moving fluid increases, its kinetic energy increases and consequently, the pressure it exerts must correspondingly decrease*. We can conclude that the flow requires energy and that the energy used is reflected in loss of pressure.

With Bernoulli's theorem you can create two different pressures. One way to use this to our advantage is as a pump. This type of pump is called an ejector pumping system, as shown in figure 3–29.

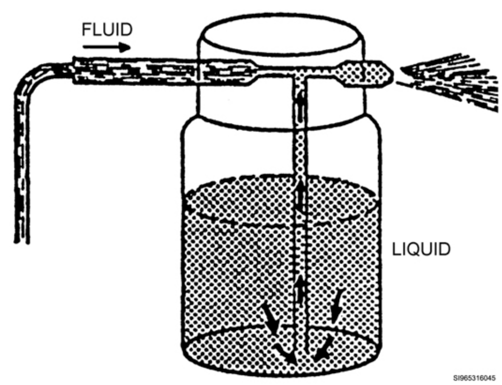

Figure 3–29. Ejector pump.

By forcing a fluid through the narrow portion of the tube (or venturi), you create a low pressure or actually a type of suction at the top of the tube section that extends down into the container, causing the liquid to be drawn out. This type of system can use air as the driving force to pump out sumps in pits or tanks. We can also use this principle in aiding the opening of automatic valves. By lowering the pressure above a diaphragm, the line pressure will open a valve (fig. 3–30).

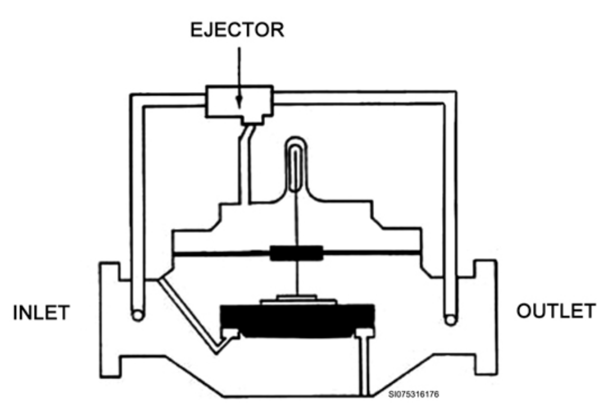

Figure 3–30. Automatic valve.

Using an orifice plate, we can also create two different pressures to control fuel flow through an automatic valve. An orifice plate is nothing more than a restriction in a pipeline, the same as a venturi. Figure 3–31 shows how it creates a differential pressure. Instead of the pipe gradually reducing in size and then increasing again, the smaller hole of the orifice plate immediately reduces the path the flow must take. This forces the liquid through the reduced opening at a greater rate which reduces the pressure that is sensed immediately as it passes the opening. Higher pressure is sensed as the liquid hits the orifice plate and lower pressure is sensed as it passes through. You will see later how an automatic valve can be controlled by this differential pressure.

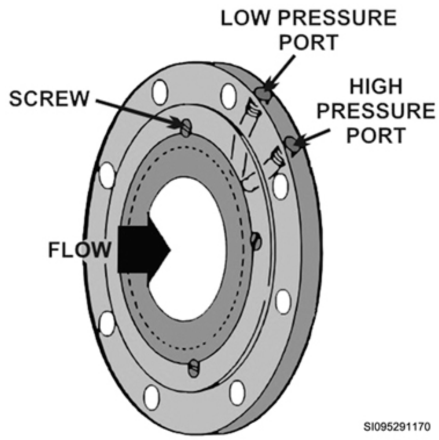

Figure 3–31. Orifice plate.

Forces applied to automatic valves

The operation of an automatic valve involves the controlled struggle between opposing forces. Those forces include fluid pressure being directed above and below the valve diaphragm as well as gravity and spring tension. Refer to figure 3–32 for the following discussion.

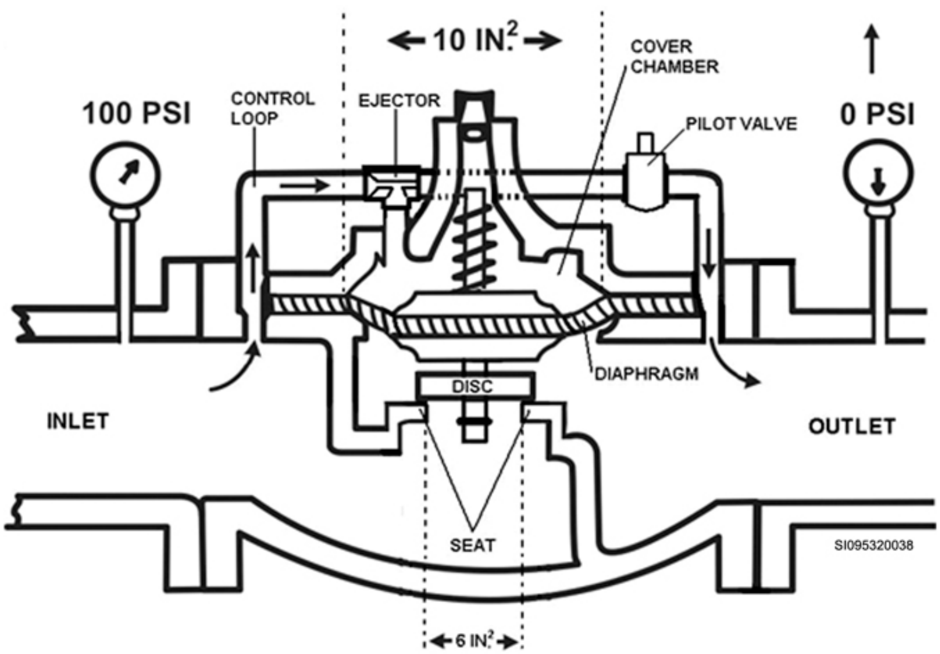

Figure 3–32. Automatic valve.

The automatic valve employs a flexible diaphragm and a rigid disc instead of pistons for its operation. The diaphragm and disc have an effective area for pressure to be applied. Automatic valves commonly have pilot valves located in the control loop. The pilot valve, simply explained, allows the automatic valve to open when it is open and close the automatic valve when it is closed. For this example, the diaphragm's effective area is 10 in^2 and the disc's effective area is 6 in^2.

First let us assume the pilot valve is closed. A pressure of 100 psi at the valve inlet creates 600 psi (100 psi × 6 in^2) under the disc trying to push the disc off the seat. The same 100 psi enters the control loop and creates 1,000 psi (100 psi × 10 in^2) to the top of the diaphragm in the cover chamber. Since the pressure cannot continue through the pilot valve, all the pressure remains on top of the diaphragm.

Now let us compare forces. There is 1,000 psi on top of the diaphragm (downward force), spring tension (downward force) and the weight of the disc (gravity) that act together to keep the disc firmly on the seat. There is only 600 psi trying to push the disc off the seat (upward force). Since the upward force cannot overcome the downward force, the valve will not open. If we disregard the spring and the disc weight, there is 1,000 psi on top of the diaphragm and only 600 psi under the disc. We have a net pressure of 400 psi between the opposing forces (1,000 psi – 600 psi) keeping the valve closed.

Next, let us assume the pilot valve is open. The same pressure is applied to all areas, but the pressure that would have gone on top of the diaphragm can now pass through the pilot valve. Also, if you remember the ejector pump, the ejector in the control loop works exactly the same by creating a low-pressure area to draw pressure from the cover chamber. With the lowered pressure in the cover chamber, the 600 psi (upward force) under the disc can overcome the spring tension and disc weight (downward force) to push the disc off the seat allowing flow through the valve.

Some automatic valves will have inlet flow and pressure applied under the diaphragm (the outlet side of figure 3–32 becomes the inlet) instead of under the disc. This change of flow will not change the effects of the forces. Remember, if the upward force is greater than the downward force, the valve will open. If not, the valve will remain closed. In later volumes, you will see how the different components in the control loop will use these forces to enable these valves to be truly automatic.

018. Hydraulic shock

Hydraulic shock, or water-hammer pressure, is a series of shocks, or hammer-like blows, produced by suddenly stopping or reducing the liquid flow. If a valve is closed quickly, the kinetic energy of the moving liquid is expended in trying to compress the liquid and stretching the pipe walls. Starting at the suddenly closed valve, a wave of increased pressure is transmitted back through the pipe with constant velocity and intensity. A complete cycle of pressure waves and reversals of flow occupies the time required for two round trips. The amplitude pressure of the pressure vibrations becomes less with succeeding cycles because of friction, but the frequency (time interval) remains constant.

If a high-pressure wave in its travel through the pipe enters a branch pipe with a closed or dead end, there will be almost a doubling in the increase of pressure when the wave strikes the closed end. If the back wave from a branch pipe with a dead end has access to another branch, the high pressure may receive further augmentation.

The intensity of the excess pressure in a water-hammer wave depends on the amount of extinguished velocity. This statement is true whether the velocity is suddenly reduced or stopped. For instance, a velocity suddenly reduced from 7 to 4 fps will produce the same amount of excess pressure as suddenly stopping a velocity of 3 fps. If the flow is not checked or absorbed rapidly before that first wave of excess pressure makes a complete cycle, great damage can occur to flange gaskets, automatic valve diaphragms, pressure gauges, hoses, and so forth. Therefore, it is wise to use slow-closing valves, surge suppressors (arrestors), and pressure reliefs. These components will prevent or reduce the destructive nature of hydraulic shock.

Self-Test Questions

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

015. Physical properties of fluids

1. What are the classes or states of fluids? What is the major difference between them?

2. Why do liquid molecules flow and take the shape of any container they are poured into?

3. Explain how temperature affects the pressure, weight, and viscosity of a liquid.

4. What is Pascal’s principle?

5. How does transmission of force differ between solids and liquids?

016. Liquids at rest

1. What is static pressure?

2. Briefly explain an example of how liquids exert pressure in all directions.

3. How do you find the static pressure exerted on the bottom of a tank?

4. Explain the hydrostatic paradox.

5. What is the law of buoyancy?

6. What is the term used for liquids that separate when they settle, creating a clear-cut line? What is the clear-cut line called?

017. Liquids in motion

1. Match the characteristics of liquids in motion in column A with their definition in column B. Items in column B may be used once or more than once.

Column A	*Column B*
____ (1) Liquid flowing in a streamlined manner.	a. Volume of flow.
____ (2) Rate of speed a liquid is flowing.	b. Velocity of flow.
____ (3) Liquid particles tend to tumble and jostle each other.	c. Laminar flow.
____ (4) Amount of liquid that passes a given point in a unit of time.	d. Turbulent flow.
____ (5) Used to flush pipelines.	
____ (6) Is rated by the average flow across the cross-section of a pipe.	
____ (7) Can be determined by multiplying the area of a pipe by the velocity in feet per second.	
____ (8) Particles of liquid following each other and moving alongside each other.	
____ (9) Measured in gallons per min.	
____ (10) Measured in fps.	

2. Name the five physical factors that can act on a liquid to affect its behavior.

3. Which physical factors are the dynamic factors?

4. In what position do valves normally have pressure losses?

5. Explain Bernoulli's Principle.

6. Using figure 3–32, answer the following questions.

   a. An automatic valve with an inlet pressure of 120 psi, an effective diaphragm area of 20 inches, and an opening disc area of 8 inches has how much pressure psi applied to the diaphragm area?

   b. An automatic valve with an inlet pressure of 100 psi, an effective diaphragm area of 25 inches, and an opening seat area of 6 inches has how much pressure psi applied to the opening disc area?

   c. An automatic valve with an inlet pressure of 150 psi, an effective diaphragm area of 30 inches, and an opening seat disc of 12 inches has how much pressure force holding the valve closed?

018. Hydraulic shock

1. What causes hydraulic shock?

2. Describe a complete hydraulic shock cycle.

3. Which would create more shock, a system with a velocity of 7 fps slowed suddenly to 4 fps or a system with a velocity of 3 fps stopped quickly?

Answers to Self-Test Questions

013

1. (1) b.
   (2) a.
   (3) c.
   (4) b.
   (5) c.
2. Gravity and friction are the unbalanced forces acting on the ball.
3. Mass is the amount of material an object has in it; weight is determined by the gravitational pull acting on the object.
4. The second law of motion.
5. The third law of motion.

014

1. It is equal to the force times the distance an object is moved.
2. The ratio of resistance to effort.
3. Three.
4. 50/4 = 12.5 lbs. You do not count the rope in your hand; only four ropes supporting the 50 lb.
5. Because of the friction against the threads.
6. Work/time.
7. Driven.
8. Direct, belt, gear, and fluid drives.
9. The resistance that opposes every effort to slide or roll one body over another.

015

1. Liquid and gas. Gas is much more compressible than liquid.
2. Liquid molecules have a weaker attraction to themselves than do solid molecules.
3. Temperature increases the movement of the molecules, which increases the collisions, causing the liquid to exert more pressure and expand. This expansion increases its size also gives the liquid more weight. When the molecules are moving faster, they are able to slip over each other more easily, offering less resistance, thus a better flow.
4. Pressure applied to a confined liquid is transmitted equally and undiminished in all directions throughout the vessel, regardless of the shape or size of the vessel.
5. When a solid is struck, the force is transmitted in the direction of the blow. A blow to a column of liquid will transmit the force in all directions.

016

1. The pressure created by a liquid over a given area.
2. Fill a tank with water, bore a hole in the bottom and water will flow out proving fluids push down. Boring a hole in the side, the water will also flow out proving fluids exert pressure sideways. Push a piece of wood down into the water and release it; the wood will rise proving it exerts pressure upwards.
3. Multiply depth from the top of the liquid (in feet) by .433 psi/ft and then multiply the result by the liquid's specific gravity. That is depth (in feet) X .433 psi/ft X specific gravity.
4. The force exerted on the bottom of a vessel is determined by the height and not the volume of the liquid.
5. A body immersed in a liquid is buoyed up by a force equal to the weight of the liquid displaced by it.
6. Immiscible; interface.

017

1. (1) c.
   (2) b.
   (3) d.
   (4) a.
   (5) d.
   (6) b.
   (7) a.
   (8) c.
   (9) a.
   (10) b.
2. Gravity, atmospheric pressure, specific applied forces, inertia, and friction.
3. Inertia and friction.
4. Wide open.
5. As the velocity of a moving fluid increases, its kinetic energy increases and consequently, the pressure it exerts must correspondingly decrease.
6. (a) $20 \times 120 = 2{,}400$ psi.
   (b) $6 \times 100 = 600$ psi.
   (c) $4{,}500 - 1{,}800 = 2{,}700$ psi.

018

1. It is produced by suddenly stopping or reducing liquid flow.
2. A complete cycle of pressure waves and reversals of flow occupies the time required for two round trips.
3. Neither. The same excess pressure is produced by suddenly reducing the velocity by 3 ft per second, as by entirely stopping the velocity by 3 ft per second.

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).

30. (013) Which law of motion states that a body continues in its state of rest or uniform motion in a straight line unless an unbalanced force acts on it?
    a. First.
    b. Second.
    c. Third.
    d. Fourth.

31. (013) When pressure is no longer applied to open an automatic valve, which unbalanced force closes it?
    a. Fuel pressure and diaphragm weight.
    b. Fuel pressure and spring tension.
    c. Gravity and diaphragm weight.
    d. Gravity and spring tension.

32. (013) Which law is used to help determine the pump size required to move liquid?
    a. Fourth.
    b. Third.
    c. Second.
    d. First.

33. (014) Mechanical advantage (MA) is determined by the formula
    a. resistance × effort.
    b. distance × effort.
    c. resistance/effort.
    d. distance/effort.

34. (014) Which is the *correct* formula for determining the mechanical advantage of the wheel and axle?
    a. Radius of crank/radius of axle.
    b. Radius of crank × radius of axle.
    c. Radius of wheel/diameter of axle.
    d. Radius of wheel × diameter of axle.

35. (014) A single pulley with a radius of 2 inches has what kind of mechanical advantage (MA)?
    a. 1 to 1.
    b. 2 to 1.
    c. 3 to 1.
    d. 4 to 1.

36. (014) What would the mechanical advantage (MA) be if you used a block and tackle with seven supporting ropes, counting the rope you use to pull on?
    a. 5 to 1.
    b. 6 to 1.
    c. 7 to 1.
    d. 8 to 1.

37. (014) Which is the mechanical advantage (MA) of an inclined plane that is 8 feet long and 4 feet high?
    a. 2 to 1.
    b. 4 to 1.
    c. 8 to 1.
    d. 16 to 1.

38. (014) What determines the ease with which a screw can be turned?
    a. Width of the axis.
    b. Width of the handle.
    c. Length of the screw.
    d. Length of the handle.

39. (014) How much power would be used to move a 15-pound (lb.) valve housing 10 feet in 5 minutes?
    a. 15 foot-pounds force per minute (ft-lbf/min).
    b. 30 ft-lbf/min.
    c. 150 ft-lbf/min.
    d. 300 ft-lbf/min.

40. (014) The formula used to determine power is
    a. work/time.
    b. work × time.
    c. distance/time.
    d. distance × time.

41. (014) What type of drive would use two turbine fans that face each other?
    a. Flexible.
    b. Direct.
    c. Fluid.
    d. Fan.

42. (015) What are the four *main* properties that affect liquids?
    a. Temperature, molecular attraction, gravity, and expansion.
    b. Weight, pressure, viscosity, and temperature.
    c. Pressure, temperature, vacuum, and gravity.
    d. Weight, gravity, heat, and viscosity.

43. (015) An increase in temperature causes viscous liquids to flow
    a. faster and increase in weight.
    b. faster and decrease in weight.
    c. slower and increase in weight.
    d. slower and decrease in weight.

44. (015) Using Pascal's principle, determine the pressure exerted in an enclosed 10-inch cylinder when a connected 1-inch cylinder has 15 pounds per square inch (psi) applied to it.
    a. 10 psi.
    b. 15 psi.
    c. 150 psi.
    d. 300 psi.

45. (016) The lifting force of a liquid on a body is called
    a. laminar.
    b. interface.
    c. buoyancy.
    d. dynamic pressure.

46. (016) Immiscible liquids are *best* described as
    a. mixing well together.
    b. one liquid floating on the other.
    c. becoming an entrained solution.
    d. repelling each other and reacting violently.

47. (017) Which units of measurement would indicate volume of flow?
    a. Barrels per hour.
    b. Meters per hour.
    c. Feet per minute.
    d. Inches per second.

48. (017) Which units of measurement would indicate velocity of flow?
    a. Cubic gallons per minute (gmp).
    b. Cubic feet per second (fps).
    c. Gpm.
    d. Fps.

49. (017) Which physical factors affect the behavior of liquids in both rest and motion?
    a. Friction, applied forces, and gravity.
    b. Friction, inertia, and atmospheric pressure.
    c. Gravity, atmospheric pressure, and inertia.
    d. Gravity, atmospheric pressure, and applied forces.

50. (017) What happens to fuel's kinetic energy and the pressure it will exert when it passes through a venturi?
    a. Energy increases and pressure increases.
    b. Energy increases and pressure decreases.
    c. Energy decreases and pressure increases.
    d. Energy decreases and pressure decreases.

51. (017) What would be the net difference between the opposing forces of an automatic valve that has a 2-inch seat, an effective diaphragm area of 6 inches, and an inlet pressure of 50 pounds per square inch (psi)?
    a. 100 psi.
    b. 150 psi.
    c. 200 psi.
    d. 300 psi.

52. (018) Intensity of the excess pressure in a water-hammer wave is determined by the
    a. size of the pipe.
    b. specific gravity of the fuel.
    c. change in gallons per minute (gpm).
    d. amount of extinguished velocity.

Please read the unit menu for unit 4 and continue ➔

Unit 4. Electrical Fundamentals and Circuit Testing

MOST OF US know something about electricity because electrical devices and appliances are a part of our everyday life. We can flip a switch to give us light or turn a knob to start the motor of a washing machine. By doing so, we put electrical energy to work. In our career field, electricity energizes motors, operates controls, and opens valves.

In this unit we discuss the principles of electricity and electronics as well as the methods of determining their characteristics. This will lay the groundwork in order for you to better understand how to effectively troubleshoot circuits and their components.

4–1. Electrical Fundamentals

In this section we will discuss the basic fundamentals of electricity. This information will not make you a master electrician, but it will teach you enough to troubleshoot electrical problems, call an electrician, and show them about where the problem is.

Your understanding of the fundamentals of electricity and electronics is essential for you to do your job properly. Anyone can connect two wires and make a light bulb work, but your job requires an in-depth understanding of how everything works together. This section covers electrical principles and terms associated with alternating current (AC) and direct current (DC).

019. Electron theory and electricity

Some of the information in this lesson may simply be a refresher from the science classes you attended in high school and more recently the training you received at Sheppard Air Force Base (AFB), Texas. Yet some of the information will be new to you in order to help facilitate your knowledge and understanding of your job.

Atomic structure

The electron theory states that all matter is comprised of molecules which, in turn, are comprised of atoms. These atoms are composed of even smaller matter called protons, neutrons, and electrons. The theory also explains that all atoms are similarly constructed of a central nucleus and orbiting electrons. The protons and neutrons are contained in a closely packed nucleus in the center of the atom. The electrons spin around the nucleus in much the same manner that our planets orbit the sun. Each proton and each electron carries an electrical charge; protons carry a positive charge and electrons carry a negative charge. The neutrons carry no charge.

Figure 4–1 shows you the atoms of four common elements: hydrogen, helium, lithium, and carbon. While all atoms contain protons, neutrons, and electrons (with the protons and neutrons located in the nucleus) for simplicity we will show only the charged components of the atom: protons and electrons. You will notice how each atom differs in the number and arrangement of the protons and electrons. These differences are known as their atomic structure, and they distinguish one element from another.

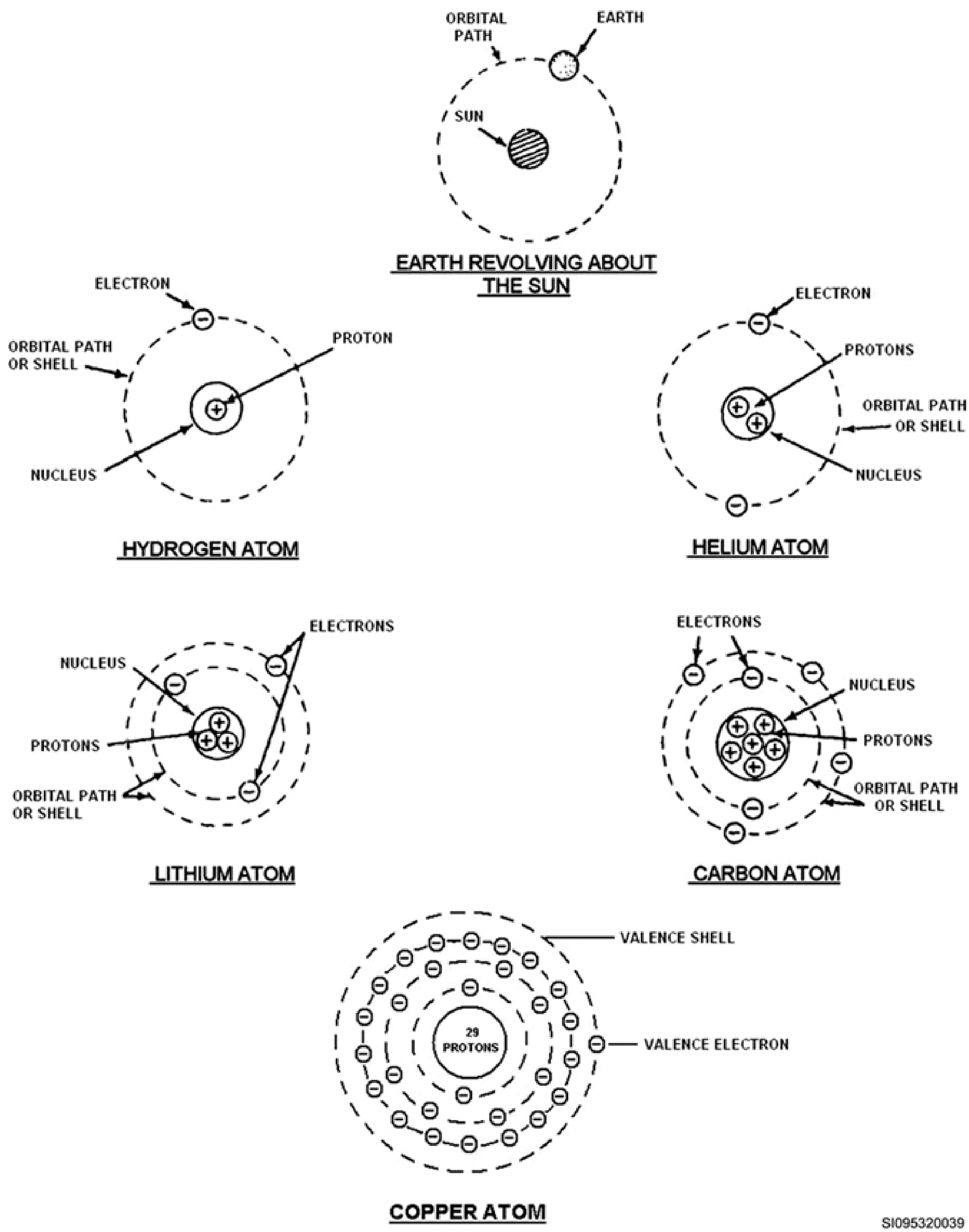

Figure 4–1. Structure of common atoms.

Hydrogen atom

The hydrogen atom shown is the simplest of all atoms. Since nature, even at the atomic level, likes a balance, it contains one electron revolving around one proton. Because the negative charge of the electron is equal to the positive charge of the proton, the atom is considered electrically balanced or neutral. An equal number of protons and electrons gives an atom that neutral balance.

Helium atom

Look at the helium atom shown in figure 4–1. Notice that the nucleus contains two protons. The positive charges of these two protons are balanced by the negative charges of the two electrons revolving in a single orbiting path, causing the atom to also to have a neutral electrical charge. The atoms of other elements are more complex than the hydrogen and helium atoms.

Lithium atom

For example, look at the lithium atom. Notice that there are three electrons revolving around the nucleus in two different orbiting paths (or shells).

Carbon atom

An even more complex atom, the carbon atom, is also shown in the figure. It has six electrons revolving around the nucleus in two different shells—an inner and outer shell.

We are telling you this because in most elements, the outermost shell does not contain its maximum number of electrons. Some atoms, such as copper (most electrical wiring is copper), have only one electron in its outer shell. Since there is only one electron in its outer shell, it is not strongly attached to the atom and can be easily pulled or forced from one atom to another. Electrons that are easily taken from an atom's outer shell are called free electrons. It is this movement or displacement of free electrons from their outer shell that gives us electrical energy.

Insulators and conductors

All electrical devices require an insulator and a conductor. Without an insulator, the system would use a great amount of power and burn itself out quickly. Without a conductor, it wouldn't be able to move. Let's look at the types of materiel used for these items.

Valence electrons

In electricity, the outermost shell is our primary interest. This shell contributes all electrical properties of an atom. The number of electrons in this shell determines whether a material is a good or poor conductor of electricity. This outermost shell is called the valence shell, and the electrons that are in the valence shell are called valence electrons.

An atom with the maximum number of electrons in its valence shell is termed *stable* or *balanced*. If the valence shell contains fewer than the maximum number of electrons, the attraction between the negative charge of the electrons and the positive charge of the protons is not always sufficient to hold these electrons in their orbit. If some outside force is applied that causes an electron to leave its atom, the electron becomes a free electron. When an electron leaves one atom, it goes to another atom. There are two effects of this action: positive ion (pronounced "eye on") and negative ion.

Positive ion

Because the atom that lost an electron has more protons than electrons, it has a positive charge. Thus, the atom is called a positive ion. It then seeks a negative charge (another electron) to again balance its own charge.

Negative ion

Because the atom that gained an electron has more electrons than protons, it has a negative charge. Thus, it is called a negative ion. This ion tries to throw off an electron. As you can see in figure 4–1, the electrons are passed from atom to atom.

Types of material

The two types of material used in electronics are conductors and insulators. Both are necessary for effective electrical operation.

Conductors

A substance that permits a large number of free electrons to move through it is called a conductor. The more electrons that can be moved through the material, the better conductor the material is.

A good conductor is a material that offers small opposition to electron movement. You could say that a good conductor gives up its valence electrons with ease. Generally, all metals are good conductors. The best conductors are silver, copper, and aluminum followed by gold, iron, steel, and mercury.

Insulators

An insulator is a substance that has few free electrons. When the electrons are more tightly bound to the atoms, the electrons are less likely to move from atom to atom.

A good insulator is a material that offers a lot of opposition to the flow of free electrons. An insulator has electrons, just as do all materials, but it has practically no free electrons. The valence shell is complete, which leaves no free electrons. Generally, all non-metals are good insulators. Rubber, plastics, glass, dry air, and mica are examples of good insulators.

It is incorrect to say that all materials are either conductors or insulators because there is no clear dividing line. The best conductors are used in electric circuits as paths for electron flow, and the poorest conductors are used as insulators to prevent electron movement to the surrounding areas. All substances offer some opposition to current flow. Likewise, all substances will allow electrons to pass through them if enough pressure is applied.

020. Main components of electricity

The three main components of electricity that affect power to our equipment and controls are current, voltage, and resistance. It is important to have a basic understanding of these components in order to ensure proper equipment operation.

Current

The uniform movement of electrons in a specific direction through a conductor is known as electric current. This current always flows from a point of negative potential (excess of electrons) to a point of positive potential (deficiency of electrons).

Think of water as it moves through a pipe to reach your kitchen faucet. Similarly, electrons move by way of a conductor to its intended load. Imagine a shift of billions upon billions of free electrons throughout the entire length of a conductor at the speed of light. Excess electrons at one end of the conductor force electrons from nearby atoms, causing them to crowd out other electrons and so on. This electron flow principle is illustrated in figure 4–2.

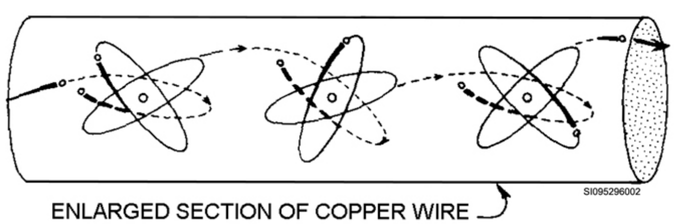

Figure 4–2. Electron movement in a conductor.

We measure current flow by counting the number of electrons that pass a given point in 1 second. The charge of each electron is too small and they are too numerous to count physically. Charles A. de Coulomb, a French scientist, developed a method of counting the electrical charges. He determined that it would take 6,280,000,000,000,000,000 (usually written 6.28×10^{18}) of these charges to make up the unit that is called a Coulomb. As you can see, this is simply a quantity of electrons that is measured in a way similar to the way you measure gallons of water.

The amount of water flowing through a pipe is measured in gpm. One Coulomb unit of charge passing through a given point in a conductor in 1 second is referred to as 1 ampere (amp) of current flowing in the line or conductor. Thus, the unit of measure for current flow is the amp. The symbol for current is “I” (representing *intensity* of current), which is used in math formulas. The symbol “a” or “A” (for quantity of amps) is used on drawings to designate the quantity of amps. An ammeter, or a multimeter using the ammeter function, is used to measure amps or current flow.

The four effects of electrons flowing through an electric circuit are heat, chemical change, magnetism, and physical shock.

Effect	Explanation	Use/Example
Heat	Heat is generated in a current-carrying conductor by the energy required to move the electrons from their atoms and by collisions between electrons that are moving in the circuit.	Use of this effect is made in stoves, control devices, and lights. Electric stoves and heaters flow current through an element with a high resistance, generating heat. Incandescent lamps have a filament that is heated by electron flow until it glows; this produces light.
Chemical change	Chemical change takes place when electrons flow in a solution or circuit.	Oxidation and electrolysis are two examples of chemical change caused by electron flow.
Magnetism	A magnetic field is created around a current-carrying conductor. This magnetic field is totally predictable as to strength and direction if we know the amount and direction of current flow.	Motors, solenoids, and generators make use of this effect of current flow.
Electrical shock	Electrical shock is a possibility when current flows. It is the shock effect in normal day-to-day situations that we wish to eliminate. Current flow is what kills when someone is electrocuted. As little as one-tenth of 1 amp of current can be fatal under certain conditions. This is the reason we continuously stress safety at all levels of electrical work. Thus, you are just as likely to get a fatal shock on low-voltage (house current) circuits as you are on high-voltage distribution circuits.	Shock treatment is used in hospitals to restart normal heart rhythm.

Voltage

Voltage is one of the most important concepts of electronics. To move a sufficient number of electrons from atom to atom throughout a circuit, there must be a force capable of causing the electrons to move. The force that moves the electrons from one atom to another is often referred to as electromotive force (emf), electrical pressure, and potential difference, but is better known as voltage. The basic unit of measure of this electron moving force is the volt. The symbol for voltage when used in a formula is “E,” and the symbol for its quantity (volts) is “V.” The instrument used to measure voltage is the voltmeter.

Sources of voltage

Voltage can be created in many ways. In nature, potential difference is caused by friction when wind blows electrons from one cloud and deposits them on another cloud. When the potential difference (voltage) becomes great enough, a massive amount of electrons may jump from cloud to cloud or from cloud to ground, better known as lightning. There are several main sources of electrical pressure (voltage) which are listed in the tables below.

Type	Source
Chemical action =	Battery
Mechanical =	Generator
Heat =	Thermocouple
Light =	Solar cell
Static =	Friction
Pressure =	Crystals

Source	Explanation
Battery	An electric battery is a device for producing a voltage by chemical reaction. When you connect a battery into a circuit, chemical energy is changed into electrical energy.
Generator	A generator, like a battery, produces a voltage and provides current flow in a circuit. A generator produces voltage by changing mechanical energy to electrical energy. Due to mechanical energy, the rotating conductor intersects magnetic lines of force and produces a voltage.
Thermocouple	A thermocouple is two different metals joined together, such as antimony and bismuth, copper and iron wire, or other unlike materials. When we heat this junction, the heat energy is changed into electrical energy and produces current flow. In each of these cases, we use energy to produce voltage. The post or terminal with an excess of electrons is called the negative terminal and the post or terminal with few electrons is called the positive terminal.
Solar cell	Solar cells, also known as photovoltaics (PV), generate electricity when photons (sunlight particles) reach a semiconducting material such as silicon. As the atoms absorb the light, electrons are forced to move and collect on one side of the PV. This causes an imbalanced charge between the front and back of the cell, similar to a charge between terminals of a battery. This direct current can be used as it is, or it can be converted to alternating current.
Friction	Static electricity is generated by the movement of electrons, which occurs when unlike materials come in contact with each other and are then separated. When two conductors do this, the excess electrons in one will return to the other before separation is complete. Two ungrounded insulators, on the other hand, will become charged (positively and negatively) because excess electrons will become trapped on one when the separation occurs.
Crystals	Voltage produced by pressure is referred to as piezoelectricity (pronounced pē-ā’-zō-electricity). The compression or decompression of certain substances in their crystallized form generates voltage. Some examples include Rochelle salt and quartz. Crystals are used in communications equipment.

Resistance

The movement of electrons (current) and the force that causes those electrons to move (voltage) are just two of the three basic electrical fundamentals. Now, it is time to look at the opposition those electrons encounter as they move through the conductors.

Most materials are in a state of atomic balance. Because of this, these materials are reluctant to give up their electrons. For this reason, some pressure (voltage) is required to move the electrons in even the best conductors. This opposition to current flow that is offered by a material is called *resistance*.

All forms of opposition to current flow are measured or calculated in ohms. This unit of measurement, which was devised by Georg Simon Ohm, states that when 1V of pressure pushes 1 amp of current flow through an electrical path, then 1 ohm of resistance is present. This relationship between the three factors of electricity is referred to as Ohm’s law. We explain the use of this relationship later in this section.

The symbol we use in math formulas to calculate resistance is “R,” and the symbol we use on electrical drawings is the omega (Ω).

There are five factors that affect resistance:

1. Conductor length.

2. Conductor size (cross-sectional thickness).
3. Conductor material.
4. Temperature.
5. Reactance.

Conductor length

The longer the conductor, the more opposition to current flow there is in the electric path (circuit). A longer segment of wire requires more atoms to be influenced by the pressure that moves the electrons.

Conductor size (cross-sectional thickness)

The larger the wire, the less resistance it offers to current flow. This still applies to normal wiring conditions. However, the surface area is the true key to the amount of current that a conductor can carry. Experiments with high-voltage transmission lines that were hollow show that the pipe-type line carries more current than a solid conductor of the same size because the surface area is increased. It is not practical, however, to install smaller distribution systems in this manner. Therefore, for practical wiring situations, assume that a large conductor carries more current (has less resistance) than a smaller wire of the same material.

Conductor material

We mentioned earlier that different materials have different molecular and atomic structures. For this reason, different materials offer different values of resistance. This means that two conductors of the same size (but made up of different materials), such as copper and aluminum, do not have the same resistance. The reason for this is that the number of free electrons in the two materials is not the same. Some materials offer more resistance than others. Nichrome and carbon are materials that offer a little more resistance than conductors. We refer to materials such as these as resistors. Other materials, such as mica and rubber, so effectively stop electron flow that we use them as insulators.

Temperature

The fourth factor that affects resistance is temperature. Normally, as the temperature increases, the resistance increases. In a material, an expansion takes place both in the atoms themselves and in the area that separates the atoms. As the atom is heated, the electrons of the atom are forced out from their particular shell by the heat energy. Because of the increase in distance, the speed of the electrons increases and the likelihood of collisions between electrons increases. When the electrons are forced into this condition, then still more molecular friction and subatomic collisions occur. This increase produces still more heat, more friction, and more collisions. This condition reduces the number of electrons that can effectively be acted upon by the voltage. When you reduce the number of electrons that flow in a circuit, you increase resistance. Thus, current flow is reduced because the resistance increases.

Reactance

Reactance is an opposition to current flow in an AC circuit that is caused either by a capacitor or inductor coils. Reactance does not actually use power in the circuit, but it does cause an “out-of phase” relationship between the voltage and current in the circuit.

Inductive reactance

In a circuit containing inductors (coils), such as transformers and regulators, the “inductive” reactance generated by the magnetic field of the coils causes the current to lag behind the voltage.

Capacitive reactance

The “capacitive” reactance generated as electricity passes through the plates within the capacitor causes the current to lead the voltage in a circuit containing a capacitor.

Because the current and voltage are out of phase, they do not rise and fall at the same time; therefore, their instantaneous values provide less power than if they were in phase. This fact then causes a loss in power to the circuit. This loss is reflected when you compare the true power of the circuit with the apparent power of the circuit.

Reasons for reactance

Since it is necessary to have coils to produce sufficient magnetic force to perform a function (motor, transformer, etc.), you'll have inductive reactance in an AC circuit. You may add capacitors to counteract part of the effect of the coils and cause the current and voltage to move more nearly into phase with each other. At the same time, you are adding resistance to the circuit, thereby reducing the power available to the circuit.

021. Direct current and alternating current

As you learned earlier, current flow is the uniform movement of electrons in a specific direction. The two types of electric current are DC and AC. The main difference in DC and AC voltage is the direction of current flow. If the electrons move in only one direction, you have DC. If they move back and forth along the conductor, you have AC. There are several ways of producing voltage. The most common methods are with the use of chemical energy and with mechanical means.

DC

Batteries provide the major source of DC voltage. Batteries are used in flashlights, cars, emergency lights, and portable electronic devices. Other sources of DC voltage include DC generators and thermocouples. Current moves in one direction from the negative terminal of the source (as on a DC generator or battery), through the circuit, then to the positive terminal in a DC circuit. Figure 4–3 shows how the current flows through a DC circuit. You also see a graphic picture of the waveform. DC voltage is limited in its use. Due to the characteristics inherent in DC, it cannot be transformed to a higher or lower voltage. We cannot send DC over long distances because of the great loss of power.

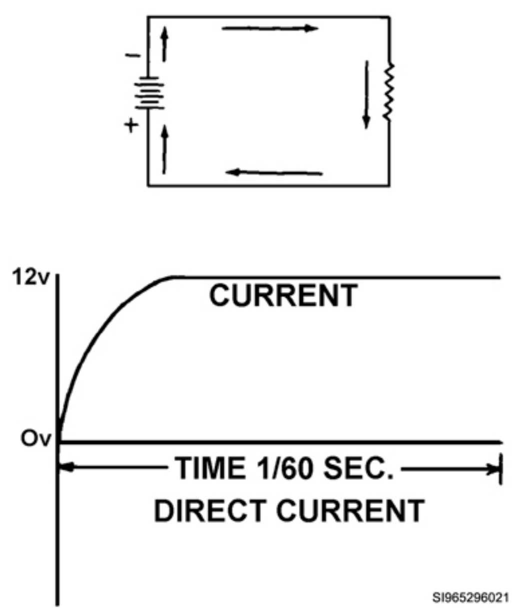

Figure 4–3. DC waveform.

Transforming energy

Changing chemical energy into electrical energy is the method a storage battery or a dry-cell battery employs. A battery stores energy until that energy is needed. As you can see in figure 4–4, there are two basic cells: the wet cell shown on the left and the dry cell shown on the right.

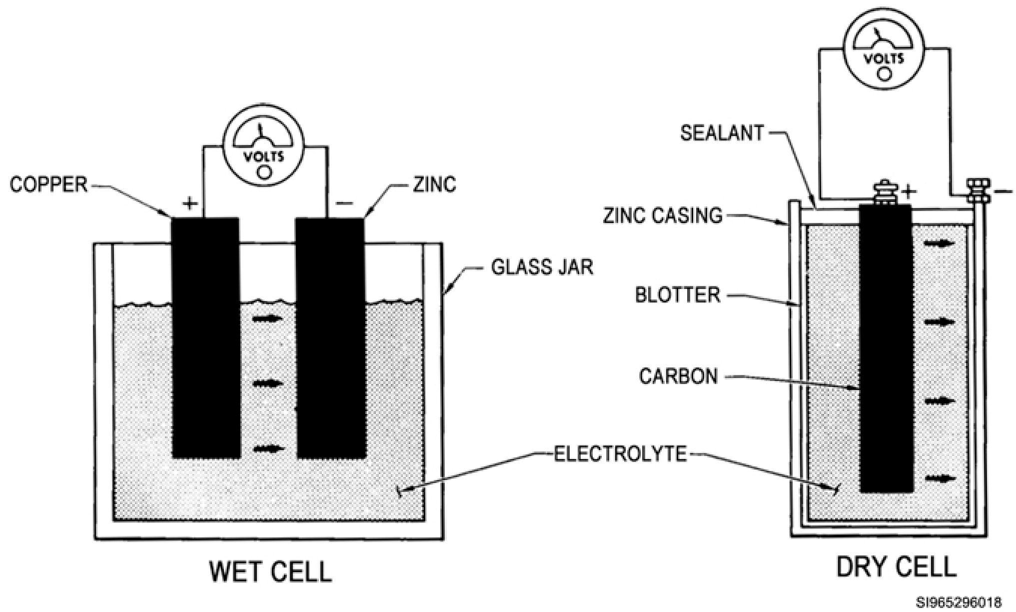

Figure 4–4. Elementary battery cells.

Chemical reaction

When you place two unlike materials (they could be different metals or metal and carbon) in a solution called an electrolyte, the chemical reaction on one is greater than it is on the other. This reaction is a chemical interaction between the electrons of the two metals. While this chemical reaction takes place, a difference of potential is developed between the two materials and a voltage is produced. If you place a conductor between the two metals, electrons flow from one metal plate to the other. The arrows in figure 4–4 show the flow of electrons, and the difference in potential is shown in the meter connected across the two wires.

Cell or battery

We use the terms *cell* and *battery* to mean the same thing. Cells are divided into two general types—primary and secondary. The most common primary cell is a dry cell like the one shown on the right side of figure 4–4. An example of this is a flashlight battery. Once a primary cell is discharged, it is useless. On the other hand, a secondary cell can be recharged. An example of a secondary cell (storage battery) is the battery in a car.

AC

The characteristics of AC and DC circuits are quite different. AC changes its flow first in one direction and then in the other direction. All of this occurs at regular intervals. Figure 4–5 shows how the current flows through a circuit. Note the graphic picture of the waveform.

All generators produce a form of wavering or AC. Figure 4–6 shows the two types of generator construction. In figure 4–6A, note the use of slip rings to produce AC voltage. In figure 4–6B, note the use of a commutator to produce DC voltage.

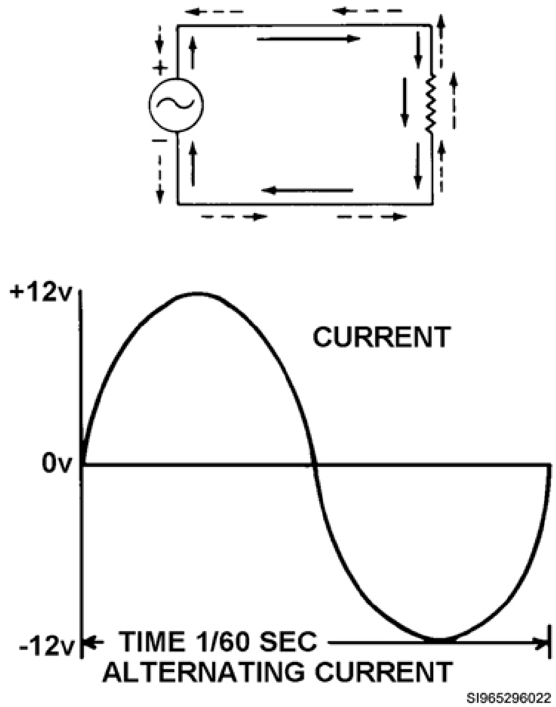

Figure 4–5. AC waveform.

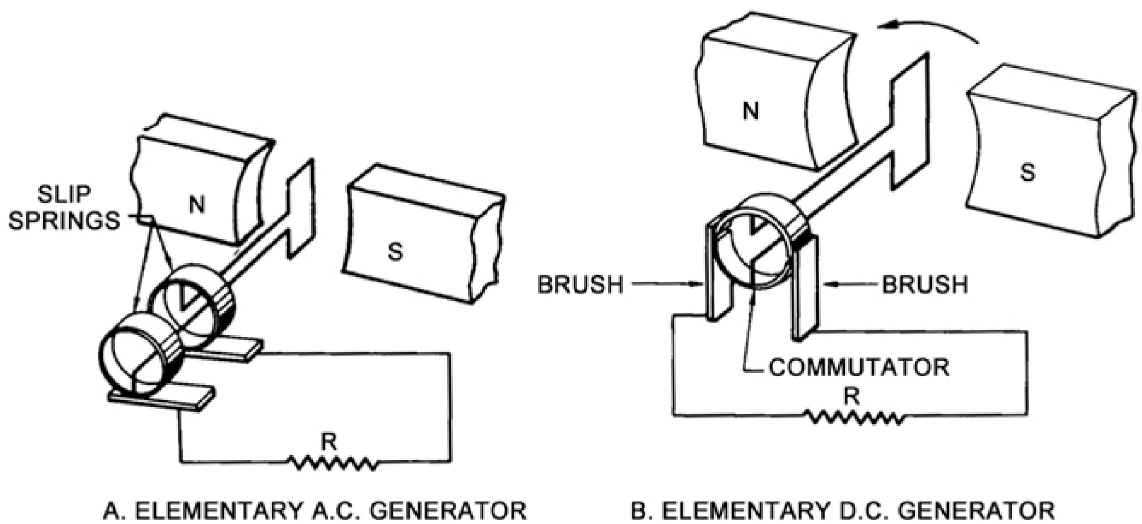

Figure 4–6. Elementary generators.

AC generators are the major source of AC voltage. You can send the power supplied over great distances without too much loss of power. You use AC voltage to light your house and to run your appliances. The generator changes mechanical energy to electrical energy by the principle of electromagnetic induction. For this type of voltage production, three things are required: (1) a magnetic field, (2) a conductor, and (3) relative motion. Voltage and current are produced when a conductor cuts the magnetic field of a magnet. This is shown in figure 4–7.

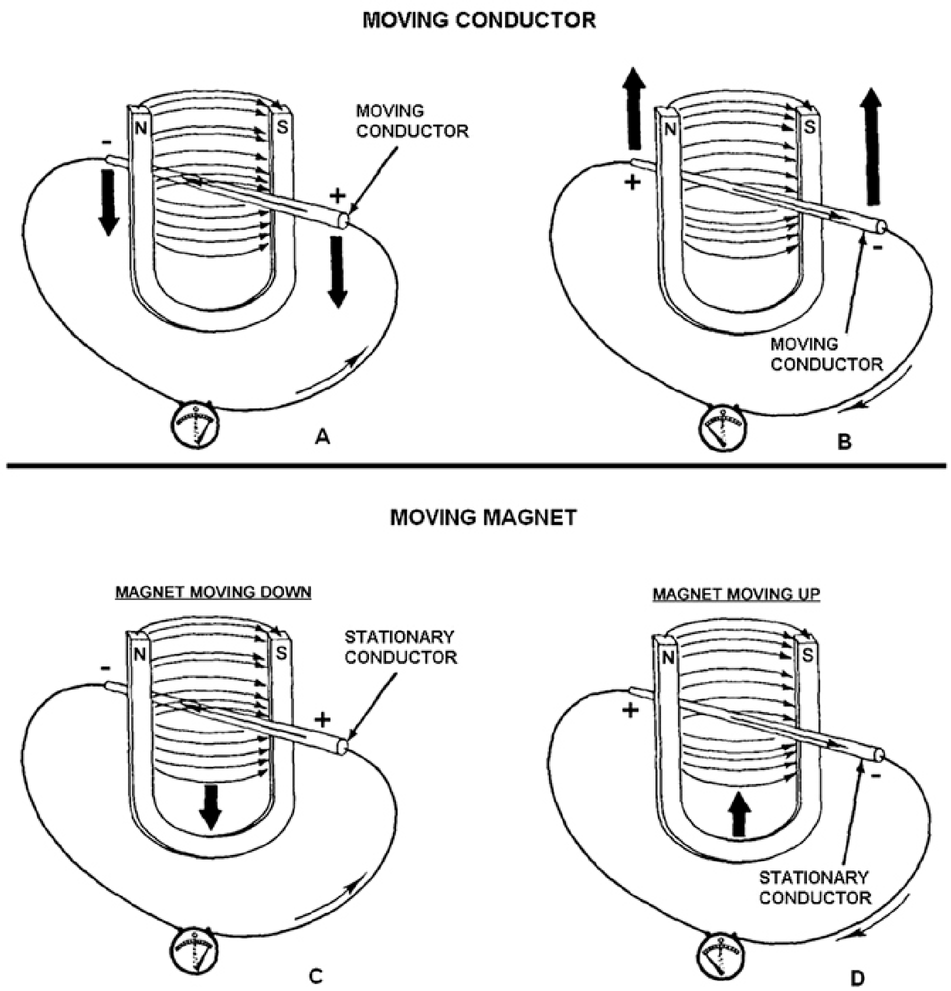

Figure 4–7. Electromagnetic induction.

As you can see in these figures, the conductor is hooked up to a meter, which you use to read a small voltage change. In figure 4–7A, the conductor is moved down in a horseshoe magnet, and the meter moves to show voltage. If the conductor stops at any point in the magnet, the meter returns to zero, and a voltage no longer exists. If the conductor is moved up, as in figure 4–7B, the meter shows that a voltage of the opposite polarity is produced. The same effects can be achieved by moving the magnet, as we show in figure 4–7C and D.

022. Interpreting electrical schematics and diagrams

Identifying and following routes are essential to knowing your WFSM systems. Just like following a pipeline to get to your destination, the electricity follows a route too. To figure out what is wrong with a device, you also must know the route of it. Here we will discuss symbols, how to read a legend, and some characteristics of electrical diagrams.

Symbols

The location of outlets, switches, fixtures, and so forth is shown on an electrical floor plan by means of pictures that represent the actual device. These pictures are called symbols and are standardized for ease of understanding by those who make the drawings for those who read the drawings. A set of standardized symbols, put out by the ANSI, is used for electrical blueprints and drawings. A few of the more common symbols you will see and use are shown in figures 4–8 and 4–9. You should learn these symbols and be able to associate each symbol with the wiring device it represents.

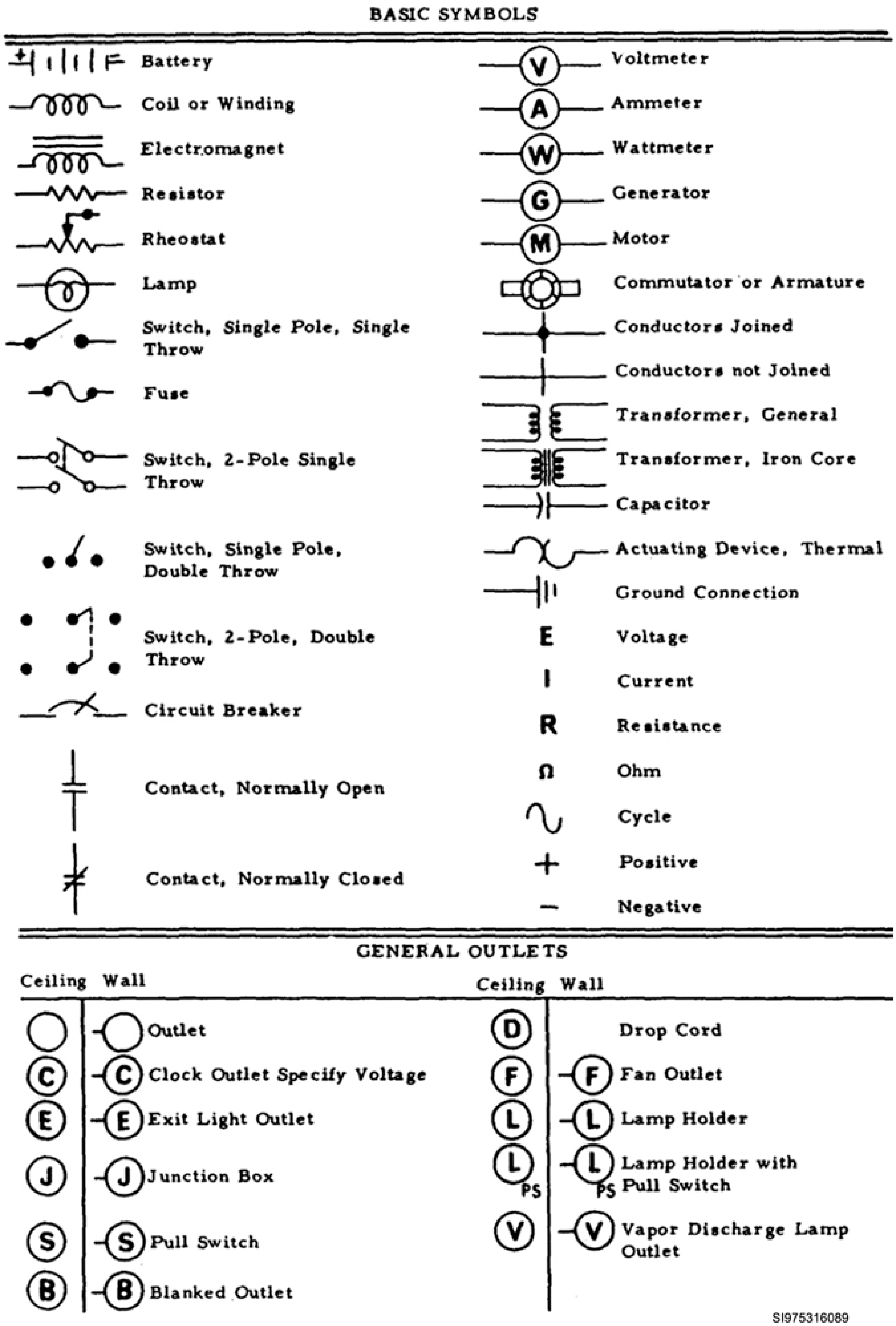

Figure 4–8. Symbols.

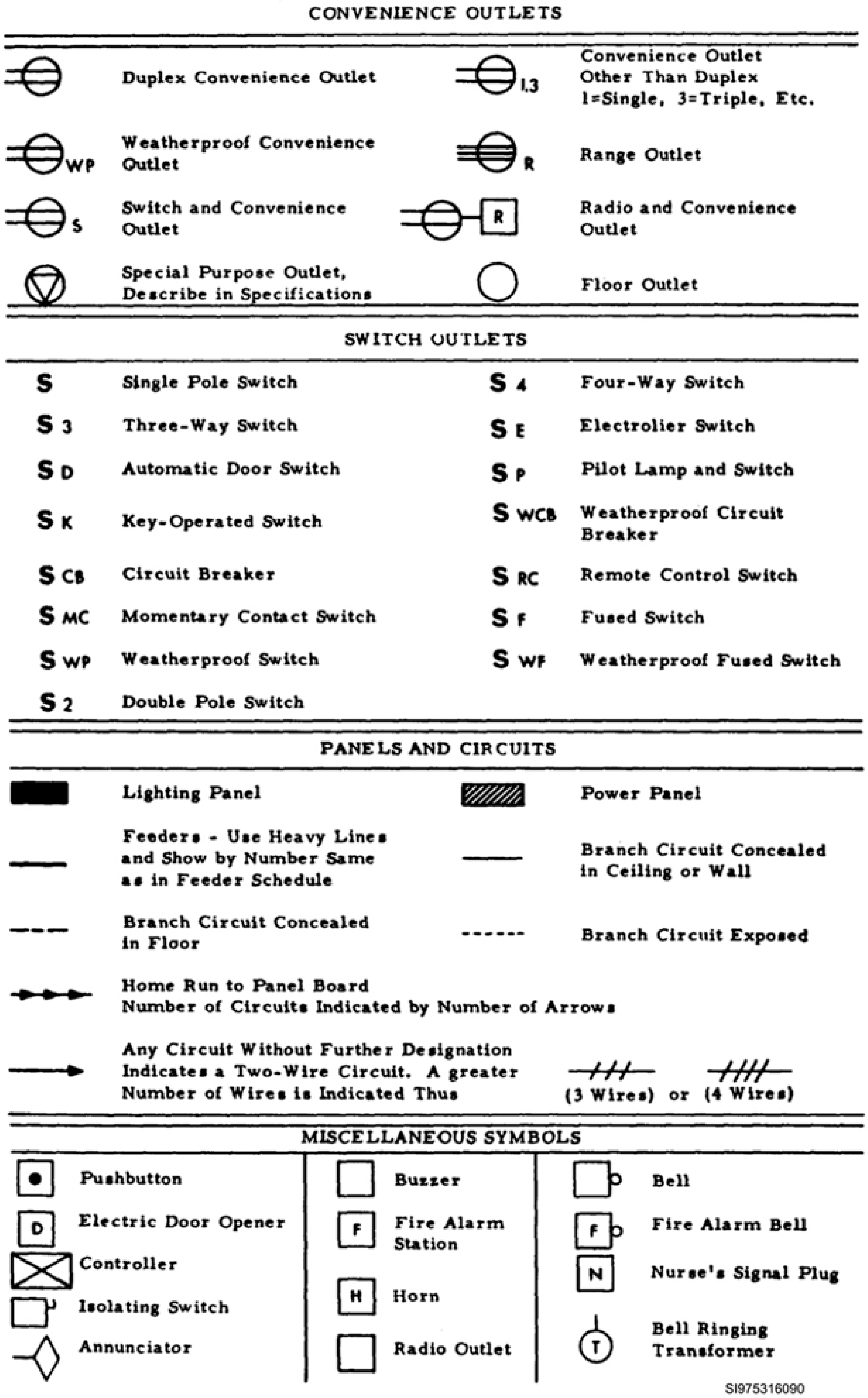

Figure 4–9. Symbols (cont'd).

Legends and specifications

Legends used with floor plans or other drawings are a clarification of the symbols used on that particular drawing. The legend helps other workers, who may not be familiar with electrical symbols, determine where outlets and switches will be installed. Specifications are also a vital part of a set of drawings. They are used to clarify information shown on the drawings. They are written instructions that pertain to the materials that will be used to complete the job. Some of the things included in the specifications may be types and kinds of materials, dimensions, colors, quality, finishes, and other details. “Specs” also give a running account of the installation of the equipment on a job.

Characteristics of electrical diagrams

A diagram is defined as a line drawing that shows arrangement or relationship of parts. Electrical diagrams are usually used to show how parts of a piece of equipment or several pieces of equipment are wired together.

As shown in figure 4–10, there are basically four types of electrical diagrams: block, wiring, connection, and schematic. These diagrams are similar to each other and their names are sometimes used interchangeably, although they do have differences.

Block diagram

A block diagram is a simple drawing showing the relationship of major parts of a system. Figure 4–10A shows a block diagram of a motor control system. You can easily see why it is called a block diagram. The parts or components in any block diagram are just as they appear in this drawing, as blocks. They are connected by a line or lines that show the relationship of the parts. Block diagrams are used often to explain power distribution systems. The internal connections of the components are not shown in these drawings. The blocks are simply labeled to show what each represents. These drawings would be of little help for troubleshooting.

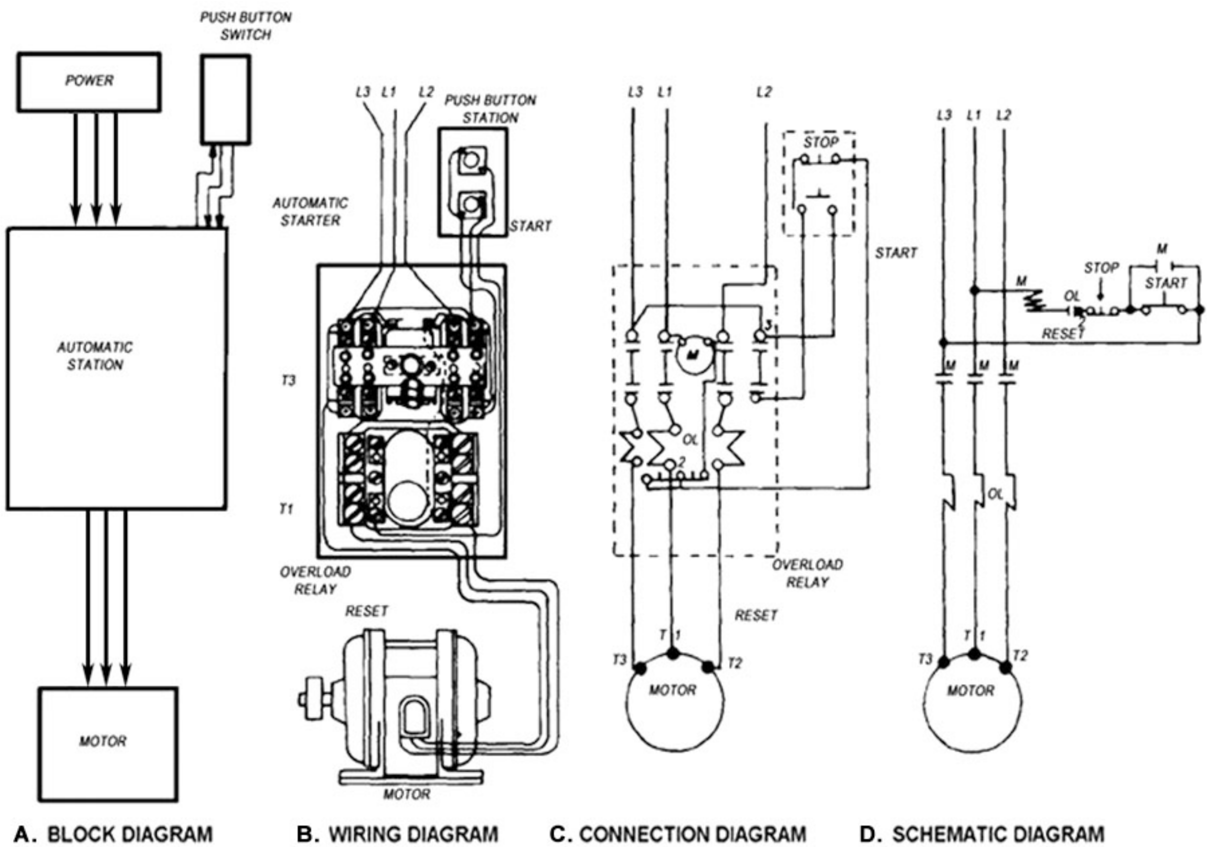

Figure 4–10. Electrical diagrams.

Wiring diagram

Figure 4–10B shows a wiring diagram of the same motor control system shown by the block diagram. The wiring diagram uses pictures of components instead of blocks and shows the wiring between components and the relative position of those components. You can also see that the lines used to show the wiring is marked numerically or alphanumerically. Lines L1, L2, and L3 are incoming power leads, and the diagram shows which terminals they are connected to in the starter. Wiring diagrams are used often with a list of repair parts and can be used to do some troubleshooting.

Connection diagram

Figure 4–10C depicts a connection diagram. In the connection diagram, the components are still shown in their relative positions, but it makes use of diagram symbols instead of pictures to show components. It also shows all the internal and external circuit connections, and these can be read and traced more easily than on the wiring diagram. This diagram can be used to help you connect all the wiring and trace any part of the circuit, which makes it a very valuable troubleshooting tool. It is often found inside the cover of a piece of equipment.

Schematic diagram

The schematic diagram is a drawing that shows the electrical plan of operation of a piece of equipment or component. The relative position of parts is not shown in this type of diagram. The schematic diagram, like the connection diagram, makes use of symbols instead of pictures. The schematic shown in figure 4–10D is of the same motor control system shown in the other three diagrams. It is laid out so that the components are in line to make it easy to trace the connections. Notice the use of heavy and light lines in the drawing. In this case, the heavy lines show the main power circuit, and the light lines show the control circuit. The schematic is sometimes called an elementary or one-line diagram and is very useful in troubleshooting or tracing the plan of operation.

Since we are not electricians, interpreting electrical schematics and diagrams by no means is an easy task. Reviewing these documents with an experienced coworker or supervisor is the best way to learn. Even the experienced WFSM worker may need help. Anyone who is in need of help troubleshooting a circuit or reading electrical schematics should also enlist the help of an electrician.

Self-Test Questions

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

019. Electron theory and electricity

1. How are all atoms similarly constructed?

2. What type of charge does a proton carry? An electron?

3. What gives an atom its neutral balance?

4. How many electrons does a copper atom have in its outer shell?

5. What are free electrons and how do they give us electrical energy?

6. What is an atom that has gained an electron called?

7. What type of charge does a normal atom have when it has lost one electron?

8. Identify the materials that are good insulators by placing an *I* in the correct space and the materials that are good conductors by placing a *C* in the correct space.

____a. Rubber.
____b. Aluminum.
____c. Dry air.
____d. Iron.
____e. Copper.
____f. Glass.
____g. Mercury.
____h. Silver.
____i. Mica.

020. Main components of electricity

1. Write the word or words that are appropriate to the given definition or statement.

   a. The uniform movement of free electrons in a specific direction through a conductor.

   b. 6.28×10^{18} electrical charges.

   c. One coulomb passing a given point per second.

   d. Symbol for current (amps) used in math formulas.

   e. Symbol for amps on drawings.

2. List four effects of current flow.

3. Provide the term appropriate to each of the following definitions or phrases.

   a. Unit of measure for “electrical pressure.”

   b. The force that causes electrons to move from atom to atom.

   c. Symbol for voltage in a math formula.

   d. Changes mechanical energy into electrical energy.

   e. Changes heat energy into electrical energy.

4. Give the terms that apply to the definitions or phrases below.

   a. Unit of measure for all forms of opposition to current flow.

   b. When 1V of pressure pushes 1 amp of current flow through an electrical path, then 1 ohm of resistance is present.

   c. Symbol for resistance in a math formula.

5. Name five factors that affect resistance.

021. Direct current and alternating current

1. Identify each of the statements below as applying to AC voltage or DC voltage by writing “AC” and/or “DC” in the space provided.

   ____a. Cannot be transformed to a higher or lower voltage.
   ____b. Current changes flow.
   ____c. Electrons flowing in one direction.
   ____d. Common household electricity.
   ____e. Slip rings used in a generator produce it.
   ____f. Produced by a battery.

2. How is voltage and current produced?

022. Interpreting electrical schematics and diagrams

1. Who standardized the symbols used on electrical blueprints and drawings?

2. What are the functions of legends and specifications on blueprints, drawings, and plans?

3. What kind of electrical diagram shows the relationship of parts by using lines?

4. Describe a wiring diagram.

5. Describe a connection diagram.

6. What kind of electrical drawing is laid out so that the components are in-line in order to trace the connections easier?

4–2. Circuit Testing

Previously in 3E451A, volume 1, unit 2, you learned about electrical safety, hazards, and first aid. Occasionally, you may have to disconnect a motor and have it serviced, replace a solenoid on an automatic valve, or troubleshoot a circuit. Before you begin, you must know how to perform electrical checks with the right test equipment.

023. Using a multimeter

There are many different types of multimeters, but all of them serve basically the same purpose. Getting used to using one takes time, but it is one of the most valuable tools in your toolbox.

A few more electrical safety rules

As you have learned, one of the hazards you encounter on your job is that posed by electricity. If you are not careful, you can be seriously hurt or killed by it. Do not believe that only high voltage kills. Many people have been killed when they were exposed to 120V house current, and others have been killed by even lower voltage. Yet others have experienced shock from both low and high voltages and suffered no injury. Since you never know what your body resistance is, always remove all jewelry and if possible avoid contact with any live circuit, especially when your body is wet (i.e., sweating profusely). Your body will offer less resistance to electrical shock when you are wet than when you are dry. Working with electricity around fuel systems only compounds the dangers. So a healthy respect and vigilance is needed.

Once again, treat all electrical circuits as being live until you have checked the circuit yourself and know it is deactivated and have followed the proper lock-out/tag-out procedures. Also, check the schematics to determine whether the circuit can be energized at a secondary location, and take steps to prevent this from happening.

Multimeter components and functions

Multimeters are the primary tool used when we are tasked to perform work with any component that uses electricity in our systems. You will also need to know how to check for the proper voltage (V), current flow (amperage, amps), and amount of resistance (ohms) to determine whether the wiring, power supply or the component itself is defective. Never underestimate the power of electricity or the damage it could cause to your body. Remember, as little as 100 milliamperes (mil amp) can kill you. The life you save may be your own! It is important that you become thoroughly familiar with the multimeter and other test equipment in your shop in order to perform electrical checks proficiently and safely.

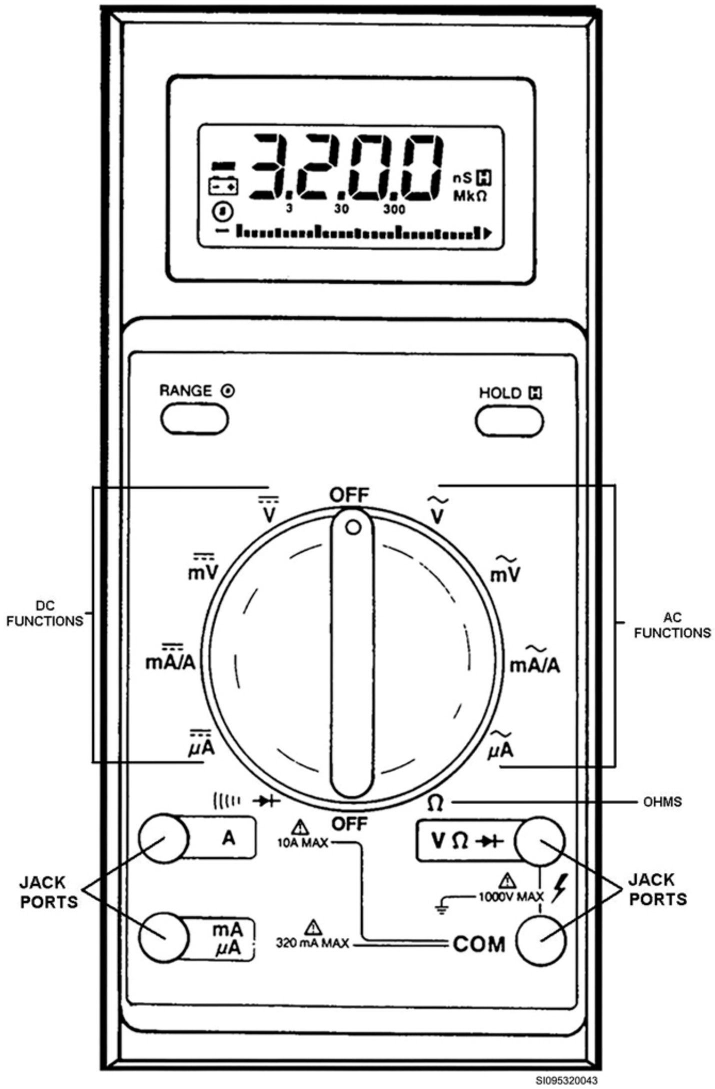

Figure 4–11. Fluke 8025A multimeter.

There are many different types of multimeters, but all of them serve basically the same purpose. All multimeters consist of a meter coil, a means of selecting a function (AC, DC, mil amp, etc.), a means of selecting the range or scale of measurement (0.5 to 1,000), and a scale, which shows the value of measurement.

One common multimeter that the AF has used for years is the "8025A Multimeter." This multimeter (fig. 4–11) is three meters in one. It is an ohmmeter, a voltmeter (AC and DC), and an ammeter, but it can be used for only one function at a time. Before the multimeter came along, you needed all three separate meters to check for V, amps, and ohms. Now, multimeters have a single rotary switch which is used to select the function the multimeter is to perform. The rotary switch in the center panel has 12 positions: two OFF positions, four DC functions, four AC functions, one for ohms (Ω), and one for continuity (→+).

This meter comes with a red test lead (positive) with a metal probe end and a black teat lead (negative) also with a metal probe end. As you can see in figure 4–11, the meter has two jack ports on the lower left-hand side of the front panel and two jack ports on the lower right hand side. To prepare the meter for use, insert the black lead in the common (COM) jack and the red lead into any of the other three jacks depending on the test. The most important safety precaution when using a multimeter is to never touch the metal probes of either test lead when testing a live circuit.

Checking for proper voltage

A voltmeters or the voltmeter function of a multimeter are used to check the potential difference between two points (voltage) on AC and DC circuits. The reading on a voltmeter scale indicates applied voltage (electrical pressure). Remove all jewelry.

When you use this meter as a DC voltmeter on DC circuits or batteries, you turn the function switch to the DC “V” or “mV” (millivolt) functions, depending on the voltage expected. Next, insert the black lead in the “COM” port and the red lead in the “V Ω →+” port. Finally, connect the black probe end to the wire or negative post of the battery, and the red probe end to a grounding connection or the positive post of the battery to get your DC voltage reading.

When you use the meter as an AC voltmeter, turn the function switch to the AC “V” or “mV” function and insert the black lead in the “COM” port and the red lead in the “V Ω →+” port. Select the correct scale range when the value is known. If the value is not known, you should always select the highest range. This is a safety precaution that will protect you and prevent overload damage to the meter. Be very careful because the meter could blow up. On an AC circuit, you will be connecting the leads to the circuit in parallel. “In parallel” means that you do ***not*** have to open the circuit to connect the multimeter between two wires or connections.

A three-phase motor has three “legs” or “phases” of power connected to it. To check for proper voltage on a three-phase motor, first, open the door to the switch box (fig. 4–12). In most boxes, you cannot open the switch box door unless the power is turned off first. Having selected the proper scale and zeroed the meter, turn the power back on and put the black (negative) lead probe on the ground connection. Next, put the red (positive) lead probe on the three “hot” legs one at a time. If each leg is supposed to have 120V, a voltage measurement of less than + or – 10 percent is acceptable (more than 110V or less than 130V). A very big loss of or gain in voltage or a “zero” reading (missing a leg) of any phase in a motor switch box is indicative of trouble that could reduce the service life of the motor. A three-phase motor, for example, will not run normal when it is missing a leg or phase. You can expect a three-phase motor to “groan” or make quite a bit of noise if it is missing a leg.

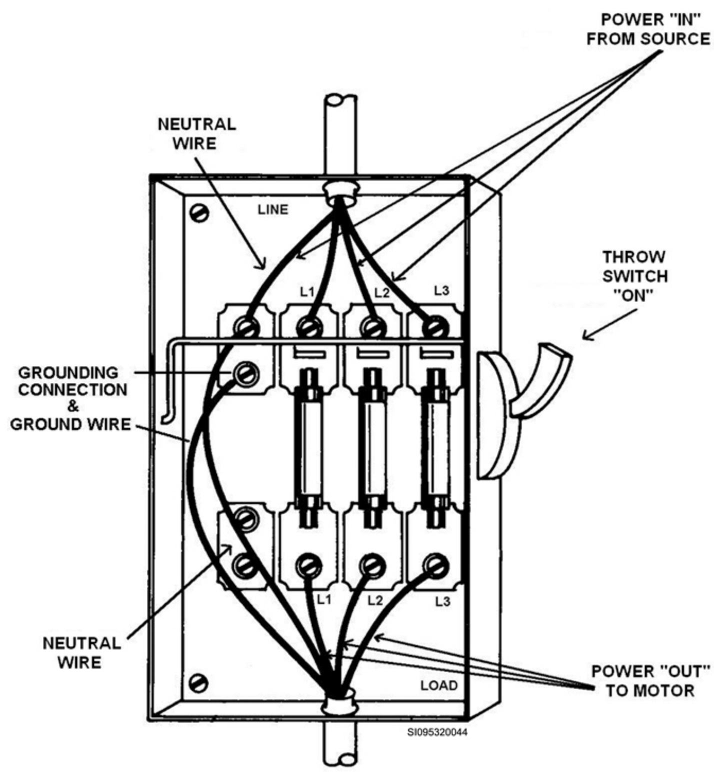

Figure 4–12. Safety fused switch.

Another acceptable method to measure voltage is to compare the voltage between the legs. To do this, you put the black probe on one leg and the red probe on another. The voltage measured should be the sum of both legs together (+ or – 10 percent). If the expected voltage measurement is not obtained, you will have to test each leg separately to find which one is inaccurate.

NOTE: Never check for voltage across a fuse. If you do so and the fuse is blown, your meter now becomes the conductor and you could break the meter and injure yourself.

Remember, never use your meter as a voltmeter on a source of voltage that exceeds its calibrated scale. When the voltage is unknown, always use the highest voltage range to protect your meter and yourself. When you use this meter as a voltmeter near high voltage, connect the meter to the circuit before turning on the power. *Do not* touch the meter leads while power is on in the circuit being measured.

Checking for resistance

Ohmmeters are used to check the resistance of a unit or a circuit. In terms of electricity, you can think of resistance as a break or obstruction in wiring. Any obstruction in the path of electricity (resistance) will cause the electrical unit to fail or work inefficiently. For example, a wire that has somehow become corroded over the years would show a high resistance because it is harder for the electricity to flow *through* the corroded area of that wire. Depending on the degree of corrosion, that same wire would show a proportionate increase in ohms resistance. Ohmmeters have the most value for us because we normally only check for good fuses. You can check a fuse's *continuity* using a multimeter (selected to ohms). Be sure to disconnect power and remove the fuse from the circuit before attempting this. A reading of zero Ω across a fuse is indicative of no resistance and a good fuse. A reading of infinity (∞) across a fuse indicates a break in continuity (a broken wire) or a bad fuse.

When testing for resistance, set the function switch to the Ω position. Before taking a measurement, zero the meter by touching the red and black test leads together. The display should read zero Ω. This indicates that your meter, internal battery, and test leads are all serviceable.

WARNING: DO NOT test the resistance of an energized circuit. This could lead to the damage and possible explosion of the multimeter and injury to you.

Isolate the unit of resistance to be tested by disconnecting at least one lead from the rest of the circuit. This prevents the meter from measuring the resistance of the rest of the circuit instead of your resistance unit. Make sure your meter leads make good contact with the unit of resistance leads. Remove any dirt, grease, varnish, or paint, or any other material on the unit of resistance leads that may prevent current flow. Keep your hands on the insulated part of the meter test leads. If you touch the leads, your body resistance will distort your ohmmeter reading. When you have finished using this meter as an ohmmeter, move the function switch to one of the OFF positions to preserve the internal battery.

Checking for proper current flow

Ammeters are used to check the current flow of a unit or a circuit. 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 including the multimeter you can use to measure current flow, but the simplest and easiest meter to use is the clamp-on ammeter meter. The clamp-on type ammeter (fig. 4–13) is easier to use because you do not have to interrupt the circuit to connect the meter "in series" in order to take the current readings. You simply clamp the meter end around a circuit leg. By using this meter to check the legs of a three-phase system, you can verify that each phase is drawing the same amount of current to the motor. Should one phase reading be different from the other two, you know that the system is out of balance. This identifies potential trouble.

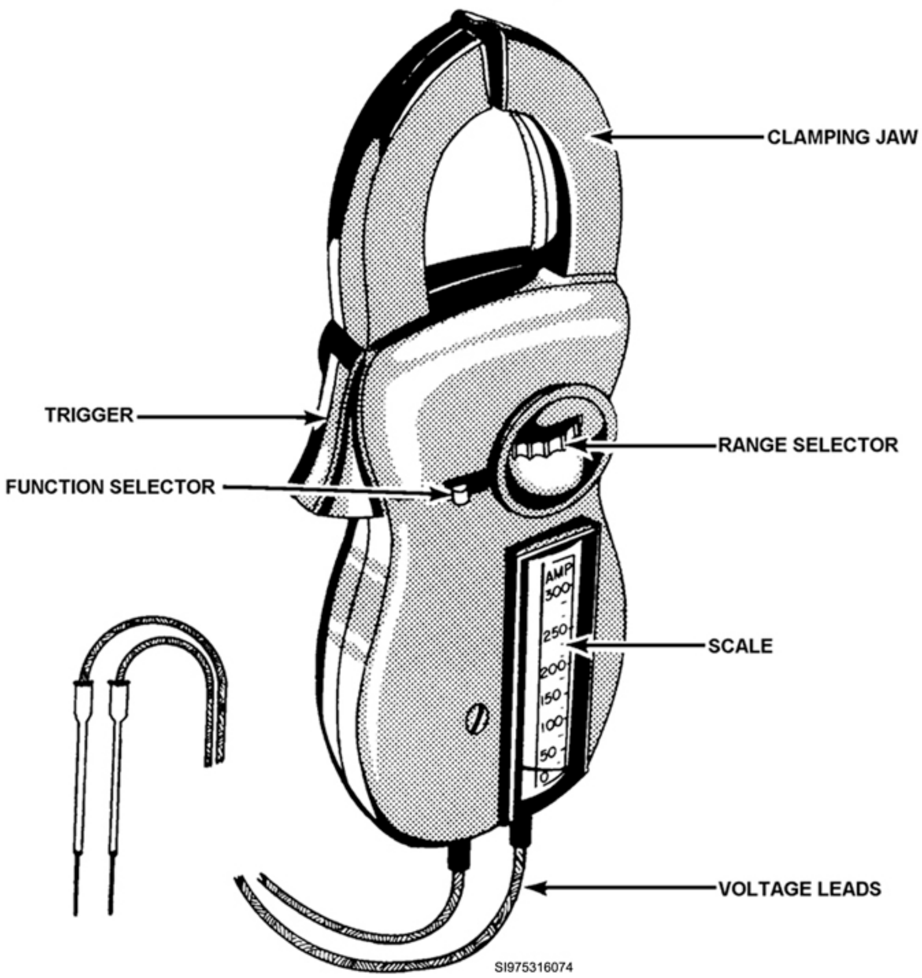

Figure 4–13. Volt-amp multimeter.

Checking for proper current flow becomes especially critical for a three-phase motor that can cost several thousands of dollars to replace. We can compare the amp readings of each leg to the amperage limits listed on the motor's data plate. A motor that is drawing more amps than normal (under load) would indicate potential trouble. A few causes of abnormal motor amperage are:

- Worn out motor bearings due to improper lubrication.
- Pump bearings going bad or a flow restriction such as a partially closed valve.
- A change in the load for which it was intended (pump attached to motor used to pump JP–8 now pumping a thicker product).
- Potential motor windings problems.

Of course, there are many more causes of abnormal amperage. You need to remember that higher or lower than normal amperage on a motor indicates potential trouble.

When you take current readings using the clamp-on meter, move the selector switch to the desired amperage range (fig. 4–14). If the current is unknown, set the range selector to the highest setting, which, on this meter, is 1,000 amps.

Connect your clamp-on meter in a circuit as shown in figure 4–14. Squeeze the trigger assembly to open the clamping jaws. Place the open jaws around one of the circuit leads. Close the jaws.

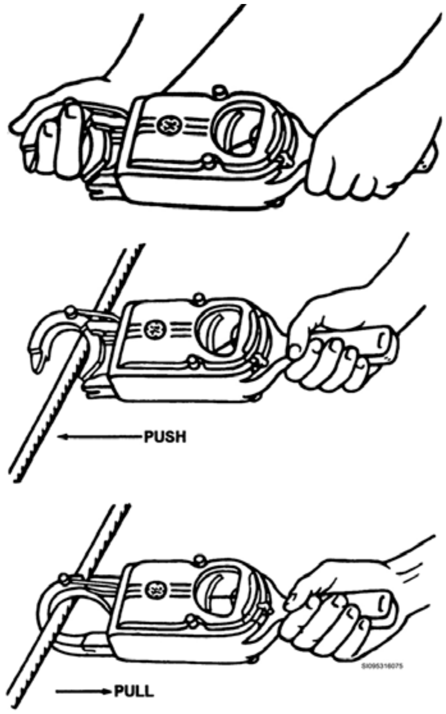

Figure 4–14. Proper procedure for using a clamp-on multimeter.

NOTE: Check only one conductor at a time. If the jaws encircle two phases, their magnetic fields cancel out and you get an inaccurate reading.

If the reading is below that of the next scale, remove the meter from the line and adjust the selector down. Take another reading. Continue this until you reach a readable level.

When you are taking measurements, hold the meter *only* by the handgrip. Make sure the jaws of the meter are closed properly and never allow an energized bare wire to touch the metal surfaces of the jaws.

Self-Test Questions

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

023. Using a multimeter

1. What are the different meters that make up a multimeter?

2. What are voltmeters used to check?

3. When you read a voltmeter, what does the reading on the scale indicate?

4. When you use a voltmeter, what range should you use first if the value is not known?

5. What does a very big gain or loss of voltage in any leg of a three-phase motor indicate?

6. What are ohmmeters used to check?

7. When testing a fuse or a wire, what does a reading of zero Ω indicate?

8. What must you do to the ohmmeter or multimeter before taking an Ω measurement?

9. When testing for Ω, what must you remove from the unit being tested that may prevent the leads from making good contact?

10. What is an ammeter used to check and which type is the easiest to use?

11. What are some causes of abnormal motor amperage?

12. When using a clamp-on meter and the current you want to measure is unknown, at what setting should you set the range selector?

13. What happens when you try to check two legs of a circuit with a clamp-on ammeter?

Answers to Self-Test Questions

019

1. With a central nucleus and orbiting electrons.
2. Protons are positive. Electrons are negative.
3. An equal number of protons and electrons.
4. One.
5. Electrons that can be easily taken from an atom’s outer shell; it is the movement or displacement of free electrons that give us electrical energy.
6. Negative ion.

7. Positive.
8. a. I.
   b. C.
   c. I.
   d. C.
   e. C.
   f. I.
   g. C.
   h. C
   i. I.

020

1. a. Current flow.
   b. Coulomb.
   c. Ampere.
   d. I.
   e. A or a.
2. (1) Heat, (2) chemical change, (3) magnetism, and (4) electrical shock.
3. a. Volt.
   b. Electromotive force, electrical pressure, potential difference, or voltage.
   c. E.
   d. Generator.
   e. Thermocouple.
4. a. Ohm.
   b. Ohm's law.
   c. R.
5. (1) Conductor length, (2) conductor size, (3) conductor material, (4) temperature, and (5) reactance.

021

1. a. DC.
   b. AC.
   c. DC.
   d. AC
   e. AC.
   f. DC.
2. In cycles per second, hertz per second or simply hertz.

022

1. The ANSI.
2. They help the reader determine the location of objects and clarify information shown on them.
3. Block diagram.
4. A wiring diagram uses pictures of components instead of blocks and shows the wiring between those components.
5. A connection diagram shows the components in their relative positions, but it makes use of diagram symbols instead of pictures to show components. It also shows internal and external circuit connections.
6. A schematic diagram.

023

1. An ohmmeter, a voltmeter (AC and DC), and an ammeter.
2. The potential difference between two points (voltage) on AC and DC circuits.
3. Applied voltage.
4. Always select the highest range.
5. It is an indication of trouble that could reduce the service live of the motor.
6. The resistance of a unit or a circuit.
7. No resistance, a good fuse or wire.
8. Zero the meter by touching the two test leads together.
9. Grease, varnish, paint.
10. Current flow in a circuit; clamp-on.
11. Worn out motor bearings, pump bearing going bad or flow restriction, a change in the load for which it was intended or potential motor winding problems.
12. Highest range first.
13. Their magnetic fields cancel out and you get an inaccurate reading.

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).

53. (019) According to the electron theory, atoms are composed of
    a. neutrons, electrons, and matter.
    b. neutrons, elements, and protons.
    c. electrons, protons, and neutrons.
    d. electrons, molecules, and elements.

54. (019) In electricity, which shell contributes *all* electrical properties of an atom?
    a. Outermost.
    b. Middle.
    c. Second.
    d. First.

55. (019) A positive ion is *best* described as an atom that
    a. has an equal number of electrons and protons.
    b. has lost an electron and has more protons.
    c. has lost a proton and has more electrons.
    d. cannot throw off any protons.

56. (019) A material that permits a large number of free electrons to move through it is called
    a. an insulator.
    b. a conductor.
    c. a resistor.
    d. an ion.

57. (020) The uniform movement of electrons in a specific direction is called
    a. ionization.
    b. free electrons.
    c. electric current.
    d. electrical potential.

58. (020) Which of these is the *smallest* current that can be fatal under certain conditions?
    a. $^1/_2$ of 1 ampere (amp).
    b. $^1/_3$ of 1 amp.
    c. $^1/_8$ of 1 amp.
    d. $^1/_{10}$ of 1 amp.

59. (020) What is used to move a sufficient number of electrons from atom to atom?
    a. Heat.
    b. Current.
    c. Voltage.
    d. Inductance.

60. (020) What *normally* causes the resistance of a conductor to increase?
    a. Increase in size.
    b. Decrease in length.
    c. Increase in temperature.
    d. Decrease in temperature.

61. (021) What are the two *most common* methods of producing voltage?
    a. Chemical energy and mechanical means.
    b. Magnetic induction and mechanical means.
    c. Magnetic induction and heat energy.
    d. Chemical and heat energy.

62. (021) What are the three things needed to produce voltage by the principle of electromagnetic induction?
    a. Coil, core, and current.
    b. Magnet, housing, and prime mover.
    c. Coil, conductors, and relative motion.
    d. Magnetic field, conductor, and relative motion.

63. (022) Which *best* describes a schematic diagram?
    a. Used to show the wiring is marked numerically and alphanumerically.
    b. Sometimes called a one-line diagram and is very useful in troubleshooting.
    c. Can be used to help you connect all the wiring and trace any part of a circuit.
    d. Internal connections are not shown and would be of little help in troubleshooting.

64. (023) The *most* important safety precaution you should apply when using a multimeter is to
    a. select the correct scale.
    b. always adjust your meter to zero.
    c. always observe polarity when using the alternating current (AC) meter.
    d. never touch the metal probes of either test lead while the circuit is energized.

65. (023) The reading on a voltmeter indicates
    a. current draw (flow).
    b. electrical pressure.
    c. specific capacity.
    d. resistance.

66. (023) Ohmmeters are used to check for
    a. current draw (flow).
    b. electrical pressure.
    c. specific capacity.
    d. resistance.

67. (023) Before taking a measurement when you are using your multimeter in the ohmmeter function, what is the *first* thing you should do?
    a. Move the selector knob to higher ranges for a better reading.
    b. Touch the black and red leads together to zero the meter.
    c. Keep your hands on the bare metal portion of the leads.
    d. Connect the meter in series with the circuit.

68. (023) The easiest and simplest meter to use to measure current flow in a circuit is
    a. a voltmeter.
    b. an ohmmeter.
    c. a manometer.
    d. a clamp-on ammeter.

Please read the unit menu for unit 5 and continue ➔

Unit 5. Motors and Controls

INSTALLING AND MAINTAINING motors and motor controls is an important part of your job. In this unit, you will learn about the components and operation for motors and motor controls. You will also learn how to install, maintain, inspect, and troubleshoot these components and their electrical circuitry.

5–1. Motors

In our automated world, we take for granted one of the most efficient devices ever invented—the electric motor. Almost all industries, and most residences, use motors in some way or another. An electric motor is simply a rotating machine that converts electrical energy into mechanical energy. Nearly all motors are designed to meet the requirements of a specific function. All electric motors fall into these basic types—DC and AC.

Since we deal mostly with AC motors, we will discuss DC motors very briefly and then move on to the most widely used AC motors you will see in your career. The material presented should give you the basis for performing inspections, maintenance and troubleshooting most motors and controls.

024. Direct current motors

On military installations, DC motors are used only if AC voltage is unavailable or where a wide range of speed control is desired. As a result, it is likely that you will have very little contact with DC motors on most military installations, but they are still used for certain applications. Motors that are specifically designed to run on DC current are constructed differently from AC motors.

Components

The main parts of a DC motor are the armature, the frame, and the endbells. Each of these components contains subassemblies that are essential for the proper operation of the motor. Figure 5–1 shows the three main parts mentioned above, along with other components typically found on DC motors. Motors are mounted on (or with) some type of a base, bracket, or platform, which is usually adjustable to some degree to allow for proper alignment with the driven load.

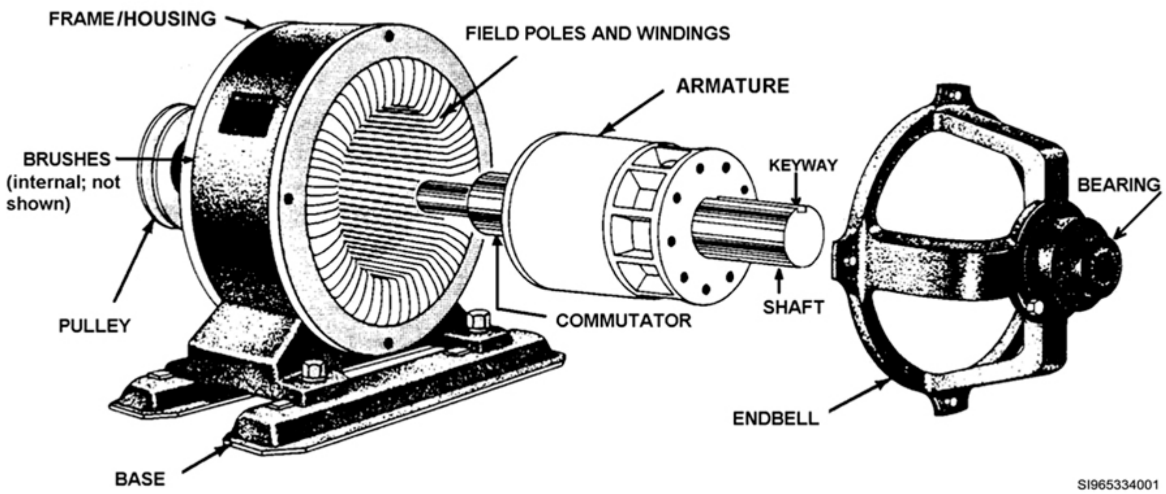

Figure 5–1. Parts of a direct current motor.

Armature

The armature is the rotating part of a DC motor. It has a laminated iron core, windings, and commutator—all mounted on a steel shaft. The core is laminated to reduce eddy currents, which are electric currents induced by alternating magnetic fields. The windings are in slots of the laminated iron core and are held in place by wooden or fiber wedges. The ends of the windings are brought out and connected to the correct commutator segments. The commutator is made of segments of hard-drawn copper that are separated from each other by insulating material.

The raised part of each commutator segment is called a *riser*. The coil ends from the armature windings are *soldered* to the riser. The commutator segments connect the stationary terminals (or brush circuit) to the rotating armature windings.

Frame

The frame, sometimes called the “housing,” is made of cast or fabricated steel. The frame has several functions. It serves as a means of support for the motor, it protects the windings, and it completes the magnetic circuit, which causes the armature to spin the shaft. The two assemblies discussed next are normally an integral part of the frame.

Field assembly

The field assembly, located within the frame, consists of pole pieces and field coils. Usually, the poles pieces are laminated and bolted to the inside of the frame. The field coils or windings are placed around the pole pieces. The field windings are connected to produce alternate north and south poles. The number of pole pieces in DC motors is always an even number since they are in sets of north and south poles.

Brush assembly

The brush assembly is also contained within the frame or directly outside of the frame in a separate housing. This assembly consists of the brushes, brush holders, and springs. The brushes ride on the surface of the commutator and form the electrical contact between the armature windings and the external power (completing the circuit). Usually, brushes are made of high-grade carbon and are held in place by brush holders insulated from the frame. The brushes must be free to slide up and down in their holders to follow irregularities on the surface of the commutator. A flexible braided copper conductor (pigtail) connects each brush to the external circuit. Pressure is exerted on the brush by a spring.

Endbells

The primary functions of the endbells are to keep the armature in position, house the bearings, and complete the frame. They are held in place by bolts that typically run through the entire length of the motor. The endbells contain bearings to allow the shaft to spin freely. The endbells also *center* the armature, enabling the armature to rotate without rubbing against the field poles. The distance between the armature and the field poles is known as the *air gap.*

Operation

In operation, a magnetic field of permanent polarity is set up in the field poles when DC current flows through the field windings. The current applied through the brushes and commutator segments into the armature coil also produces a magnetic field (fig. 5–2). The armature's magnetic field is attracted by the magnetic field around the pole pieces. This attraction causes the armature to rotate. Before the magnetic fields can line up with each other, the energized commutator segments have rotated past the brush contact point.

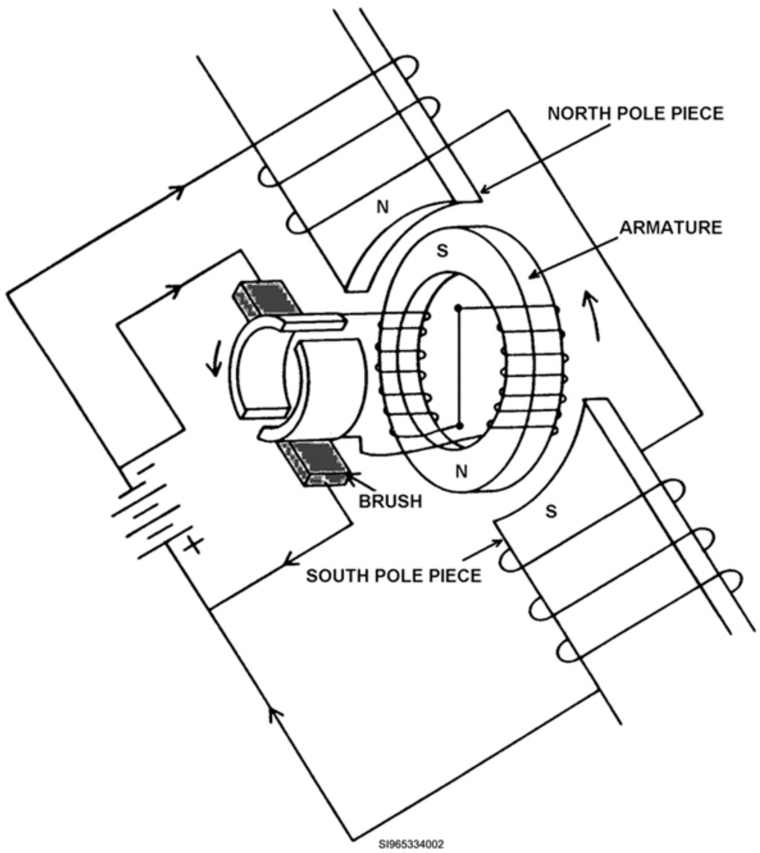

Figure 5–2. Basic direct control motor operation.

Now let us concentrate on figure 5–2. What happens to the position of our brushes and the commutator segments as the armature turns? The left-hand brush comes into contact with the right half of the commutator segment. The brush on the right half of the figure contacts the commutator segment that was on the left.

The direction of DC current has been *reversed* through the armature coil. The positive DC brush on the right of figure 5–2 energizes the opposite end of the armature coil. If the DC current through the armature coil is reversed, then the north and south magnetic poles in the armature also have reversed. All through the reversal action of the armature field, the armature continues to turn so that the armature field and the permanent field pass through center. In other words, both magnetic fields are just past a point where they would line up with each other.

Now we have like poles (north facing north and south facing south) opposite each other. The law of magnetism tells us that like poles repel, so the stationary field poles repel or push the armature further past the center point. The armature continues to turn and the opposite, or unlike, field pole begins to attract the armature field as it continues to revolve. At this point, the poles are back to where they started. An actual motor would have many coils on the armature and an equal number of commutator segments. Because this allows a stronger attracting and repelling action, it produces a more uniform and smoother turning force. All motors operate on this basic principle of attracting or repelling magnetic fields. DC motors are classified by the way that the armature and field windings are connected to power. The basic types of DC motors include series, shunt, and compound.

Series motor

In a series DC motor, the entire current flows through both the field and armature windings. This action produces the highest starting torque of any DC motor. The distinguishing characteristic of a series motor is that speed changes rapidly with load. When load is high, speed is low; when load is low, speed is high. So, never operate a series motor without a load. It has no speed control except its load to give resistance and may disintegrate due to excessive speed if operated unloaded. The series motor is used when high starting torque is required and rapid fluctuations of torque occur.

Shunt motor

In a DC shunt motor, the field coils and armature are connected in *parallel* so the resistance in the field windings is high; therefore, the current flow through the field is low. Since the field windings are connected directly across the power supply, the current stays constant. Because the field current does not vary with motor speed, as in the series motor, torque of the shunt motor varies only with the current through the armature. The speed of a shunt motor varies very little when load changes. Shunt motors are used when constant speed is desired and when high starting torque is not needed.

Compound motor

Connect a compound motor so that part of the field windings is connected across the power supply and the other part is connected in series with the armature. Using this method, the characteristics of the series motor and shunt motor are combined. A series field connection and an armature connection provide high starting torque, while the shunt field windings provide for speed control. A compound motor has the advantages of high starting torque and good speed regulation under load.

025. Three-phase alternating current induction motors

There are two distinct types of AC motors: *induction* and *synchronous.* The most popular motor used today for general-purpose applications is the squirrel-cage induction motor. These three-phase induction motors are in widespread use because of their great load capacity and they cost less than synchronous motors, therefore they are often a planner’s first choice.

Components

As a minimum, three-phase induction AC motors will contain these three basic parts: stator, rotor, and endbells.

Stator

The stator (fig. 5–3), or frame, serves to house the stationary windings and provides an attachment point for the supply voltage. It is made of cast iron or steel and has a silicon steel core pressed inside. The steel core is made with semi-closed slots that hold the field windings. The field windings are made up of many varnish-insulated coils separated by 120 electrical degrees, or $^{1}/_{3}$ cycle of AC power. The coils are insulated from the core with treated paper called fish paper. The coils are connected to form three separate windings. The field windings and the steel core together make up the stator part of the motor.

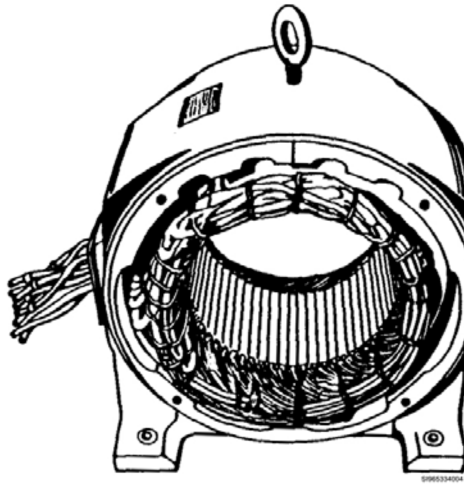

Figure 5–3. Three-phase stator.

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 using a shaft. Rotors may be either the wire-wound or the squirrel-cage type, depending on the manufacturing and motor requirements.

Squirrel-cage rotors are cheaper to build and need less maintenance than the wound rotor. The squirrel-cage rotor is a laminated iron core with rotor bars and end rings mounted on a spider or framework secured to a shaft (fig. 5–4). Rotor bars of copper, aluminum, or any alloy that is a good conductor, are laid in slots in the core. All the bars are connected to end rings forming a complete current path. Smaller motors, less than one horsepower (hp) may have the rotor cast in one piece and the rotor bars are on an angle to the shaft. This is called *skew*, and the effect increases the torque of the motor. Squirrel-cage rotors do not have electrical connections from the power source, insulation, commutator, or slip rings. The rotor bars and end rings make up a squirrel-cage winding. Fan blades are added on the end of the rotor for ventilation.

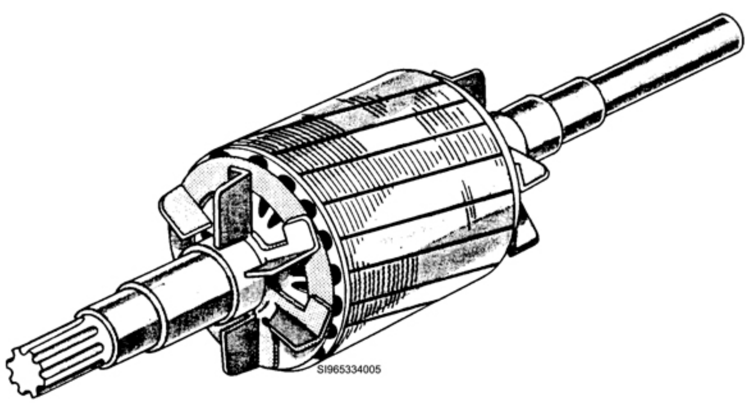

Figure 5–4. Squirrel-cage rotor.

The wire-wound rotor, shown in figure 5–5, has a laminated silicon steel core mounted on a shaft. The rotor windings are made of coils of copper wire similar to those used in the stator. Because of its unique wiring configurations and its connections to the slip rings and resistors, the wire-wound rotor is the rotor of choice when you need variable speed control and low starting current.

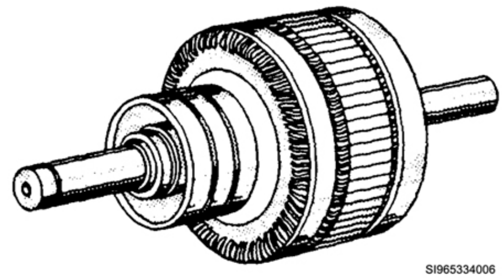

Figure 5–5. Three-phase wire-wound rotor.

Endbells

The endbells serve the same three functions as they do in a DC motor. They house the bearings, support and align the rotor and shaft, and complete the frame of the motor.

Operation

The basic operation of a three-phase induction motor is fairly simple. In fact, three-phase induction motors are easier to understand than single-phase motors because of their simple construction. Knowing how they work will help you with installation, maintenance, and troubleshooting.

A three-phase induction motor depends on a rotating magnetic field for operation. This rotating magnetic field comes directly from the source of power, which begins at the generating plant and makes its way through the distribution system, eventually ending at the load. When current flows through the stator windings, it produces a rotating magnetic field that induces a voltage in the rotor. The current flow in the rotor sets up a magnetic field that is attracted to the rotating field in the stator. This rotating magnetic field is produced by three main factors:

1. The difference in amount of current flow in the three-phase power caused by the characteristics of generating three-phase voltage.
2. The reversal in direction of current flow caused by the characteristics of AC power.
3. The arrangement of field windings in the stator core that establishes an even spread of the magnetic field around the stator.

The rotating magnetic field is set up by the rising and falling current in the stator windings. Look at the three-phase sine wave again in the upper part of figure 5–6.

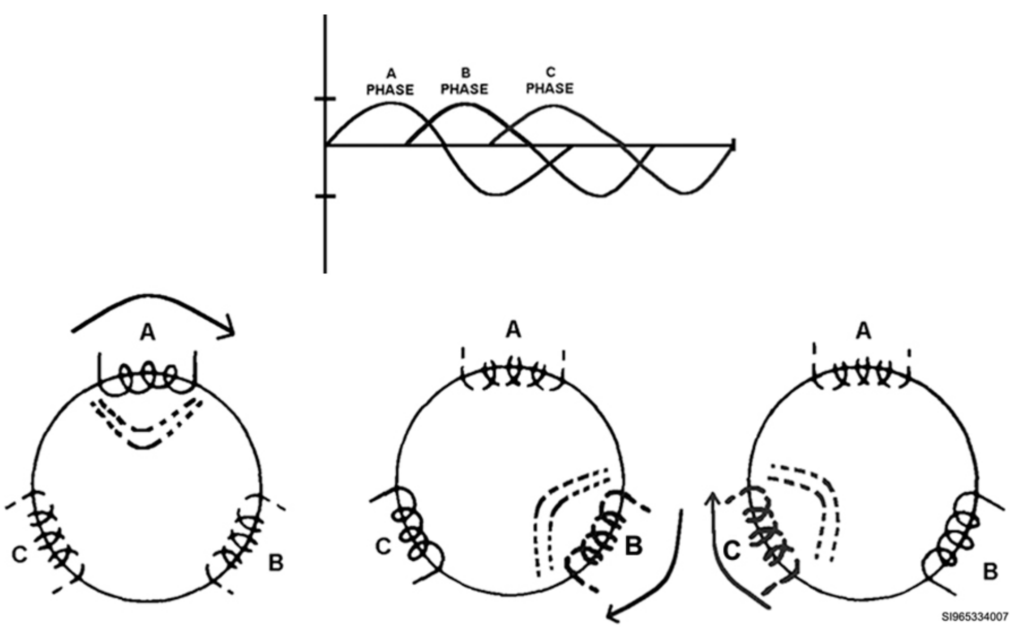

Figure 5–6. Three-phase sine wave and corresponding magnetic field.

Notice that the "A" phase begins at zero volts and climbs at a steady rate to peak voltage, then drops back past zero to a negative peak value and then back to zero again. It then repeats itself at a predetermined frequency (60 hertz [Hz] in the United States [US]) based on the speed and number of poles of the generator providing the power. Keep in mind that current is directly proportional to the voltage, so you may also think of this wave in terms of current. When the current reaches its maximum value, it produces a strong magnetic field. As the current decreases, the current in the next phase increases, causing the magnetic field to move. Notice the "B" phase starts 120 electrical degrees later than "A" phase, and the "C" phase starts 120 degrees after the "B" phase. As the current decreases in each successive phase, it increases in the next phase, causing the magnetic field to move again. This rotating magnetic field is transferred to the motor's stator through the input leads on the motor. The windings in the motor's stator are distributed so that this rotation of the magnetic field is uniform and continuous.

Notice how the magnetic field rotates around the stator in the lower part of figure 5–6. The "A, B, C" rotation of the magnetic field in the stator mimics the input power depicted in the upper portion of the figure. These magnetic fields cut across the rotor, inducing voltage in the rotor. This voltage causes a current to flow in the rotor that produces a magnetic field. Since the voltage is induced, the magnetic field in the rotor is opposite to the magnetic field that produced it. Proving the principle that, unlike poles attracting each other, the rotor follows the rotating magnetic field.

026. Single-phase alternating current induction motors

Single-phase motors range from a fraction of a hp up to 10 hp. Most of the motorized appliances and machines found in the home are equipped with single-phase AC motors. Single-phase motors are divided generally into two classes: commutator and induction. The induction motor is the most widely used AC motor because of its simple and sturdy design. Single-phase motors are found in gas station dispensers and product recovery tanks. One of the major differences between a single-phase and a three-phase motor is that the single-phase motor requires some starting means, whereas the three-phase motor does not.

Split-phase motors

Split-phase motors are usually fractional (less than one) hp and are used to operate such devices as washing machines, small pumps, dryers, and blowers. Basically, a split-phase motor is constructed the same as a three-phase motor. It has a stator, a squirrel-cage rotor, and two endbells. The windings, however, are located and connected differently than they are in a three-phase motor. The split-phase motor has two windings. One winding is located at the bottom of the slots in the stator and is called the run winding or the main winding. The other winding is called the start winding and is located in the stator centered and laid on top of the run winding. Also, a centrifugal switch is used during starting (fig. 5–7). A rotating part of the centrifugal switch is located on the rotor, and a stationary part (containing a set of contacts) is located in the endbell.

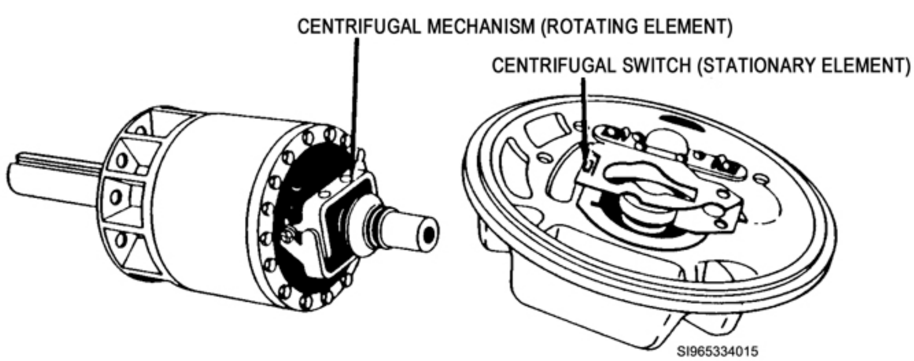

Figure 5–7. Components of a centrifugal switch.

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, causing them to open. These contacts are in series with the start winding. Therefore, the purpose of the centrifugal switch is to open these contacts and de-energize the start winding after the rotor reaches a predetermined number of rpms. Figure 5–8 is a schematic diagram of a split-phase motor. The start winding and the run windings are connected to power until the motor reaches 75 percent of its maximum rpm. A centrifugal switch then disconnects the start winding from the power. The run winding has many turns of heavy copper wire; the start winding has fewer turns of smaller wire. If the start winding is not disconnected after a short period of time, it will burn up.

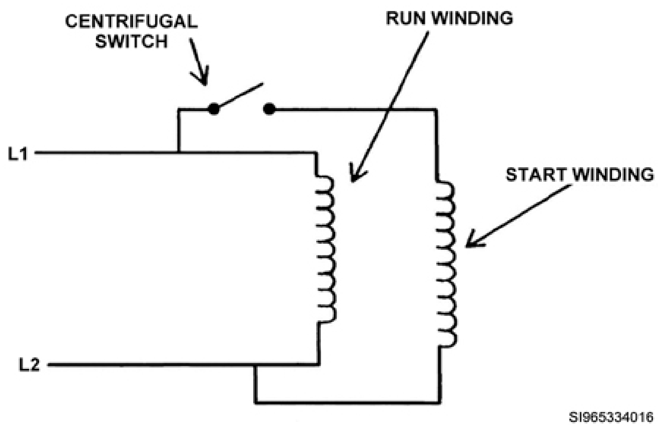

Figure 5–8. Split-phase motor schematic.

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 an opposing magnetic field. The magnetic fields combine in such a manner to cause rotation of the rotor. The start winding is used only for starting the motor. After the start winding is cut out by the centrifugal switch, the motor operates on a shifting magnetic field. The run current is shifting from positive to negative and back to positive.

Capacitor-start motors

A capacitor-start motor, as shown on the schematic diagram in figure 5–9, is an improved version of the basic split-phase type of motor. The only difference is that an intermittent type of capacitor is connected in series with the start winding. The centrifugal switch cuts out the start windings and the capacitor when the motor reaches 75 percent of full speed. The power stored in the capacitor gives the motor a greater starting torque than a basic split-phase motor.

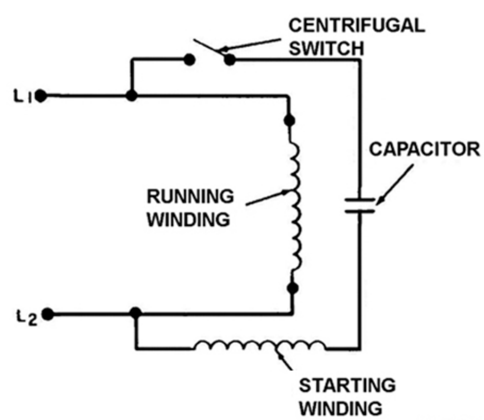

Figure 5–9. Capacitor-start motor schematic.

To create a starting torque in a capacitor motor, a stronger rotating magnetic field is established inside the motor. This is done by placing the start winding out of phase with the run windings by more electrical degrees. A capacitor is used to enable the current in the start winding to reach its maximum value before the current in the run winding reaches its maximum. The capacitor, by giving the start winding this “boost,” causes the current in the start winding to lead the run winding current. Thus, the start winding’s magnetic field in the stator will induce a current in the rotor first, and then begin the rotor’s rotation before the run winding. However, when the rpms reach 75 percent of full speed, the centrifugal switch cuts the power to the start winding and the run winding takes over motor rotation. Remember, when the motor stops, the centrifugal switch contacts will close by spring pressure so that the motor can be started again. Capacitor-start motors are furnished usually in ratings from $^1/_6$ to 1 hp and are used on compressors, pumps, fans, and machine tools.

Self-Test Questions

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

024. Direct current motors

1. Name the three major parts of any DC motor.

2. What is the relationship of the commutator to the armature?

3. How are the field assembly pole pieces attached to the frame?

4. Where are the field coils placed?

5. How is a circuit completed from the commutator to the external power?

6. What are the primary functions of the endbells?

7. What determines the polarity of an electromagnet?

8. What force(s) causes the armature of a DC motor to rotate?

9. Name the three types of DC motors.

10. Which DC motor should not be operated without a load?

11. State the type of DC motor that you should use in each case below:

    (a) When high starting torque is required and rapid fluctuations of torque occur.

    (b) When constant speed is desired and high starting torque is not needed.

    (c) When high starting torque is required with good speed control.

025. Three-phase alternating current induction motors

1. What are the basic parts of a three-phase induction motor?

2. Other than housing the stator windings, what function does a stator serve?

3. What is the purpose of the rotor in an AC induction motor?

4. Name the parts of a squirrel-cage rotor.

5. Which type of rotor has slip rings for variable speed control?

6. When is the use of a wound rotor desirable?

7. On what does the operation of a three-phase motor depend?

8. What factors are necessary for producing a rotating magnetic field in a three-phase motor?

026. Single-phase alternating current induction motors

1. List the two sets of windings found in a split-phase motor.

2. How are the contacts of the centrifugal switch connected in relation to the start winding?

3. What is the purpose of the centrifugal switch in a split-phase motor?

4. How is the addition of a capacitor in the start winding of a capacitor-start motor beneficial?

5–2. Electrical Components

In this section, we will cover some of the common AC electrical components and controllers. The term “controller” refers to any switch or device that normally starts and stops a motor. A controller can be very simple or very complex, depending on the application. You will be responsible for ensuring that motors, controllers, and components are operating properly. In order to do this, you will need to understand how they work.

027. Transformers

Before we get to the motor controls, we first need to consider how transformers work. This will include how a transformer can change an incoming voltage (from a main power line), and then provide it to the specific motor control or other component.

Purpose

Though transformers are not actual “sources” of power (devices that *produce* electricity), transformers are used to provide the exact voltage required for a particular load. A transformer is a device that transfers energy from one circuit to another by electromagnetic induction. The energy is always transferred without a change in frequency. The actual change is usually within the voltage and current.

Transformers are built in various shapes and sizes and serve various purposes. A step-up transformer receives electrical energy at one voltage and delivers it at a higher voltage. Conversely, a step-down transformer receives energy at one voltage and delivers it at a lower voltage. Transformers require little care and maintenance because of their simple, rugged, and durable construction. It is this high efficiency that transformers provide that is responsible for the extensive use of AC.

Various types of small transformers are used in switchgear. In many installations, transformers are used on switchboards to step down the voltage for indicating lights, instruments, and electrical protective devices. Other common uses include low-voltage supplies for lighting circuits, and so forth.

Instrument transformers include both voltage and current transformers. They are commonly used with AC instruments to measure high voltages or large currents and to isolate the high-power circuits.

Electronic circuits and devices use many types of transformers to provide necessary voltages for proper operation of components. If you own a cell phone, you use an AC to DC transformer to charge your phone. It takes the 120 volts, alternating current (VAC) wall outlet voltage and changes it to the lower DC voltage. While there may be a few AC to DC transformers in fuel systems, there are several different components used in the Type III and IV fuel systems that need transformers to reduce a higher AC voltage to a lower AC voltage in order to operate them.

Transformer action

In order to function properly, a transformer needs an internal core (normally iron), primary and secondary windings wrapped opposite of each other around the core and current flow. If you apply an AC to an electromagnet, a magnetic field builds up and collapses during each half cycle. In other words, the magnetic field that the current builds up during one-half of the cycle collapses and builds up in the opposite direction during the next half of the cycle. For example, a 60-cycle current builds up and collapses a magnetic field 120 times per second.

If you place a second winding around the iron core, the same magnetic field builds up and collapses across the turns on the second winding to induce a voltage in this second circuit. This action is called transformer action and is the principle upon which transformers operate. So, in an AC circuit it is the buildup and collapse of the magnetic field in the primary winding that causes the induction of voltage and current in the second winding.

The ratio between the number of turns in the primary and the number of turns in the secondary determines the voltage ratio of the transformer. If both windings have the same number of turns, the voltage and current induced in the secondary winding are the same as that applied to the primary winding. If the secondary has more turns than the primary, a greater voltage and a smaller amount of current is induced in the secondary than that applied to the primary. If the secondary has fewer turns than the primary, a lesser voltage and a greater amount of current is induced. Figure 5–10 illustrates the relationship between the turn ratio and the voltage.

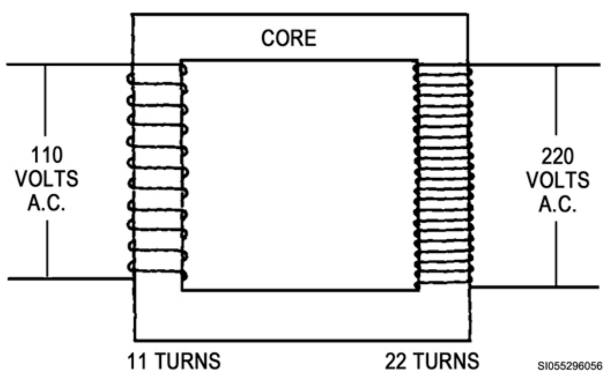

Figure 5–10. Basic transformer.

If the left-hand coil (with 11 turns) is connected to a 110V AC source, it is the primary winding. Because there are 22 turns on the secondary coil (or twice as many as on the primary coil), the induced 220V is twice the voltage applied to the primary. The turn ratio is then stated as 1 to 2, the primary number being given first. A transformer with a greater secondary voltage is called a step-up transformer.

Conversely, if we had applied 220V to the 22-turn winding (fig. 5–10), then the output of the secondary with its 11 turns would be 110V. This we call a step-down transformer because the secondary voltage is less than the primary. We state the ratio of the transformer when we connect it in this way as 2 to 1.

028. Switches and electromagnetic devices

Switches or across-the-line controls are devices that start and stop a motor as well as provide some form of motor over-current protection. To stop and start a motor, an across-the-line control must contain a means to make and break electrical contacts in the power supply lines to the motor. The term “across-the-line” means that when the circuit is closed and the connection is made, full voltage from the supply power is applied. Across-the-line AC motor controls are either manual or magnetic.

Manual control

A manual motor-control is a device, either hand or mechanically operated, for controlling a motor from a single point. A manual motor control will always be located next to the pump motor in a fuel transfer or hydrant supply pipeline for maintenance purposes. These manual controls are usually operated by moving a switch or pushing a button. Each controller must be capable of starting and stopping the motor that it controls. The manual control can be a plain switch with or without an internal overload protection feature. The term “overload protection” refers to a device that reacts to excess motor current. This device is designed to protect the motor windings by interrupting the current flow when an overload situation exists. Manual controllers control both single-phase and three-phase motors, using toggle switches, fused safety switches, and pushbutton controllers.

Toggle switches

You use a toggle switch or light switch to control a small motor. You simply flip the toggle switch to turn the motor on or off. In a 120V circuit, such as for a bench grinding wheel, only a single-pole switch is necessary. In a 240V circuit, such as for a pump house exhaust fan motor, a double-pole switch would be needed. Remember that a toggle switch is limited to the size motor it can control safely. To protect these types of circuits, as well as the motor, the over-current protection device is usually a circuit breaker, located in the circuit breaker panel.

Fused safety switch

Older systems still may use a fused safety switch, or a fused disconnect switch on small single-phase or three-phase motors. It operates on the same principle as the toggle switch. The fused disconnect switch in figure 5–11 is shown with the handle in the down position (OFF), which means it is not sending power to the motor.

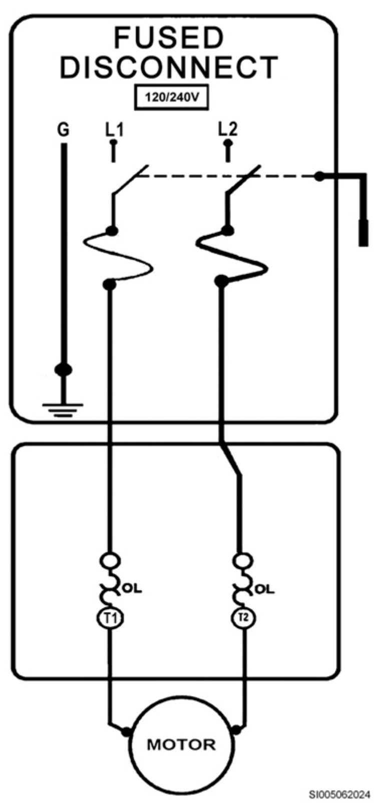

Figure 5–11. Fused disconnect feeding a motor.

Pushbutton controllers

A pushbutton controller is the one that you may be most familiar with. This type of controller usually has a green start button and a red stop button. The start button will complete a circuit to a coil in a controller, or starter, and the coil will close the contacts to the motor. As in all motor control circuits, an overload device must be in series with all ungrounded conductors. If one overload device operates, it will de-energize the coil, which will open all contacts to the motor.

Magnetic motor controls

Another across-the-line motor-control device that is often used is the magnetic control. This control (sometimes called a *starter*) is operated magnetically and connects the motor across the line using an electromagnet to close the main or load contacts. This type of starter provides a safe, convenient, and economical means for controlling an electric motor. Magnetic controls are the most commonly used starters and offer the advantage of being controllable with an automatic device or a remote control. A magnetic control, commonly called an across-the-line magnetic starter, has two main sections: the contactor and the overload relay.

Magnetic contactor

A typical contactor is made up of three sections:

- Operating (or holding) coil and armature.
- Main and auxiliary contacts.
- Three line (L1, L2, L3) and three load (T1, T2, T3) terminals (for a three-phase contactor).

The coil is the stationary portion of the contactor and uses a laminated iron core and a winding to produce an electromagnetic effect. The armature is the movable portion of the contactor that is attracted to the operating coil when the coil is energized. While one side of the main contacts is connected to the armature, the other side of the main contacts is stationary. When the electromagnetic coil is energized, it sets up a magnetic field attracting the armature. This closes the main or load contacts and completes the circuit, thus starting the motor. Shaded rings are placed on the stationary core to provide a split-second time delay, thus preventing contact chatter and wear in the moving parts of AC magnetic controls. Figure 5–12 shows a line drawing of the basic parts of a magnetic contactor.

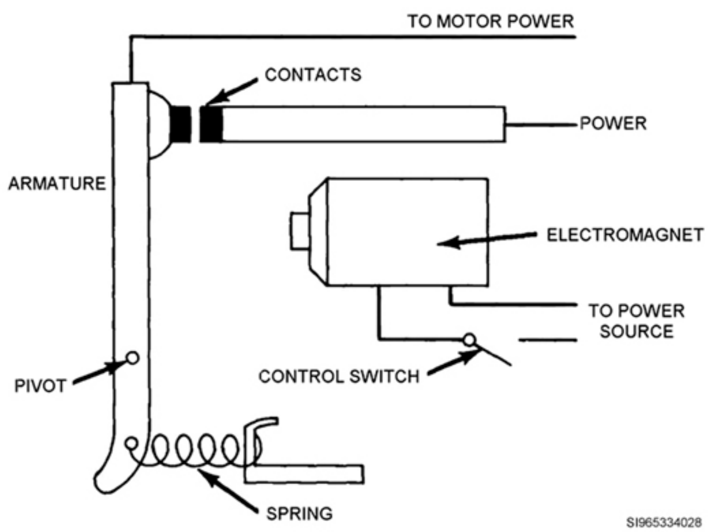

Figure 5–12. Magnetic contactor.

The auxiliary contacts, or holding contacts, are located also on the contactor. They are usually joined by an insulated connecting bar so that all contacts close, both main and auxiliary, when the holding coil becomes energized. The contactor also provides terminals for the attachment of the supply conductors. These terminals usually are identified with the letter "L." For example, terminals L1 and L2 are the supply conductor terminals of a single-phase magnetic starter. The auxiliary contacts also have terminals. Auxiliary terminals attach the conductors from control devices and are identified with the numbers 2 and 3. Auxiliary contacts are covered in more detail later.

Overload relay

Nearly all magnetic starters are equipped with an overload device or overload relay to protect the motor from excessive current in a running situation. Current-sensitive elements of the overload relay are connected either directly or indirectly and act to de-energize the starter and stop the motor when excessive current is drawn. The basic requirement for overload protection is that the motor be allowed to carry its full-rated load and yet prevent any prolonged or serious overload. When a motor is overloaded mechanically, motor current increases which, in turn, increases the temperature of the motor and its windings. The same increases in current and temperature are caused by the loss of single phase on three-phase motors or a partial fault in the motor windings. Therefore, to give full overload protection, we need only to sense or measure the current draw by the motor and break the circuit when this current exceeds the rated value for the motor.

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 used, it is activated by an excessive current flow in the motor. 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 open the main or load contacts. Overload relays must be reset automatically or manually after each tripping. Use the automatic reset type only on equipment that is designed to prevent danger to life or equipment from the restarting of the motor. To better understand the overload relay, let's look at each type individually.

Thermal overload relays

Thermal relays are usually the bimetallic or melting-alloy types. The bimetallic type is constructed of two dissimilar metals; when heated, it bends due to the different rate of expansion of the two metals. 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, opening the holding coil circuit. Figure 5–13 is a line drawing of a bimetallic overload relay. A reset button is depressed to reactivate the mechanism when the strip has cooled to operating tolerance.

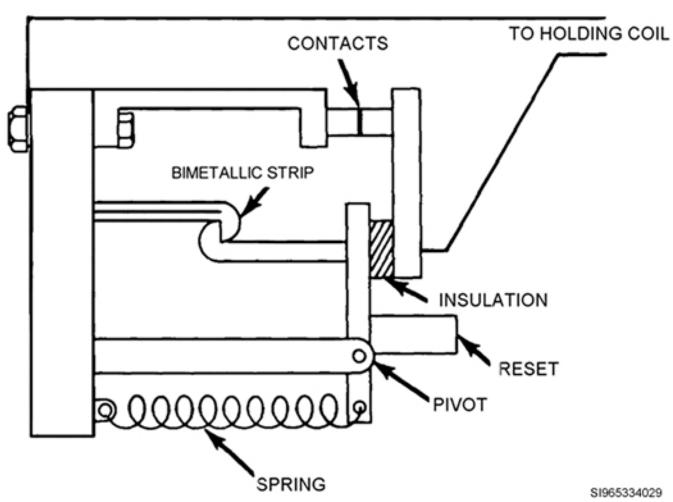

Figure 5–13. Bimetallic overload relay.

The melting-alloy overload relay employs a heating coil connected in the motor-line circuit, as shown in figure 5–14. The heat caused by excessive current in the motor circuit melts the metal alloy (similar to solder), releasing the spring-loaded shaft. The shaft is then capable of turning. This permits the reset contacts to open, disrupting service to the motor. When the alloy has cooled and solidified sufficiently, you may restart the motor by depressing the reset button. A laboratory example of the melting-alloy principle is shown in figure 5–14. Melting-alloy relays are not prone to varying amperage ratings, even after repeated operations. The bimetallic type, however, *is* prone to this type of amperage variance after repeated heating.

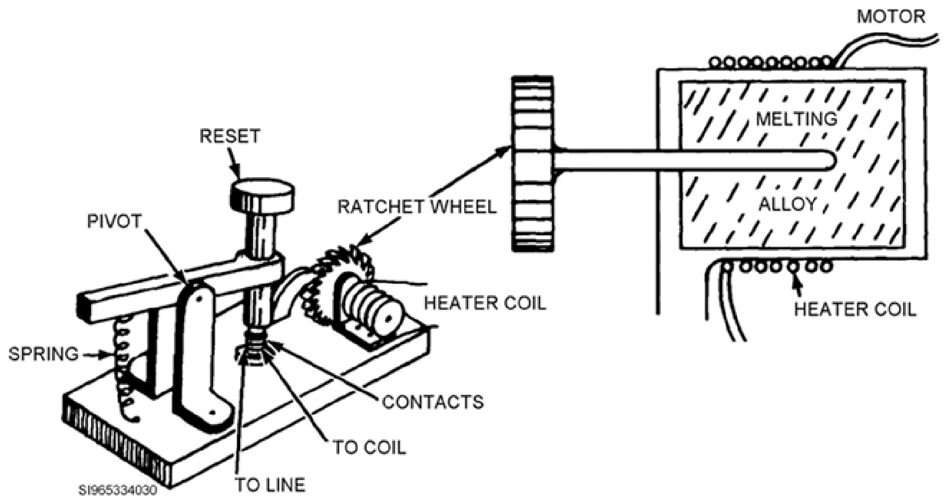

Figure 5–14. Melting-alloy thermal overload relay.

Magnetic overload relays

The magnetic overload relay has a coil, a piston, a dashpot, and a set of contacts (fig. 5–15). The coil is connected in series with the motor. The magnetic field pulls up the plunger, causing the contacts to open when a determined amount of current passes through the coil. By adjusting the length of the plunger, the amount of current required to pull the plunger up can be varied. An oil-filled dashpot is added to provide a time delay. A plate on the bottom of the plunger is submerged in the oil and acts as a piston. The plate has holes in it that can be adjusted in size to change the time delay. When the coil pulls the plunger up, the oil must flow through the hole in the plate as the plunger rises. By changing the size of the hole, the time delay can be increased or decreased. Quick tripping is obtained through the use of a light-grade dashpot oil.

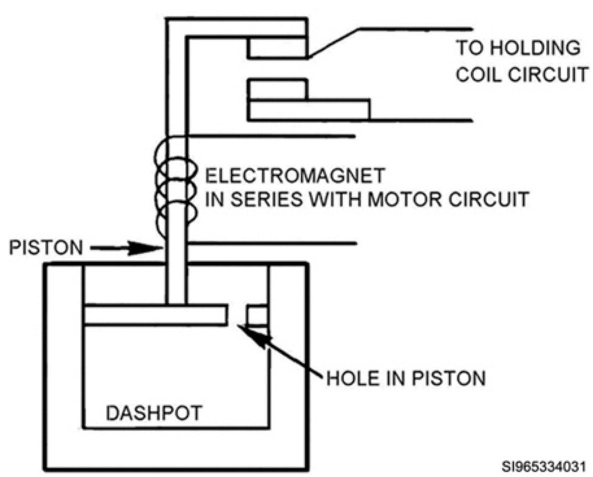

Figure 5–15. Magnetic overload relay.

Selecting overload relays

The size of an overload relay (also referred to as a *thermal switch* or *heater*) is determined by the full load current (FLC) rating of the motor it protects. When selecting the heaters to protect a motor, you should check the motor data plate to find the FLC rating. Each manufacturer normally puts a heater selection table in the controller cover. Heaters are not identified by amperage but by the manufacturer's catalog number. By using the FLC of the motor and referring to the manufacturer's table, you can select the proper heater. The overload relay also provides terminals for the attachment of the supply conductors. These terminals usually are identified with the letter "T." For example, terminals T1 and T2 are the load terminals of a single-phase magnetic starter and provide a point to connect the conductors supplying the motor.

029. Motor control operation and solid-state components

The operation of an across-the-line magnetic starter is fairly simple. When the electromagnetic coil is energized, it sets up a magnetic field attracting the armature. When the armature moves toward the electromagnet, the movable contact connects with the stationary contact. This completes the circuit to the motor and the motor starts. When the switch in the circuit that supplies power for the electromagnetic coil is opened, the coil is de-energized, causing a loss of the magnetic force, and spring tension or gravity pulls the contacts apart. Other magnetic line starters have more contacts and motor over-current-protection relays.

The across-the-line magnetic starter contains two electrical circuits: the load circuit and the control circuit.

Load circuit

The load circuit contains the main or load contacts, the line terminals, the load terminals, and the heater coil portion of the overload relay. The load circuit is the determining factor as to the size of motor it controls. It must have a larger rating than the connected motor.

Control circuit

The control circuit contains the holding coil, the reset contacts of the overload relay, and the auxiliary contacts. The control circuit is the portion of the magnetic starter that performs the function of starting, stopping, controlling, and protecting a motor.

In addition to the starter control circuit, some type of control unit, generally called an accessory, must open and close the application of power to the operating coil. Generally, these devices are connected using a two or three-wire circuit.

Two-wire control circuit

A two-wire control circuit receives its power from the incoming leads to the starter. The basic control circuit is a series circuit from L1. It goes through the control device, the holding coil, and the overload reset contacts. It returns to L2 or to neutral depending on the voltage rating of the coil.

Figure 5–16 shows a diagram of a two-wire control circuit using a single-pole toggle switch as a control device. The magnetic coil is connected to the line on one side through the overload reset contacts and on the other side through the contacts of the toggle switch. As long as the contact of the toggle switch remains closed, the contactor is energized. When the contacts of the toggle switch open, the coil is de-energized and the contactor opens. Notice that when an overload occurs, the overload relay reset contacts will open; this removes the holding coil from the circuit. When the overload relay is reset, the contactor will again immediately pick up because the toggle switch is in the closed position.

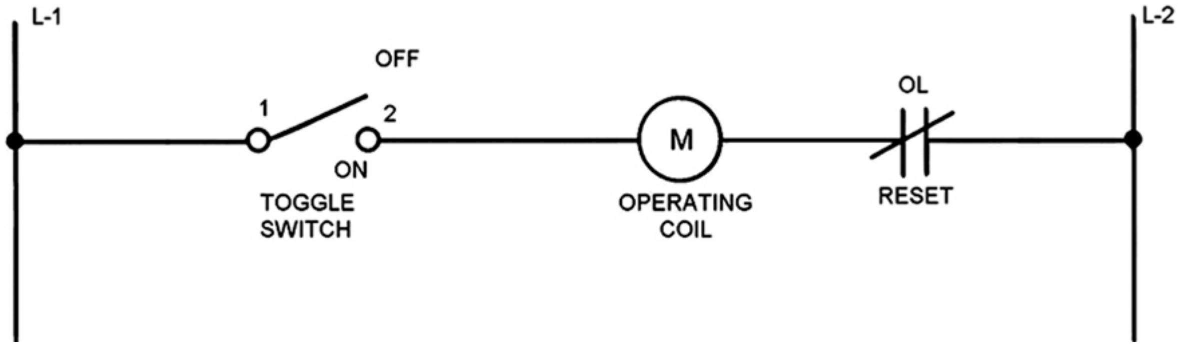

Figure 5–16. Two-wire control circuit.

Three-wire control circuit

A three-wire control circuit also receives its power from the incoming leads to the starter. This circuit uses the same components as the two-wire circuit, except that the auxiliary contacts and a stop-start station are introduced. Remember, the auxiliary contacts are controlled by the holding coil and close and open at the same time as the main contacts. The stop-start station is a manual control device containing a start and stop button. When the start button is pressed, a normally open set of contacts is closed. Conversely, when the stop button is pressed, a normally closed set of contacts is opened. Spring action returns the buttons to their original position when finger pressure is removed.

To operate a magnetic starter by a stop-start station, connect the holding coil to the stop-start station so that when the start button is pressed, the coil becomes energized. When the stop button is pressed, the holding coil circuit is opened. A diagram of a typical three-wire across-the-line magnetic starter equipped with two thermal overload relays and connected to a stop-start pushbutton station is presented in figure 5–17. When the start button of the station is pressed, it completes the circuit from L1 through the normally closed contacts of the overload relays and through the holding coil to L2. Thus, the coil is energized and the main contacts are closed, connecting the motor across the line.

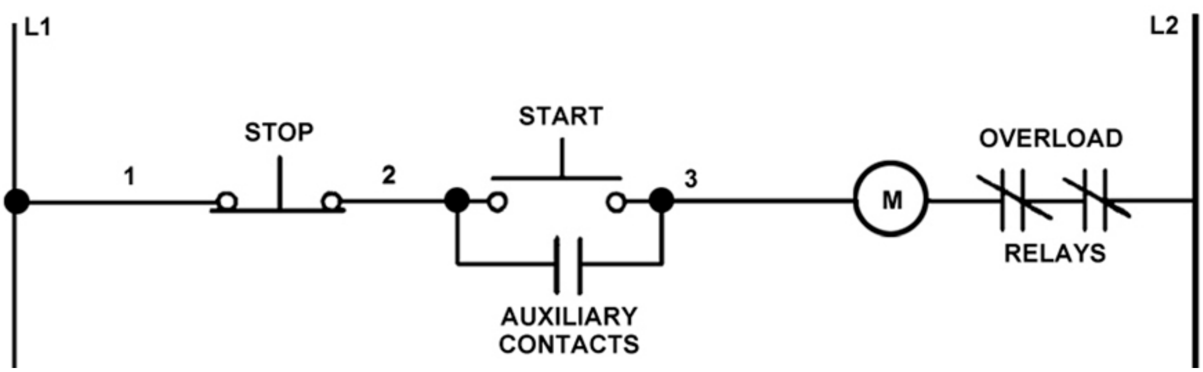

Figure 5–17. Three-wire control circuit.

This action also closes the auxiliary contacts, which keep the holding coil energized after the finger is removed from the start button. Pressing the stop button opens the control circuit and causes all contacts to open. If a prolonged overload should occur during the operation of the motor, the overload relay contacts open and de-energize the holding coil. If an overload condition has caused the relay to trip, it is necessary to reset the relay contacts by hand before the motor can be restarted.

Single-phase controller

The single-phase controller, or starter, has line terminals labeled L1 and L2 for the input (line) conductors, and T1 and T2 for the motor (load) conductors. A thermal or magnetic overload protection device, such as an overload relay, must be installed on each ungrounded conductor. In looking at figure 5–18, notice the overload devices are identified by the letters “OL.” Since our circuit is a 208V, two-wire, one-phase system, it has two ungrounded conductors attached to L1 and L2. One OL device must be installed in series with each one of these ungrounded conductors.

Refer to the diagram in figure 5–18. Notice that an L2 wire is connected directly from the line side of the controller at L2. This wire is “hot” at all times as long as the power feeding the contactor is on. In this situation, we can deduce that the coil is rated for phase-to-phase voltage, since there are two phases and no neutral available. In this case, 208V is required to energize the coil. Since one side of the coil always has a hot wire going to it, we must provide another “leg” or hot wire to the other side of the coil. See if you can tell where we are going to get the other phase to energize the coil by tracing the diagram.

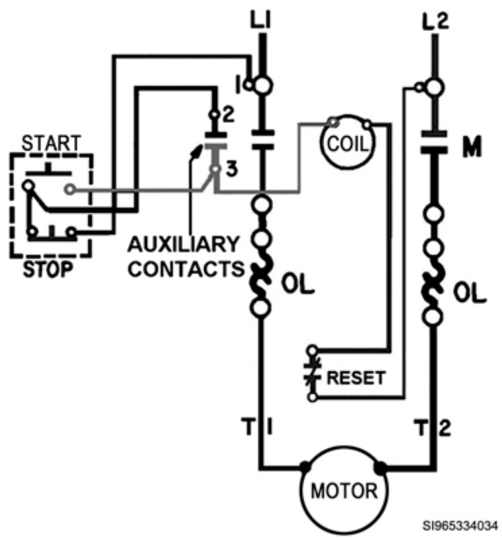

Figure 5–18. Single-phase across-the-line magnetic starter.

If you followed the diagram correctly, you can see that if the start button were pressed, it would send 120V through the wire to terminal #3, and on to the other side of the coil. When the coil is energized with the full 208V, it closes both of the main contacts simultaneously. In addition to closing the main contacts, the auxiliary contacts are closed at terminals 2 and 3. The motor now has both phases connected directly to it, and the motor spins as required.

Three-phase controller

To control a three-phase motor, a three-phase across-the-line magnetic starter, or similar equipment, is used. The three-phase starter will have line terminals L1, L2, and L3 for the connection of the line conductors, and T1, T2, and T3 for the connection of the motor load conductors. Like the one-phase controller, the three-phase magnetic starter must also have an overload relay with thermal or magnetic cutouts for each ungrounded conductor. This means there are three overload devices for this controller.

Figure 5–19 shows a diagram of a three-phase across-the-line magnetic starter. Three-phase equipment is usually color coded. The industry standard is black-red-blue to identify three-phase 120/208V and 120/240V systems. The black-red-blue system has been around for a long time, but current standards don’t *require* the use of this particular marking method; they only require the phases to be distinguished from each other and a legend posted on the equipment.

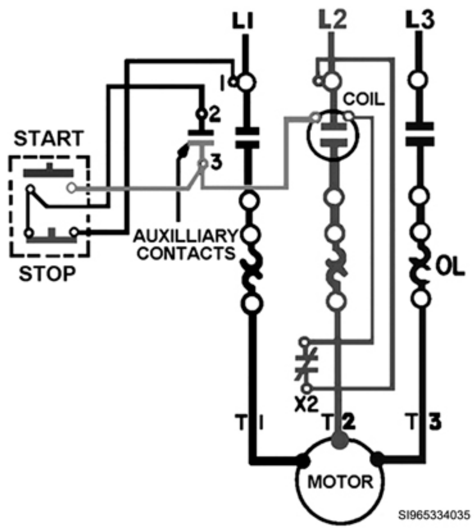

Figure 5–19. Three-phase across-the-line magnetic starter.

Automatic controls

Automatic devices can be used to control or operate a magnetic starter. They are installed in series with the control circuit like the toggle switch in figure 5–19. Some of the most common types include float switches, pressure switches, thermostats, and photocells.

Float switches

Often fluid levels are controlled by the use of a float switch. This switch is a set of contacts that are opened or closed mechanically by a lever and float assembly. By using motor-driven pumps controlled by a float switch, the level of liquid can be increased or decreased automatically. An example of a common use of float switches is to control the water level in water towers.

Pressure switches

Pressure switches 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

Thermostats are devices sensitive to temperature and are widely used in heating and cooling systems to control the system.

Photocells

Photoelectric cells are sensitive to light and are used widely to turn on and off exterior lights, such as streetlights.

Solid-state components

The term “solid-state” gets its name from the path that electrical signals take through solid pieces of semi-conductor material that have no moving parts. Before their use, electricity had to pass through heated glass vacuum tubes that contained various less-refined metal elements. Today, most semi-conductors are made from silicon and silicon-based alloys that actually limit its conductivity to a certain degree, thus it is called a semi-conductor. The most basic solid-state components are diodes, transistors, and integrated circuits. They are the basis for all electronic equipment today.

Diodes

A common diode has two halves or layers of doped silicon. Doped silicon is a simply silicon mixed with another element like phosphorus or boron. Each half of the diode is doped differently, which allows current flow in one direction but not the other. These halves or layers are known as: (1) a cathode—that emits electrons and (2) an anode—that collects electrons (fig. 5–20). These are commonly located on both small and large circuit boards found in electronic switches and computers, like the ones used to control our Type III and IV fuel systems. They are used on circuits similar to a check valve in order to protect sensitive circuit components.

Light-emitting diodes (LED) are found everywhere, including in our fuel systems. They are basically tiny light bulbs that fit easily into an electrical circuit (fig. 5–20). But unlike ordinary incandescent bulbs, they do not have a filament that will readily burn out, and they do not get especially hot. LEDs are illuminated by the movement of electrons through a semi-conductor material, which lasts a long time. In a fuel system, they can illuminate display panels and components with green, yellow, or red lights to indicate an open or closed valve or a component that is on or off. For example, the little green light on a computer, which is also an LED, is used to indicate when the computer is powered up.

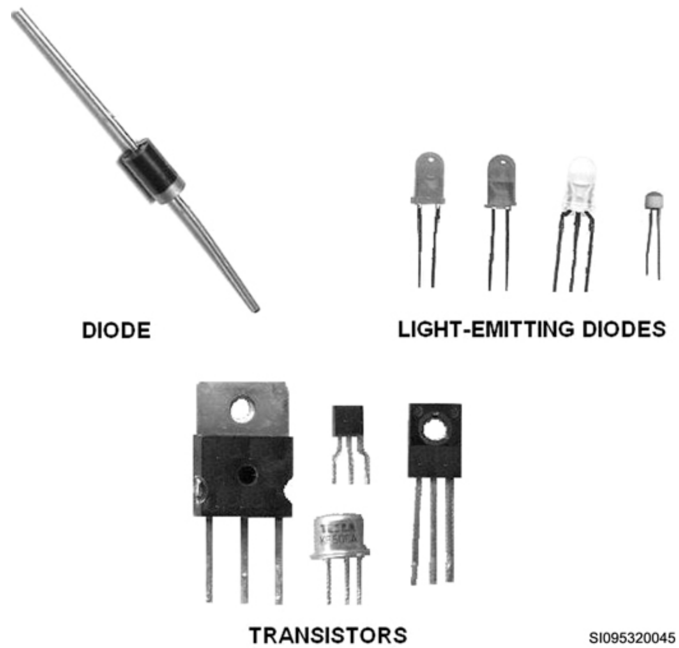

Figure 5–20. Diodes and transistors.

Transistors

Transistors are made with three layers of doped silicon, compared to the two layers within diodes, as shown in figure 5–20. When a small current is applied to the center layer of a transistor, a much larger current can flow through the unit as a whole. This gives a transistor its switching or amplifying behavior. These are also found on circuit boards.

Integrated circuits

An integrated circuit (IC), also known as a “chip” or “microchip”, is made from a chip of silicon and is composed of many interconnected transistors, diodes, resistors, and so forth. (fig. 5–21). This network of interconnected semi-conductors condenses the circuitry into a single small unit to control and route electricity to any number of small and large components performing functions. An IC can provide the electrical path to turn on pump motors, energize valve solenoids, and sound alarms at the same time.

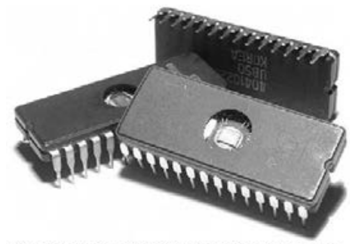

Figure 5–21. Integrated circuits.

Solid-state starters

Solid-state starters provide a highly accurate method of motor starting and speed control. At the center of solid-state systems is a silicon-controlled rectifier (SCR). The SCR controls the voltage, current, and torque during the motor's acceleration.

In conjunction with the SCR controller is the frequency inverter. If you adjust the frequency from the 60 Hz, down to a lower frequency, the motor will run slower. A frequency greater than 60 Hz can also be developed, which allows the motor to exceed its rated speed. Changing the frequency decreases the torque developed by the motor.

This method of starting provides for a smooth, one-step acceleration. It is best used with loads such as conveyors pumps, compressors, and so forth, and the starters must be sized to the motor they are to control. The advantages of these electronic starters are their long life, reduced energy cost for large motor operation, and speed control during start-up and run operations. Their disadvantage is their initial high cost.

Self-Test Questions

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

027. Transformers

1. Why are transformers used?

2. What does a transformer need in order to function properly?

3. In an AC circuit, what causes voltage to be induced in a transformer?

4. What kind of transformer has windings with a 1- to 2-turn ratio?

5. If the ratio of a step-down transformer in an AC circuit is 6 to 1 and the applied voltage to the primary winding is 120V, what is the voltage output from the secondary winding?

028. Switches and electromagnetic devices

1. List the two types of across-the-line AC motor controls.

2. What is a manual motor-control device?

3. What does the controller have that reacts to excess motor current?

4. What are the two main parts of an across-the-line magnetic starter?

5. The three-line and three-load terminals of a three-phase magnetic contactor are labeled in what manner?

6. What part of the contactor attracts the armature?

7. What is the purpose of the shaded ring on the stationary core of the armature?

8. List the two basic types of overload relays.

9. What are two types of thermal overload relays?

10. What information is needed to determine the size of an overload relay for a motor and where do you find it?

029. Motor control operation and solid-state components

1. List the two electrical circuits of the across-the-line magnetic starter.

2. What is the function of the control circuit in a magnetic starter?

3. What set of contacts keeps the holding coil energized after the start button has been released?

4. How many overload relays must be installed on a three-phase magnetic starter?

5. List four automatic devices that control magnetic starters.

6. What are the three basic components of electronic circuitry?

7. Which solid-state component exhibits a switching or amplifying behavior?

8. What is an integrated circuit?

5–3. Installation and Maintenance

The most expensive and elaborate motor system is worthless unless it meets the requirements for the job. It also must be installed correctly to meet these requirements. You should be able to determine the correct type of motor to meet system requirements and, with the help from the electric shop, be able to correctly install it.

To give proper service and have long life, a motor system requires proper inspection and maintenance. After a motor system is installed, it is expected to remain in service for a long time. In a well-planned preventive maintenance and inspection program, your maintenance is a system of routines designed to keep the system in satisfactory operating conditions through periodic inspections, cleaning, adjusting, and lubrication. The expense and critical nature of each motor on base should dictate your maintenance schedule.

030. Connect and disconnect motors

When removing a motor for replacement or just maintenance, it is imperative that you use every safety precaution for electricity you can. Let’s discuss some of the things you will need to know such as motor selection, connections, data plate information, and controller selection.

Motor selection

Before you can install a motor, you need to consider many factors: physical location, ambient temperature, duty, bearings, voltage, mechanical connection to load, and motor data plate information.

Physical location

The physical location of the motor affects the type of motor housing (enclosure) required. A different type of motor enclosure is required to protect a motor that is exposed to rain as compared to one installed in a dry location. Selecting the proper enclosure type becomes more critical as the potential hazards increase. Some of the common motor enclosures used for different environmental conditions are provided in the following table.

Enclosure	Description
Open	This motor has ventilating openings in the frame that permit the passage of outside air to cool over and around the windings.
Splash-proof	This is an open motor in which the vent slots are made to prevent liquids or solids from entering them except at indirect angles.

Enclosure	Description
Totally enclosed	This motor is built to prevent free passage of outside air. It is not airtight; therefore, it cannot be used in an explosive area.
Drip-proof	This is an open motor in which the ventilating openings are constructed so that drops of liquids or solid particles falling on the machine will not enter the motor. The shelter may either shield the motor directly or cause the liquid or solids to strike and run along a horizontal surface.
Waterproof	This is a totally enclosed motor constructed so that it prevents water from entering even if applied in the form of a stream from a hose.
Explosion-proof	These motors are designed to withstand an internal explosion of the vapors or dust from the area in which they are used and to prevent an explosion due to motor faults. This type is used in fuel systems.

Ambient temperature

Along with the type of enclosure you select, you must consider the ambient (surrounding) temperature of the space where the motor is located. The ambient temperature must not exceed what is listed on the motor's data plate. For most general-purpose motors, the maximum ambient temperature is 40°C or 104°F. If ambient temperatures exceed this value, then consider providing better ventilation or replacing the motor with one that can withstand higher temperatures.

Duty classification

Another important factor to consider when selecting a motor is its function or *duty classification*. Determine whether the motor is expected to run continuously or intermittently. A continuous-duty motor is designed to operate at full load for 24 hours a day if necessary. The intermittent-duty motor is designed for frequent starting and stopping, and it has features built in that help dissipate heat quickly. This is an important factor in the selection of motors, since motor windings heat rapidly during starting.

Bearings

The types of bearings used in a motor usually depend on its application to a load or its mounting plane, whether horizontal or vertical. As a general rule, sleeve-bearing motors are mounted horizontally and ball or roller-bearing motors are designed for either vertical or horizontal mounting.

Voltage

The voltage available to run the motor must be considered when selecting a motor. The power supply must have the required number of phases and amount of voltage to run the size motor available. If you are tasked with planning an installation, keep in mind that a higher supply voltage means less current draw to do the same amount of work. Since there is less current, you can use smaller wire, conduit, and fittings. Smaller branch circuits typically use faster installation methods. This constitutes an automatic and immediate cost-savings, so always consider sizing your motor to the maximum voltage that is practical and easily obtainable.

Mechanical connections to load and disconnecting motors

Disconnecting motors is a risky and dangerous operation. To do so requires the utmost safety precautions. Likewise, placing a motor back in operation requires a lot of time and patience to get it properly aligned.

Shaft alignment

The objective of optimized shaft alignment is to increase the operating life span of rotating machinery. To achieve this goal, components that are the most likely to fail must be made to operate within their acceptable design limits.

While misalignment has no measurable effect on motor efficiency, correct shaft alignment ensures the smooth, efficient transmission of power from the motor to the driven equipment. Incorrect alignment occurs when the centerlines of the motor and the driven equipment shafts are not in line with each other. Misalignment produces excessive vibration, noise, coupling and bearing temperature increases, and premature bearing or coupling failure.

Types of misalignment

There are three types of motor misalignment, including angular, parallel, and combination.

Angular misalignment

Angular misalignment occurs when the motor is set at an angle to the driven equipment. The angle or mismatch can be to the left or the right, or above or below. If the centerlines of the motor and the driven equipment shafts were to be extended, they would cross each other, rather than superimpose or run along a common centerline. Angular misalignment can cause severe damage to the driven equipment and the motor.

Parallel misalignment

Parallel misalignment occurs when the two shaft centerlines are parallel, but not in the same line. They are offset horizontally or vertically (or both), displaced to the left or right, or positioned at different elevations.

Combination misalignment

Combination misalignment occurs when the motor shaft suffers from angular misalignment in addition to parallel misalignment.

Alignment tolerances

Proper shaft alignment is especially critical when the motor is operated at high speeds. Typical alignment tolerances are summarized in the table below.

ALIGNMENT TOLERANCES				
Motor Speed, RPM	Parallel Offset (mils)		Angular Misalignment (mils)	
	Excellent	Acceptable	Excellent	Acceptable
1200	+/- 1.25	+/- 2.0	0.5	0.8
1800	+/- 1.0	+/- 1.5	0.3	0.5
3600	+/- 0.5	+/- 0.75	0.2	0.3

In practice, proper alignment is difficult to achieve without using alignment equipment such as dial indicators or laser alignment tools to check and correct for misalignment. The proper shaft alignment procedure is to secure the driven equipment first, and then install the coupling to the equipment. Moving a pump, for instance, would impose stress upon the connecting piping. Then the motor should be moved into proper alignment and joined to the coupling. After the equipment has operated long enough to become temperature stabilized, shut it down and immediately recheck alignment. Due to thermal growth, machines that are aligned in the “cold” pre-operating condition are almost always out of alignment when operating temperatures are attained.

Couplings

The most common methods for attaching the motor shaft to the load are pulleys, couplings, and gears. In fuel systems, pulleys with belt drives are commonly found in gas station dispensers, while gear shaft attachments for motors are rarely seen. Larger motors are usually directly coupled to their loads with rigid or flexible couplings. Rigid couplings do not compensate for any motor-to-driven-equipment misalignment while flexible couplings tolerate small amounts of misalignment. Flexible couplings can also reduce vibration transmitted from one piece of equipment to another, and some can insulate the driven equipment shaft against stray electrical currents. Even flexible couplings require a minimal alignment, defined in the instruction sheet for the coupling.

Electrical connections

At some point during the motor installation and alignment process, the motor's electrical connections need to be made. This should be done or supervised by a qualified electrician. Of course, this does not relieve you of maintaining proper lock-out/tag-out procedures.

Disconnecting motors

Disconnecting a motor in a fuels area is relatively simple compared to installing one. First, the motor must be electrically isolated using your lock-out/tag-out procedures and the area must be well ventilated before exposing any electrical connections. Next, check the check the connections with your multimeter to ensure the power is off. Then remove the power leads from the motor terminals and use electrical tape to cover the lead ends. Your next task is to remove the coupling between the motor and driven equipment shafts. Finally, un-bolt the motor mounts so that it can be removed for repair or replacement.

Motor data plate

Whether installing a new motor or replacing an old one, the information from the motor data plate contains valuable information to get either job done. Every motor must be equipped with a data plate at the time of manufacture. The data plate is attached to the motor at the factory before it is shipped, but there are times when the data plate on an in-service motor is missing due to rough handling or some other reason. Do not remove the data plate on any equipment to collect information; instead, write the information down on a piece of paper. An example of information found on a data plate is shown in figure 5–22. This information is necessary in determining circuit requirements for installing the motor. Listed below, in no specific order, is the minimum information required on a motor data plate:

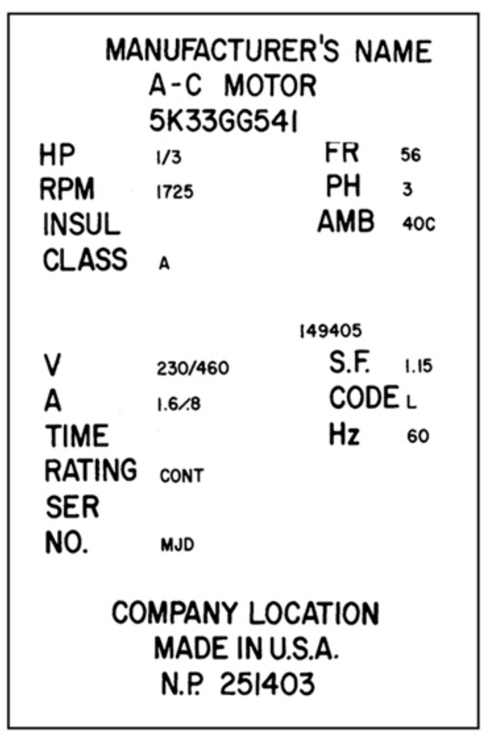

Figure 5–22. Motor data plate.

- Manufacturer's name.
- Rated horsepower (if $1/8$ or more). This determines circuit switch sizes; for example, $1/3$ hp.
- Rated volts and full-load amperes. These show the motor's operating voltage and the current the motor draws under full load. If more than one voltage is indicated, then more than one amperage rating will also be present.
- Rated frequency and number of phases. These show the motor's operating frequency and the required phases to operate the motor (marked as PH).
- Rated temperature rise of the insulation system and rated ambient temperature. This is the motor's maximum operating temperature under normal conditions. Normally, this is listed on a motor data plate as rise 40°C or Ambient 40°C.
- Rated full load speed. This shows the rpm of a motor under full-load condition. For example, rpm 1725.
- Time rating. This tells if the motor is made to run *continuous* or *intermittent*.
- Code letter. The code letter is used for determining the locked rotor kilovolt-amps (the initial current draw of the motor at full voltage from a dead stop) for the motor by using table 430–7 of the *NEC*.
- Design letters. Design letters reflect characteristics inherent to motor design such as locked rotor current, slip at rated load, and locked-rotor and breakdown torque.

Along with required information, some manufacturers furnish data plates with additional useful information, such as the frame (FR) number and service factor (SF). The FR number gives the physical dimensions of a motor. For example: shaft size, mounting configuration, keyway size, and the overall dimensions of a motor. FR numbers are standardized, regardless of manufacturer. This information is shown on the data plate as frame or FR. The SF is the amount of overload a motor can safely carry without damage to the unit. This is determined by multiplying the normal horsepower by the SF. For example, a $1/3$-hp motor with a SF of 1.15 can carry a continuous load of 0.38 hp ($1/3$ times 1.15). The normal SF of most motors is 1.15. This information is found on the motor data plate, normally expressed as SF.

Controller selection

Now that you have selected the motor for a specific job, the motor controller and related equipment must comply with the same requirements. If the motor enclosure must be explosion-proof, then the controller, when installed under the same conditions, must also be explosion-proof. The enclosure must be adequate for the location in which it is installed. These enclosure numbers identify the types of enclosures used:

Type	Requirement
Type 1	Open or general purpose
Type 3	Weather protected
Type 3R	Rain tight
Type 4	Moisture protected
Type 6	Liquid tight
Type 7	Hazardous vaporproof
Type 9	Hazardous dustproof
Type 7 and 9	Hazardous vapor and dustproof
Type 11	Oil emerged
Type 12	Oil tight, dust tight

Any additional information you need might be found in Article 430 of the *NEC*, entitled “Motors, Motor Circuits, and Controllers.”

031. Inspect electrical components and circuits

A good inspection often gives advance notice to potential troubles. At frequent intervals, electric motors should be inspected. When performing these inspections, your senses can provide a means of identifying abnormal conditions. For example, your sense of touch can identify excessive vibration and temperature. A good visual inspection of a motor includes checking for excessive wear and misalignment of shafts, gears, pulleys/belts, and couplings. Your sense of smell can detect burned or overheated windings and bearings. The motor’s frame condition must be checked for excessive dirt, cracks, or damage. Check the bearing area for evidence of vibration, any unusual noise, and excessive temperature.

Preventive maintenance of motors

You must check and maintain an electric motor just like any other piece of mechanical equipment. With proper servicing, a motor lasts longer and gives more efficient service. A few maintenance services are listed below.

Cleanliness

Inspect motors internally and externally for foreign materials, such as dust, dirt, corrosion, and paint. Open-frame motors should be vacuumed out and then may be blown out with compressed air. You should not apply too many coats of paint to motors because the thickness of the coats of paint interferes with heat dissipation.

CAUTION: Air pressure used for cleaning should not exceed 25 psi nozzle pressure. Excessive pressure can damage the insulation on the windings. Wipe all excess dirt, grease, and oil from the surfaces of a motor with a cloth moistened with an approved AF solvent.

WARNING: Never use flammable or toxic solvents for cleaning motors. They may cause injury to personnel or damage to equipment. Also instruct your workers to use the solvent sparingly. It may soak into inaccessible places, and evaporation may be delayed long enough to soften and harm the insulation.

Ventilation

Check the running temperature of all motors. If the motor temperature is hotter than that specified on the nameplate, you must diagnose the trouble. The first thing you check for when diagnosing an overheated motor is restricted ventilation. Inspect the area around the motor for any obstruction that could hamper free air circulation. If air circulation is not hampered in any way and the motor continues to run hot, reduce the load on the motor or use a motor with more power capability.

Lubrication

You should lubricate each motor according to the manufacturer’s lubrication instructions. Improper lubrication causes motor bearings to overheat and eventually causes bearing failure. Check a motor for signs of grease and oil-seal failure. If an inside seal fails, the lubricant can get into the motor windings and deteriorate the insulation. This condition lets dust adhere to the windings and restrict air circulation. When air circulation is restricted, the motor windings will heat. Inadequate lubrication causes the bearings to wear excessively and, eventually, to cease operation. When you lubricate a motor, refer to the manufacturer’s manual to determine the type of lubrication required. Some motors require lubrication with oil; others require grease. Many motor bearings are lubricated and sealed at the factory. The lubricant in these bearings usually lasts the life of the bearings.

Preventive maintenance of motor controllers

You should inspect and service control equipment on the same maintenance schedule as motors. Usually, motor starters can be repaired at the time of inspection on the job site.

Contacts

Check the contacts to make sure of a good electrical connection. When contacts open and close, the rolling and rubbing action keeps the contacts bright and clean; however, infrequently operated contacts, or contacts under heavy load, develop overheating and create oxidation on the contacts. Copper oxidation on contacts creates a poor conductor and must be removed. You may use a fine file, wire brush or light sandpaper, but *never* use an emery cloth.

Silver oxide forms on silver contacts and presents a black, dirty appearance. Although these contacts appear dirty, they seldom need cleaning. The closed pressure of contacts is an important factor in their ability to carry current. A small contact with suitable contact pressure carries more current than a larger one with little or no pressure. Thin contacts are replaced because they lose their contact pressure with wear. You must keep contact springs in good condition. Replace them when they have been damaged or have lost temper by exposure to high temperatures.

Connections

Keep connections clean and tight. Loose connections result in overheated parts that must eventually be replaced. Periodic inspection is necessary because of temperature changes, vibration, and loose connections due to carelessness. Check all wiring for discoloration, which indicates high temperature or loose connections. In some cases, you'll need to replace the wire after you have corrected the cause of the trouble. While we may not have the special equipment to test solid-state components, we can inspect them to see if any of the metal legs have been severed or melted due to an overload.

Movable core

Inspect the movable core in a controller for cleanliness. Accumulated gum and dirt cause sluggish mechanical action that impairs the opening and closing of the contact. The mechanical linkage is designed to require no lubrication. Noise results if the movable and stationary pole pieces do not fit together well when the contactor is closed and when dirt or rust prevents proper closure. The most prominent noise produced in a starter comes from a broken shaded pole (which is the single turn of wire or strap) embedded in part of the laminated magnetic structure.

Cabinet

Check the cabinet housing of the controller for cleanliness. Make sure that the cover fits properly to keep moisture, dirt, and dust from entering. Blow out the cabinet with dry, compressed air. Check for corrosion of all metal parts. They may need cleaning and refinishing.

Self-Test Questions

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

030. Connect and disconnect motors

1. To make sure of trouble-free operation, what factors should you consider when selecting a motor?

2. What type of motor enclosure is designed to prevent liquids or solids from entering it except at indirect angles?

3. What is the maximum ambient temperature for most general-purpose motors?

4. What type of bearings would you find on an electric motor mounted in a vertical position?

5. If a motor shaft is misaligned, what problems can it cause?

6. When disconnecting a motor in a fuels area, what must be done before exposing any electrical connections?

7. List six items found on the data plate of an electric motor.

8. A “type 7” motor controller is used in what type of location?

031. Inspect electrical components and circuits

1. List some of the items to look for when making a visual inspection.

2. What is the maximum air pressure that you can use to clean a motor?

3. What could happen if a motor is lubricated improperly?

4. What would you look for when checking the connections of a motor controller?

5–4. Troubleshooting

Troubleshooting is a systematic, methodical determination of malfunctions, defective components, and parts by indications, signs, and tests. Pay close attention to the procedures in the text, and you’ll reduce the time required to locate the trouble and restore all motorized equipment to its normal operation. Check the easiest possible solutions first. You would be surprised how many problems are due to improper set-up.

032. Motor malfunctions and troubleshooting

Motor failure may be due to many causes. All malfunctions in motors and controls may be corrected, except malfunctions in the internal wiring of the motors. Common malfunctions for motors happen when they will not start, run hot, stop running, operate with excessive noise, and run slowly. Let's take a look at what you should check for with each problem.

Motor will not start

When the motor will not start, perform the following steps:

1. Check all switches to ensure they are on.
2. Check for blown fuses, tripped circuit breakers, and broken or loose connections in starters and other motor controls.
3. Check the line voltage for failure. Use a voltmeter to determine if voltage is being supplied to the magnetic starter. Check the phase-to-phase voltage on the input of the controller to determine whether all line phases are getting power (i.e., at L1, L2, and L3). If the contactor closes, check load connections (i.e., at TI, T2, and T3). If the contactor does not close, you must troubleshoot the control wiring.
4. Check for a bad conductor and connections. Replace any bad conductors and re-establish good connections.

Motor runs hot

When the motor runs hot, perform the following steps:

1. Check for load blockage or hindrance. Partially closed valves at pump discharge, a blocked pump discharge, or worn or damaged pump internal components can cause overheating. Open valves fully. Disconnect the motor shaft from its load at the coupling and rotate each shaft by hand to check for hindrances. Troubleshoot pump (load).
2. Check for an overload. Use an ammeter to check for current overload. Measure the full-load amperage and check against the data plate rating. The overload relay or other over-current device may be faulty or rated too high for motor.
3. Check the rating of the overload relay against the full-load amperage on data plate. If the rating of the relay is too high, replace it with the proper rated relay.
4. Check for deficient voltage supply. Ensure the motor is not operating on under or over voltage. It may be necessary to lighten the load or install a larger motor.
5. Check for proper motor and power connections. Be sure the motor is properly connected to the available voltage.
6. Check for proper ventilation. Clean any dirt from around vents or windings.
7. Check the motor bearings (and any pump bearings) for proper lubrication. Fill oil reservoir or grease according to manufacturer's instructions.
8. Check motor duty classification. Determine whether the motor is rated for intermittent duty. If it is not rated for the service required, replace it with one of proper design.

Motor stops running

When the motor stops running, perform the following steps:

1. Check for power failure.
2. Check for temporary overload failure. Allow sufficient time for the overload device to cool. Push the reset into locked position and push in the start button. If the motor starts, maintain close observation to ensure the motor failure was not due to any severe circumstance. A recurrence would result in serious damage to the motor. Check current draw with an ammeter to determine whether the motor is electrically overloaded.
3. Check for a faulty relay or other overload device. Test the device and replace if necessary. If the motor cannot be restarted, it may be necessary to troubleshoot the motor and controls for additional malfunctions.
4. Check for frozen bearings. It may be necessary to take the motor apart to free the bearings.

6. In a Type III or IV fuel system, check flow switch and non-surge valve opening rate located in piping downstream of pump/motor. A slow opening valve or short timer on flow switch may register a "no-flow" condition prohibiting the pump motor from locking on. This will be discussed further in fuel system operations.

Motor operates with excessive noise
When the motor operates with excessive noise, perform the following steps:

1. Check for dry or worn motor bearings while the motor is in operation. Proper lubrication may stop the excessive noise, providing permanent damage has not been sustained by the bearings. Sufficient damage to the bearings may require that the bearings be replaced. Follow a regular lubricating schedule. Be certain the lubricant is the type suggested by the motor manufacturer.
2. Check the rotor shaft for any up-and-down play (movement). Any noticeable movement indicates worn bearings, which may cause the rotor to drag in the stator. This is probable when belt tension is applied. Replace the bearings if you note up-and-down movement.
3. Check for rotor endplay. This is noted by moving the rotor shaft in and out. Some endplay is not detrimental; however, it should not exceed $^{1}/_{32}$ to $^{1}/_{16}$ of an inch. Excessive endplay may be removed by adding fiber spacer washers.
4. 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.
5. Excessive noise may result from the motor not being securely mounted. You can remedy this condition by tightening the mounting bolts and the motor support securely.
6. Motor may not be mounted on a solid surface. Replacing the mounting surface may quiet the operation of the motor.

Motor operates slowly
When the motor operates slowly, perform the following steps:

1. Check for deficient voltage supply causing the motor to run too slowly. Correct the supply voltage. The voltage must be within 10 percent of the voltage rating for the motor.
2. Check binding of bearings. This may cause the motor to run at less than the rated speed. Lubricate as needed; replace if necessary.
3. Check for a faulty driven load (i.e., pump). If suspected, disconnect the motor from its load and test it independently of the driven load. Load bearing may be binding.
4. Check for excessive motor slippage. Slippage is the lag time between the stator's rotating magnetic field and the rotor's turning speed. All motors have some slippage, but a power loss or a breakdown of the motor's internal wiring can cause excessive motor slippage. If all other factors have been investigated, have an electrician check for this.
5. When troubleshooting single-phase motors, you should 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 single-phase and three-phase motors.

033. Circuit malfunctions and troubleshooting

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

Open circuits
An open circuit can exist at any point between the source of power and the electrical connections of the load. It is necessary to isolate the trouble. This must be done on a step-to-step basis. Refer to

figure 5–23 as you consider how to isolate trouble in a circuit. Disconnect the power and use a multimeter to make point-to-point checks for continuity. Follow each phase from the main disconnect, through the 30 amp disconnect, and through the rest of the control circuit.

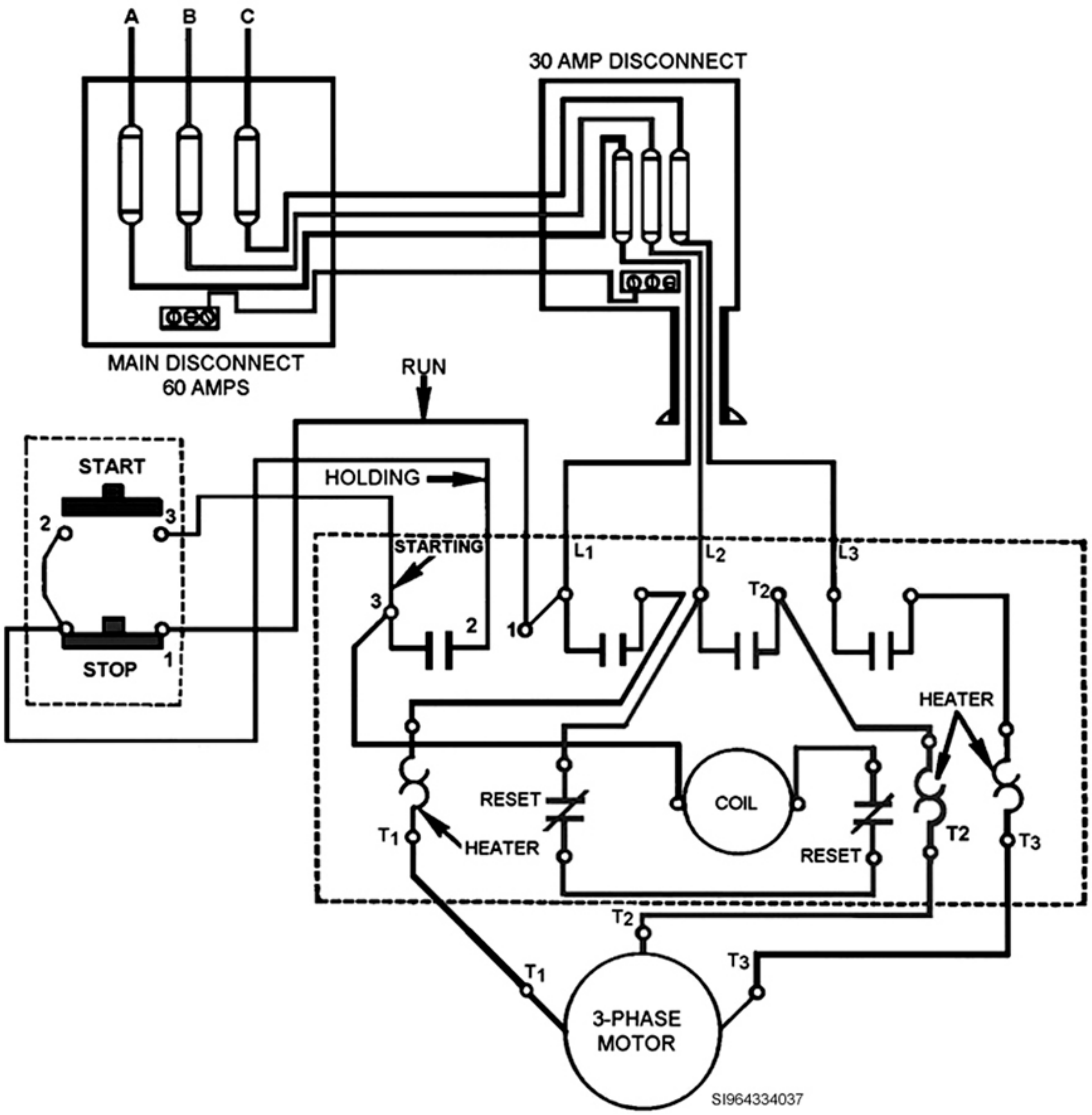

Figure 5–23. Three-phase motor controller connected to a three-phase starter.

With the multimeter, check from the source of power to the line terminals of the starter, making sure continuity exists through each fuse and to the line terminals L1, L2, and L3. Make sure of 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.) 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. Raise 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 to the motor terminals, T1, T2, and T3 of the starter, when the start button is pushed. Check for continuity between the starter terminals L1, L2, and L3, and the motor terminals, T1, T2, and T3.

Grounded circuits

You must follow the same methodical process in finding a grounded circuit as you used to find an open circuit. Start with the source of power and work toward the motor. With the main disconnect open, check with an ohmmeter across each power phase to ground. Follow this step all the way to the starter to make sure that no grounds exist from the source of power to the starter. Any ground existing in the power supply or any conductor connected to L1, L2, or L3 of the starter is indicated at any point tested by a reading of zero or near zero on an ohmmeter.

You must disconnect conductors at certain points to isolate the grounded circuit. One at a time, check across each of the conductors, connected to the start-stop station to ground (conduit), to determine whether a ground exists to the start-stop 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 ground existing in the connected motor is indicated at these points.

If no grounds can be found up to this point, request that an electrician test the motor.

Short circuits

You find short 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. Just like checking for opens and grounds, you begin checking for shorted circuits at the source of power and carry through to the motor windings.

034. Over-current protective devices

We have already discussed overload relays in magnetic starters and thermal relays to protect motors from overheating. There are two more types of protective devices we need to discuss—fuses and circuit breakers.

Fuses

Fuses are designed to protect an electrical circuit from causing fire or irreparable damage to motors and their associated electrical components, such as controls. 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 fuse's metal alloy will melt and open the circuit. The fuse will carry its rated amperage indefinitely but will melt or "blow" if its rated current is exceeded.

Fuses are specifically designed to be installed in such a way 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. The two basic types of fuses include plug fuses and cartridge fuses.

Plug fuses

Plug fuses of the Edison-base type, shown in figure 5–24, screw into sockets similar to an ordinary light socket. Plug fuses are used in low-capacity branch circuits only. They range in size from 0.5 to 30 amps 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. Fuses rated from 0.5 through 15 amps have a hexagonal window, while those rated from 16 through 30 amps have a round window. Plug fuses must be screwed in firmly for good contact, but not tight enough to make them difficult to remove. Edison-base fuses may be used only for replacements in existing installations.

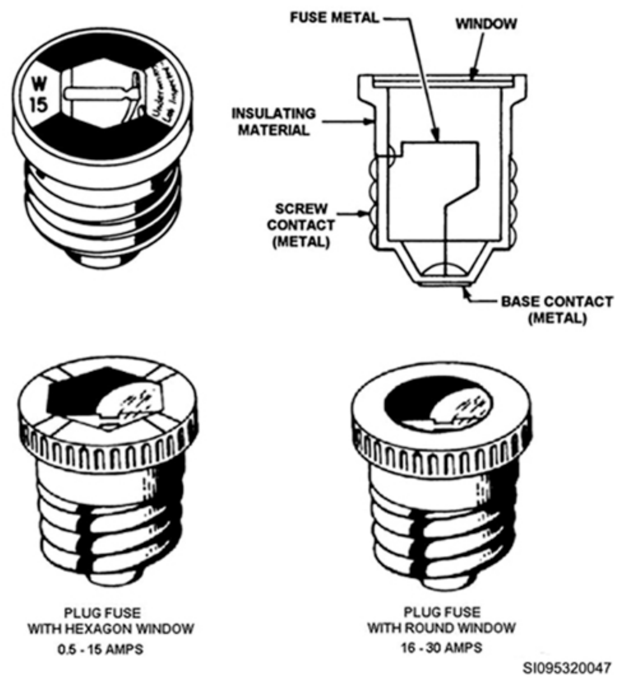

Figure 5–24. Plug fuses—Edison type.

Cartridge fuses

Cartridge fuses are of two types—ferrule and the knife-blade (fig. 5–25). Both types are available with replaceable or non-replaceable fuse links.

Ferrule fuses

The miniature ferrule or glass-tube-type ferrule is commonly used to protect control circuits, alarm systems, and electronic circuitry. Miniature ferrule fuses are rated at a maximum of 250V and low amperage. Ferrule-type fuses are available in amp ratings from 0.5 through 60. Fuse panels that use ferrule-type fuses have specially designed fuse clips in which only ferrule types will 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 utility systems equipment.

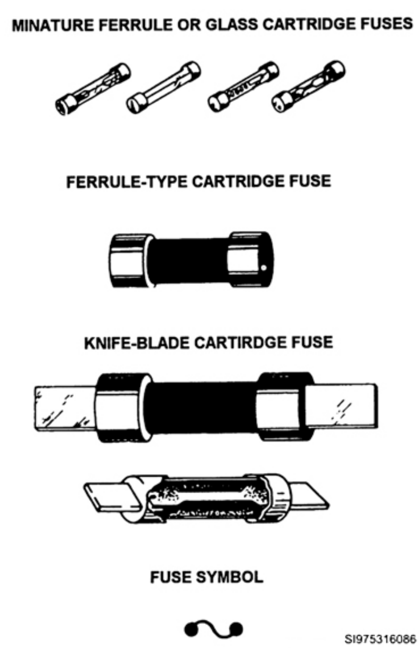

Figure 5–25. Types of cartridge fuses.

Knife-blade fuses

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 amp ratings of 61 through 600. The maximum voltage rating for the knife-blade fuse is 600V.

Two factors must be considered when selecting fuses for circuit protection. These are 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 should 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 will give running protection might blow during the initial period when high starting current is required. Delayed-action fuses are used to handle these situations.

Replacing fuses

Follow safe electrical practices when installing and replacing fuses. Before installing a fuse in a panel, check the condition of the fuse holder or clips. These must be clean and hold the fuse firmly.

Electricians are responsible for the initial installation of fuses, but you may be called on to replace "blown" fuses. *A blown fuse usually indicates that something in the circuit system went wrong and the problem must be corrected.* A good example of this would be a stuck impeller in a pump. The stuck impeller made the motor stop rotating and since the motor is made to rotate, it tried to draw more current. This caused a sharp amperage rise—which blew one or more fuses. Other times, power fluctuation (bump) such as in an electrical storm will blow fuses. If the blown fuse is the right size and type, then you must replace it with an identical fuse. When replacing any fuse, the first step is to de-energize the switch box by moving the switch handle to the OFF position.

CAUTION: Inside a fuse switch box there are pairs of cradle type contacts where the fuses are placed. One contact of each pair will still be "hot" even with the switch handle in the OFF position.

With a plug-type fuse, you will just have to unscrew the fuse and replace with a right size and type. To replace a cartridge fuse, you need to use a special tool, known as a fuse puller (fig. 5–26). You grasp the fuse with the fuse puller and remove it from the fuse holder. To install the replacement fuse, grasp the fuse with the fuse puller and push the fuse into the fuse holder. You will hear and feel a distinctive "snap" that indicates the fuse is secure. As mentioned in the previous paragraph, when replacing any fuse, be sure you replace it with an identical fuse, which will also have the same rating.

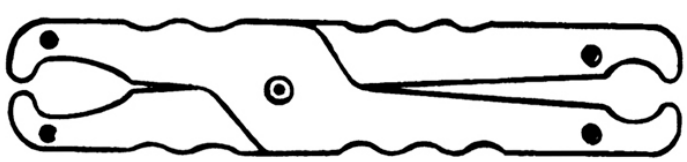

Figure 5–26. Fuse puller.

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. 5–27). A circuit breaker trips when an overload 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. The important thing to remember here is that, just like blown fuses, "tripped" circuit breakers also indicate something went wrong in the circuit. If a circuit breaker trips again after being reset, further investigation of the circuit is needed.

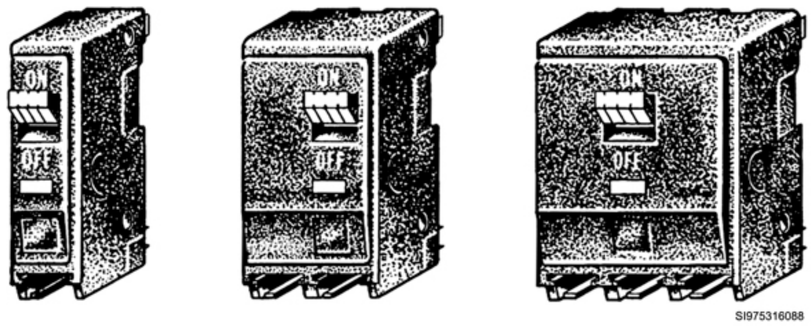

Figure 5–27. Typical circuit breakers.

Remember that fuses and circuit breakers are protective devices. You could also consider them as “warning” devices for our electrical equipment. They are installed to protect us and our equipment from damage and electrical fires.

Self-Test Questions

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

032. Motor malfunctions and troubleshooting

1. List five common malfunctions of motors.

2. Match the malfunctions in column B with their causes in column A. Column B items will be used once or more than once.

Column A	*Column B*
____ (1) Improper ventilation.	a. Motor will not start.
____ (2) Blown fuses.	b. Motor runs hot.
____ (3) Power failure.	c. Motor stops running.
____ (4) Faulty relay.	d. Motor operates with excessive noise.
____ (5) Deficient voltage supply.	e. Motor runs slowly.
____ (6) Dry motor bearings.	
____ (7) Insecure mounting.	
____ (8) Bad conductors.	
____ (9) Faulty driven load.	
____ (10) Voltage failure	

3. When a motor is running hot, how can you determine if load blockage or hindrance is at fault?

4. What instrument should you use to determine whether a motor is overloaded?

5. How can you remove excessive endplay in rotors?

033. Circuit malfunctions and troubleshooting

1. What are three common malfunctions of electrical circuits?

2. Where may an open circuit exist in a motor?

3. How do you know if you have a grounded circuit?

4. What would indicate a short circuit between the main disconnect and the start?

034. Over-current protective devices

1. What are the two additional types of over-current protective devices for electrical circuits?

2. What causes a fuse to "blow"?

3. What are the two types of fuses?

4. Which tool should you use to replace cartridge fuses?

5. What are the three types of circuit breakers?

Answers to Self-Test Questions

024

1. (1) The frame, (2) armature, and (3) endbells.
2. The commutator segments connect the stationary terminals (or brush circuit) to the rotating armature windings.
3. They are bolted to the inside of the frame.
4. Around the pole pieces.
5. The brushes of the brush assembly ride on the surface of the commutator to form the electrical contact between the armature and the external power.
6. To keep the armature in position, house the bearings and complete the frame.
7. The direction in which the current flows through the winding of an electromagnet.
8. The armature's magnetic field is attracted by the magnetic field around the pole pieces.

9. (1) Series, (2) shunt, and (3) compound.
10. A series motor.
11. (a) Series.
    (b) Shunt.
    (c) Compound.

025

1. Stator, rotor, and endbells.
2. Provides an attachment point for the supply voltage.
3. Provides a point to convert electrical energy to mechanical energy and to attach the motor to the load.
4. Laminated iron core with rotor bars and end rings mounted on a framework secured to a shaft.
5. Wire-wound rotor.
6. For variable speed control and low starting current.
7. Rotating magnetic field.
8. (1) The difference in amount of current flow in the three-phase power.
   (2) Reversal in direction of current flow.
   (3) The arrangement of the field winding in the stator core.

026

1. (1) Run winding.
   (2) Start winding.
2. In series with the start winding.
3. To de-energize the start windings after the rotor reaches a predetermined rpm.
4. The power stored in the capacitor increases starting torque.

027

1. To provide exact voltage required for a particular load.
2. An internal core, primary and secondary windings and current flow.
3. The buildup and collapse of the magnetic field in the primary winding causes the induction in the secondary winding.
4. Step up transformer.
5. 20V.

028

1. (1) Manual.
   (2) Magnetic.
2. A device mechanically operated to control a motor from a single point.
3. Overload device.
4. The contactor and the overload relay.
5. L1, L2, L3, T1, T2, T3.
6. The operating coil.
7. To provide a time delay to prevent contact chatter and moving parts wear.
8. (1) Thermal.
   (2) Magnetic.
9. (1) Bimetallic and (2) melting-alloy.
10. The full load current rating; on the motor data plate.

029

1. (1) Load circuit.
   (2) Control circuit.
2. It is the portion of the starter that starts, stops, controls, and protects the motor.
3. Auxiliary contacts.
4. Three. Each ungrounded phase must have an overload device.
5. (1) Float switch.
   (2) Pressure switch.
   (3) Thermostat.
   (4) Photocells.
6. (1) Diodes. (2) transistors, (3) integrated circuits.
7. Transistors.
8. It is a single small unit composed of interconnected semi-conductor circuitry.

030

1. (1) Physical location.
   (2) Ambient temperature.
   (3) Duty.
   (4) Bearings.
   (5) Voltage.
   (6) Mechanical connection to load.
   (7) Motor data plate.
2. Splash-proof.
3. 40°C or 104°F.
4. Ball or roller bearings.
5. Excessive vibration, noise, coupling and bearing temperature increases, and premature coupling or bearing failure.
6. Ensure the area is well ventilated.
7. Any six of the following eight: Manufacturer's name; rated horsepower; rated volts and full load amperes; rated frequency and number of phases; rated temperature rise of insulation system and rated ambient temperature; rated full load speed; time rating; code letter; and design letters.
8. In a location where hazardous vapors are present.

031

1. Check for excessive wear and misalignment of shafts, gears, pulleys/belts, and couplings.
2. 25 psi.
3. Can cause motor bearings to overheat and cause bearing failure, excessive wear to the bearing, and seizures.
4. Connections should be clean and tight. Check all wiring for discoloration.

032

1. (1) Motor will not start.
   (2) Motor runs hot.
   (3) Motor stop running.
   (4) Motor operates with excessive noise.
   (5) Motor runs slowly.

2. (1) b.
   (2) a.
   (3) c.
   (4) c.
   (5) b.
   (6) d.
   (7) d.
   (8) a.
   (9) e.
   (10) a.
3. By disconnecting the motor from its load and rotating the rotor shaft of the motor by hand.
4. An ammeter.
5. By adding fiber spacer washers.

033

1. (1) Open, (2) grounded, and (3) shorted circuits.
2. At any point between the power source and the electrical connections of a load.
3. When you get a test reading of zero or near zero on your meter when testing for ohms.
4. If continuity exists across any two conductors.

034

1. (1) Fuses and (2) circuit breakers.
2. Current flow exceeds the fuse’s rating which melts the alloy wire or ribbon.
3. (1) Plug fuses and (2) cartridge fuses.
4. A fuse puller.
5. (1) Thermal, (2) magnetic, and (3) combination thermal-magnetic.

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).

69. (024) In a direct current (DC) motor, how are coil ends from the armature windings attached to a commutator (riser)?
    a. Brazed.
    b. Welded.
    c. Wedged.
    d. Soldered.

70. (024) A direct current (DC) shunt motor has the field coils and armature connected in
    a. series.
    b. parallel.
    c. series-parallel.
    d. parallel-series.

71. (025) What part of a three-phase motor is connected to the supply voltage?
    a. Centrifugal switch.
    b. Base.
    c. Rotor.
    d. Stator.

72. (025) The component of a three-phase motor that converts electrical energy to mechanical energy is the
    a. armature.
    b. end bell.
    c. rotor.
    d. stator.

73. (025) The magnetic field of a three-phase motor rotor is caused by
    a. resistance in the squirrel cage.
    b. current flow in the rotor.
    c. impedance of the stator.
    d. voltage in the end bells.

74. (026) A centrifugal switch is used in a single-phase motor to
    a. de-energize the field windings.
    b. de-energize the start windings.
    c. engage the run windings.
    d. engage the power leads.

75. (027) A step-up transformer produces a secondary voltage
    a. higher than the primary voltage and a secondary current lower than the primary current.
    b. lower than the primary voltage and a secondary current higher than the primary current.
    c. and current higher than the voltage and current in the primary.
    d. and current lower than the voltage and current in the primary.

76. (028) Normally, an across-the-line motor control stops and starts a motor and provides some type of
    a. motor over-current protection.
    b. lightning protection.
    c. motor speed control.
    d. frequency control.

77. (028) In a magnetic motor control, when the operating coil is energized, what component does it attract?
    a. Rotor.
    b. Armature.
    c. Overload relay.
    d. Main contacts.

78. (028) Devices used in magnetic across-the-line motor controllers to prevent contact chatter are referred to as
    a. mechanical latches.
    b. plastic bumpers.
    c. shaded rings.
    d. an arc chute.

79. (028) What are the two types of thermal overload relays in magnetic controls?
    a. Bimetallic and melting-alloy.
    b. Catalytic and filament.
    c. Trimetallic and fused.
    d. Fused and non-fused.

80. (029) On an across-the-line magnetic starter, the methods used to open the contacts when the electromagnetic coil is de-energized are
    a. spring tension and gravity.
    b. metallic and magnetic.
    c. thermal and hydraulic.
    d. magnetic and thermal.

81. (029) Which one of these is *not* a basic solid-state component?
    a. Diode.
    b. Transistor.
    c. Circuit breaker.
    d. Integrated circuit.

82. (029) Which type of controller provides a highly accurate method of motor starting and speed control?
    a. Solid-state starter.
    b. Single-phase.
    c. Three-phase.
    d. Manual.

83. (030) What are the two functions or duty classifications of motors?
    a. Continuous- or intermittent-duty.
    b. Permanent- and transient-duty.
    c. Heavy- and light-duty.
    d. High- and low-duty.

84. (030) Which is *not* a type of shaft misalignment?
    a. Combination.
    b. Angular.
    c. Skewed.
    d. Parallel.

85. (031) When you clean a motor with compressed air, what is the *maximum* air pressure to use in pounds per square inch (psi)?
    a. 15.
    b. 25.
    c. 35.
    d. 50.

86. (031) What should be your *first* check on a motor that seems to be overheating?
    a. Load too big for the motor.
    b. Shorted windings.
    c. Ventilation.
    d. Wire size.

87. (032) If a *normally* operating motor suddenly stops, you should suspect
    a. overvoltage.
    b. worn brushes.
    c. electrical overload.
    d. improper connections.

88. (032) Rotor endplay should *not* exceed
    a. $^1/_{64}$ to $^1/_{32}$ of an inch.
    b. $^1/_{32}$ to $^1/_{16}$ of an inch.
    c. $^1/_{16}$ to $^1/_{18}$ of an inch.
    d. $^1/_8$ to $^1/_4$ of an inch.

89. (032) A motor that operates slowly may have a
    a. deficient voltage supply.
    b. ventilation problem.
    c. bad conductor.
    d. blown fuse.

90. (032) What percentage of the motor's voltage rating *must* a motor supply voltage be within?
    a. 1.
    b. 3.
    c. 5.
    d. 10.

91. (033) Which is *not* a circuit fault?
    a. Open.
    b. Closed.
    c. Shorted.
    d. Grounded.

92. (033) If a ground exists in a conductor you are testing, you will get a reading of
    a. zero on an ammeter.
    b. zero on an ohmmeter.
    c. infinity (∞) on an ammeter.
    d. infinity (∞) on an ohmmeter.

93. (033) What *circuit* fault exists if there is continuity across any two conductors?
    a. Open.
    b. Closed.
    c. Shorted.
    d. Grounded.

94. (034) To which effect of current flow does a fuse react?
    a. Heat.
    b. Magnetism.
    c. Physical shock.
    d. Chemical change.

95. (034) How are fuses rated?
    a. Voltage and watts.
    b. Watts and amperage.
    c. Amperage and power.
    d. Voltage and amperage.

96. (034) A hexagon window on a plug fuse indicates that the amperage rating is between what values?
    a. 0.5 and 15 amperes (amps).
    b. 16 and 30 amps.
    c. 31 and 45 amps.
    d. 46 and 60 amps.

97. (034) Two types of cartridge fuses are knife-blade and
    a. renewable.
    b. plug-in.
    c. ferrule.
    d. type S.

98. (034) What is the *first* step in replacing a fuse?
    a. Get tools.
    b. Obtain a fuse.
    c. Call an electrician.
    d. De-energize the switch box.

99. (034) What will happen when a circuit breaker is in an overload condition?
    a. Trip.
    b. Melt.
    c. Blow.
    d. Alarm.

100. (034) The three classes of circuit breakers are thermal, magnetic, and
    a. time-delay.
    b. bimetallic alloy.
    c. thermal-magnetic.
    d. conductor-insulator.

Glossary of Symbols, Abbreviations, and Acronyms

°	degree
Ω	schematic symbol for ohms/omega
∞	infinity
→+	continuity
a or A	quantity of amps
AC	alternating current
a.k.a.	also known as
AF	Air Force
AFB	Air Force base
AFI	Air Force instruction
amp	ampere
ANSI	American National Standards Institute
AFPD	Air Force policy directive
APR	air purifying respirator
AVGAS	aviation gasoline
bbl	barrel
BC	before Christ
BE	bioenvironmental engineering
bph	barrels per hour
C	Celsius
cc	cubic centimeter
CDC	career development course
CE	civil engineer (engineering)
CEI	CE environmental engineering
CEIE	civil engineering environmental and infrastructure engineering
CFR	Code of Federal Regulations
cfs	cubic feet per second
CI	corrosion inhibitor
COM	common
CPR	cardiopulmonary respiration
D	distance
DC	direct current
DD	Department of Defense

DOD	Department of Defense
DOT	Department of Transportation
E	voltage (symbol used in math formulas)
emf	electromotive force
EMS	emergency medical service; Environmental Management System
EPA	Environmental Protection Agency
ESOHCAMP	environmental, safety, and occupational health compliance assessment and management program
F	Fahrenheit/force
FLC	full load current
fps	feet per second
FR	frame
F/S	filter separator
FSII	fuel system icing inhibitors
ft-lbf/min	foot-pounds force per minute
ft-lbf/sec	foot-pounds force per second
gal.	gallon
gpm	gallons per minute
HAZCOM	hazard communication
HAZMAT	hazardous material
hp	horsepower
Hz	hertz
I	intensity of current
IC	integrated circuit
IDLH	immediately dangerous to life and health
in^2	square inch
lb.	pound
LED	light-emitting diodes
LEL	lower explosive limit
MA	mechanical advantage
MEP	Master Entry Plan
mil amp	milliamperes
MIL-STD	military standard
min	minute
mm Hg	millimeters of mercury
MOGAS	automotive gasoline
MSDS	material safety data sheet

mV	millivolt
NATO	North Atlantic Treaty Organization
NEC	*National Electric Code*
NEPA	National Environmental Policy Act
NIOSH	National Institute for Occupational Safety and Health
OI	operating instruction
OL	overload
ORM	operational risk management
O&M	operations and maintenance
OSHA	Occupational Safety and Health Administration
PCB	poly chlorinated biphenyls
pcf	pounds per cubic foot
PCS	permanent change of station
PH	phases
POL	petroleum, oils, and lubricants
PPE	personal protective equipment
ppm	parts per minute
psi	pounds per square inch
psi/ft	pounds per square inch/foot
psia	pounds per square inch absolute
PV	photovoltaics
R	resistance (symbol used in math formulas)
rpm	revolutions per minute
RPP	respiratory protection program
SAR	supplied air respirator
SCBA	self-contained breathing apparatus
SCR	silicon-controlled rectifier
SDA	static dissipating additive
sec	second
SF	service factor
SME	subject matter expert
TDY	temporary duty
TEL	tetraethyl lead
TO	technical order
UEL	upper explosive limit
UN	United Nations
US	United States

USAF	United States Air Force
V	volts
VAC	volts, alternating current
W	work
WFSM	Water and Fuel Systems Maintenance

Student Notes

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