10

Fluid Power Systems

Basic Concepts

- Recognize the differences between hydraulic and pneumatic power systems.
- Identify the advantages of using fluid power systems.
- List the uses of valves in fluid power systems.
- State the physical characteristics of liquids used in fluid power systems.
- Recognize why hydraulic cylinders can increase mechanical advantage.

Intermediate Concepts

- Give examples of various applications of fluid power systems.
- Explain the difference between gauge pressure and absolute pressure.
- Describe the operation of directional-control valves.
- Summarize the differences between how single-acting and double-acting cylinders operate.
- Discuss the safety concerns when working with liquids and gases under pressure.
- Interpret a basic fluid power circuit.

Advanced Concepts

- Calculate the mechanical advantage created by using liquids under pressure.
- Compute the size of cylinders necessary to perform a specific application.
- Design simple fluid power circuits that are controlled by electricity.

Ancient societies found many uses for the movement of water. Common uses included simple plumbing systems to circulate fresh water and to move crude transportation vehicles, such as rafts and hollowed-out logs. Early societies found that by using the fluid properties of water, their work could be made easier. See **Figure 10-1.** Fluid power systems use the energy found in liquids and gases to perform work.

Figure 10-1. The waterwheel is a fluid power system, since the water (fluid) operates the machines. A—This Illinois gristmill was built in the 1850s and is powered by an external waterwheel. B—An unusual mill with an interior waterwheel is on George Washington's Mount Vernon plantation in Virginia. Opening the sluice gate allowed water from the millrace to turn the wheel that powered grinding stones.

This chapter focuses on the technology involved in using fluid power systems to perform work. The principles behind hydraulic and pneumatic systems will be explained. The devices used to control the fluid power will also be described.

What Are Fluid Power Systems?

Hydraulic system: A system that controls and transmits energy through the use of liquids.

The study of fluid power systems includes both hydraulics and pneumatics. ***Hydraulic systems*** control and transmit energy through the use of liquids, such as oil and similar liquids. Various components have been developed to control liquids under pressure so they can do work for us. These components include cylinders, pumps, and transmission lines. See **Figure 10-2.** In pneumatic systems, gases are used in place of liquids. Air from our atmosphere is the gas most commonly used. The properties of gases and liquids are the same in many ways, and both can be described as fluids.

Career Connection

Distributors

Transportation, Distribution & Logistics

Power converters are used to change one form of power into another form of power. An example of power conversion is the changing of mechanical power into electricity. A generator is the machine power distributors use to convert power in this way.

Power distributors operate and monitor the equipment used in electrical distribution. It is their job to maintain and repair the machines. In order to keep equipment functioning properly, it is imperative to monitor and sustain quality. In order to perform these tasks, distributors must be proficient in the use of hand tools.

To properly manage electrical distribution, distributors must be familiar with mathematical functions. They should also have an understanding of mechanics and engineering. To be a worker in this field, long-term on-the-job training is required. The yearly salary may range from $39,000 to $83,000.

Why Use Fluid Power?

Fluid power systems involve the transfer of mechanical energy. The primary advantage of fluid power is the ability to multiply force in order to generate strength. Also, the components used in fluid power systems experience less wear than purely mechanical systems. Other advantages of fluid power systems include the following:

- An almost unlimited amount of power can be produced and maintained in a fluid power system.
- Easy and complete control can be maintained over a wide range of power in a fluid system. This allows for smooth, quick control of energy transfer.
- Gases used under pressure have a natural springiness, which produces a cushioning effect. This reduces shock in the system.
- The components in fluid power systems can be located far apart from each other, but still quickly transfer power.

Fluid power systems offer a wide range of mechanical functions. They are used to produce linear and rotary motion, while remaining mechanically efficient. Many industries that use modern technology employ fluid power systems, such as manufacturing plants, construction sites, farms, and manufacturing parts of vehicles that transport people and cargo worldwide. See **Figure 10-3.**

Figure 10-2. Hydraulic cylinders are able to lift heavy loads, such as the bed of this large dump truck.

Figure 10-3. Fluid power is widely used on construction projects. A—Several hydraulic cylinders are used to operate this end loader. B—One of the uses of pneumatics is to power tools, such as this jackhammer.

A

B

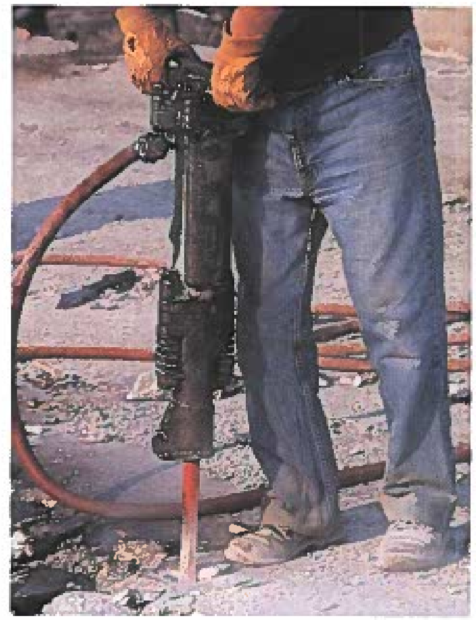


Figure 10-4. The type of water tanks used by communities to store water and provide good flow into water taps must be built to withstand tremendous pressure due to the weight of the water stored in them.

The Physics of Fluid Power Systems

The liquids and gases used in fluid systems have some similar characteristics. They exert pressure, take the shape of their container, and can flow freely from one container to another. These characteristics have been studied and used for centuries. Learning these characteristics is important to understand fluid power systems.

Fluids Exert Pressure

Long ago, scientists found that liquids exert pressure in all directions, not only on the bottoms of their containers. Because pressure is caused by the amount (weight) of liquid in a container, more pressure is exerted on its lower sides. The more liquid a container holds, the more weight pushes down and out. For this reason, large tanks that hold water and oil are made so the bottom is stronger than the top. See **Figure 10-4.**

How Fluids Act

Water and other fluids will flow from a higher level to a lower level, until both levels are the same. Fluids will also flow from an area of high pressure to an area of low pressure. The fluid will continue flowing until the pressure in both areas are equal. In **Figure 10-5,** notice that the containers are connected by a pipe at the bottom. The water begins at different levels, but water flows between the containers until the water in each container reaches the same level. If one container constantly held a higher level of water, it would exert more pressure than the container holding a lower level of water. The system is balanced when each container is filled with water to the same height, regardless of the shape or size of the container.

Measuring Effort and Rate in Fluid Systems

As with all forms of power, specialized instruments allow power to be measured. See **Figure 10-6.** A ***pressure gauge*** measures the difference between the pressure within a fluid circuit and the pressure in the surrounding atmosphere. This is typically measured in pounds per square inch (psi). The rate of flow in fluid power systems is typically measured with a ***flowmeter***. Standard units of measurement for rate of flow include gallons per minute (GPM) for liquids and cubic feet per minute (CFM) for gases. Other units of measure that indicate some type of flow per amount of time may be used as well.

When measuring pressure, there are two classifications of pressure gauge measurements that can be used: pounds per square inch gauge (psig) pressure and pounds per square inch absolute (psia) pressure. Most measurements are taken with a psig instrument. ***Pounds per square inch gauge (psig)*** pressure instruments do not

Figure 10-5. Imagine two containers connected by a tube. A—If you were to start filling one of the containers, it would also start filling the other one. B—Once the flow of water stops, the water flow continues into the other container until the water levels are equal.

A

B

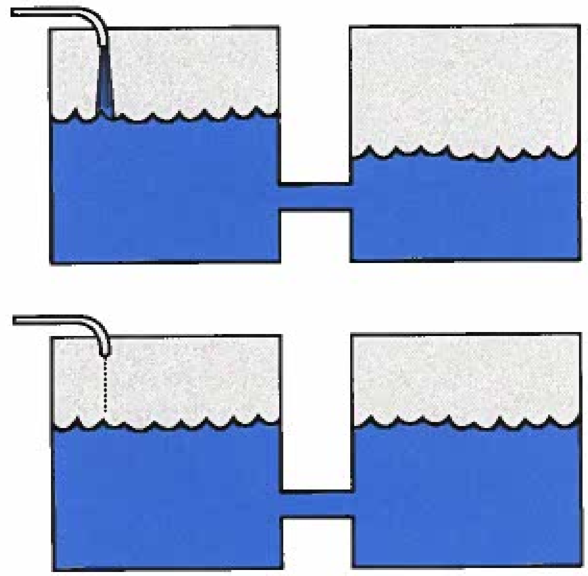
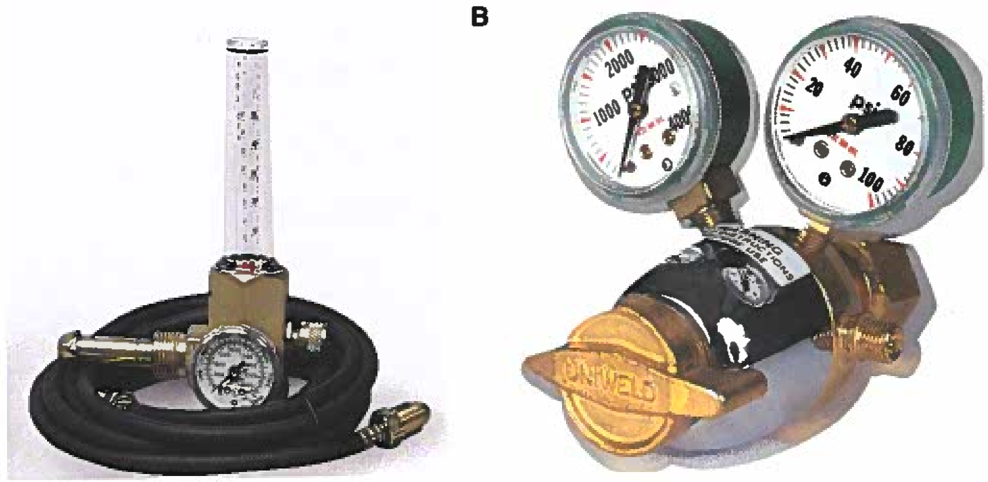


Figure 10-6. Fluid power systems make use of flowmeters and pressure gauges. A—This flowmeter measures the rate of flow of carbon dioxide (CO_2) gas in cubic feet per minute (CFM). (Miller Electric Manufacturing Company) B—A pressure gauge used with welding gas cylinders. One gauge measures the higher pressure of oxygen gas, and the other measures acetylene, which must be delivered at a lower pressure. Both are measured in pounds per square inch (psi). (Uniweld)

A

B



Pressure gauge: A device that measures the difference between the pressure within a fluid circuit and the pressure in the surrounding atmosphere.

Flowmeter: A device that measures the rate of flow in fluid power systems.

Pounds per square inch gauge (psig): A pressure instrument that determines the approximate pressure developed in a fluid circuit but does not take atmospheric pressure into account.

take atmospheric pressure into account, but they are adequate for determining the approximate pressure developed in a fluid circuit. A ***pounds per square inch absolute (psia)*** pressure gauge accounts for atmospheric pressure in its measurement. While a psig reading indicates 200 psi, for example, a psia gauge reading of the same pressure would indicate 214.7 psi. The psia gauge reading accounts for 14.7 psi at sea level. The psia gauge reading would decrease slightly if taken above sea level and increase slightly if taken below sea level.

Pounds per square inch absolute (psia): A type of pressure gauge that accounts for atmospheric pressure in its measurement.

Viscosity of Liquids

Viscosity is a measurement of internal friction, or the resistance of a fluid to flow. For example, pancake syrup does not flow as freely out of a bottle as water does. This is because water has a lower viscosity rating than pancake syrup. Likewise, different hydraulic oils have different viscosity ratings. The viscosity rating is based on the length of time it takes a given quantity of fluid, such as a quart, to flow through a fixed opening at a specified temperature. This is exactly how engine oil gets its winter-summer rating, such as 10W-40. The viscosity requirement for different applications depends on temperature, pressure, and the specifications of the hydraulic components within the fluid circuit.

Viscosity: A measurement of internal friction, or the resistance of a fluid to flow.

Opposition to Flow in Fluid Systems

There are two types of opposition to flow that occur in fluid power systems:

- Friction occurs when fluid is forced under pressure through pipes, hoses, and fittings.
- Opposition to flow can occur within the liquid itself and is known as ***turbulence***.

You may consider fluids, particularly hydraulic oils, to be relatively friction free. Plenty of effort or pressure can be lost due to friction, however, particularly if hydraulic lines or fittings are undersized. When fluids flow smoothly, they flow in stratified layers that may not be visible to the eye. This type of smooth flow is referred to as ***laminar flow***. Turbulence typically occurs when the fluid reaches a juncture point, such as a tee in the fluid circuit. The laminar lines of flow become interwoven. Internal losses are much greater in turbulent flow than in laminar flow. Other factors that affect opposition to flow in fluid circuits include the following:

- Length of the fluid circuit.
- Friction factor of the conductors used to carry fluid.
- Interior diameter of the conductors.
- Head loss (losses due to pumping fluid upward).

Turbulence: The opposition to flow that occurs within a liquid itself.

Laminar flow: The smooth flow of liquids in stratified layers that may not be visible to the eye.

Components of Fluid Power Systems

Like other power systems, fluid power systems require various components to operate together to perform work. When planning and designing these circuits, the engineers or drafters make schematic drawings that describe fluid circuits on paper. See **Figure 10-7.** Some of the components are used to produce the pressure, some components control

Figure 10-7. Drafters and engineers use symbols to represent different parts of pneumatic or hydraulic systems when drawing or designing systems.

Typical Fluid Power Symbols			
Connector	•	Flowmeter	
Line, flexible		Pressure gauge	
Motor, oscillating		Temperature gauge	
Line, joining		Pump, single fixed displacement	
Line, passing		Motor, rotary fixed displacement	
Flow direction hydraulic pneumatic		Motor, rotary variable displacement	
Manual shut-off valve		Electric motor	
Cylinder, single-acting		Lever	
Cylinder, double-acting		Spring	

GREEN TECH
Some hydraulic fluids can cause some damage to the environment. Those that are not made from natural resources, such as vegetable oil, may leak into soil or contaminate the water. This can cause damage to aquatic ecosystems.

the pressure, and others make the pressure do the necessary work. While most devices are designed specifically for use in either hydraulic or pneumatic power systems, some are used in both types of systems.

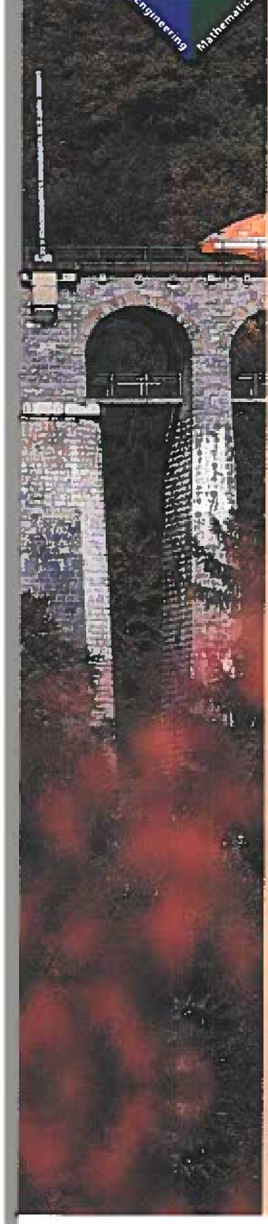
Hydraulic Pumps

Hydraulic pumps supply and transmit the pressure needed to operate a hydraulic power system. These pumps convert mechanical energy into fluid power, creating the necessary flow in the system. Pumps have many applications in modern industry and technology:

- Moving water and coolant around boilers and nuclear reactors.
- Powering hydraulic cylinders for industrial and earthmoving equipment.
- Moving water out of ship bilges.
- Supplying the power to assist automobiles in braking and steering.
- Moving bulk liquids from the holds of ships.
- Powering pneumatic clamping and drilling equipment.
- Moving clean water in the plumbing systems of skyscrapers.

Hydraulic pump: A pump that supplies and transmits the pressure needed to operate a hydraulic power system. It converts mechanical energy into fluid power, creating the necessary flow in the system.

STEM Connection



Science: The Human Heart

The human heart is the ultimate fluid pump. A healthy heart is only slightly larger than your fist, yet it will beat about 100,000 times per day, resulting in the flow of approximately 2000 gallons of blood. Over the course of a 70-year lifespan, it is estimated that the heart will beat more than 2.5 billion times.

The heart consists of four chambers and four valves. See **Figure 10-A.** The upper two chambers are known as the left and right atria. The lower two are the left and right ventricles. The four valves are as follows:

- The tricuspid valve is located between the right atrium and the right ventricle.
- The pulmonary valve is located between the right ventricle and the pulmonary artery.
- The mitral valve is located between the left atrium and the left ventricle.
- The aortic valve is located between the left ventricle and the aorta, which is the main artery of the body carrying refreshed oxygen-rich blood to all major organs of the body.

Each valve has a set of "flaps" called *cusps*. The cusps are one-way flow control devices, similar to check valves in fluid power systems. Dark blood that is low in oxygen (and appears blue in your veins), flows back to the heart after circulating through the body. The veins return the blood from your body to the right atrium of the heart. This chamber empties blood through the tricuspid valve into the right ventricle when the heart beats. The right ventricle then pumps the blood under low pressure through the pulmonary valve into the pulmonary artery. The pulmonary artery is a main artery that takes the blood to the lungs, where the blood gets fresh oxygen.

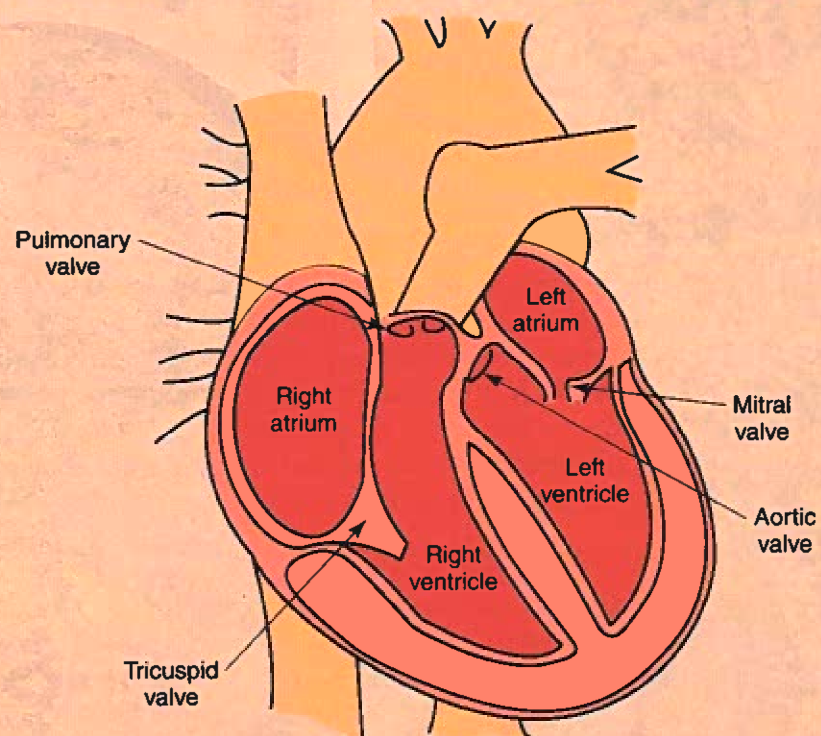
After the blood is refreshed with oxygen, it is bright red. It returns by the pulmonary veins to the left atrium. From there, it passes through the mitral valve and enters the left ventricle of the heart. This is the last stop for the oxygen-rich blood in the heart. The left ventricle pumps the refreshed blood out through the aortic valve into the aorta, which routes the blood to the rest of the body. Since the left ventricle is the last stop for blood within the heart, the blood pressure in the left ventricle is the same as the pressure measured in your arm.

The heart itself could be thought of as the first two-stage pump ever created. The right ventricle pumps the blood under lower pressure through the pulmonary arteries and veins to the left ventricle, where it is pumped at a higher pressure for circulation throughout the body. When the heart muscle contracts, or beats, it pumps blood out of the heart. This is

All pumps can be classified as either positive-displacement or nonpositive-displacement pumps. Positive-displacement pumps deliver an identical amount of fluid for every stroke of a linear pump or every rotation of a rotary pump. Nonpositive-displacement pumps deliver varying amounts of fluid to the load. If a valve is closed, preventing fluid from flowing to the load, a nonpositive-displacement pump can simply circulate fluid within the pump chamber. The fluid does not have to go anywhere, but this could cause it to heat up over time.

referred to as the *systole*, or *systolic action*. The heart contracts in two stages. First, the right and left atria contract at the same time, pumping blood to the right and left ventricles. The two ventricles then contract together to propel blood out of the heart. Lastly, the heart muscle relaxes before the next heartbeat. This allows blood to fill up the heart again. This relaxation period is referred to as the *diastole*. You may have heard of the systolic and diastolic readings when your blood pressure is taken. These readings are measurements of your heart at work and heart at rest. The heart is a very efficient fluid pump in a small package.

Figure 10-A. Each chamber of the heart has a one-way valve at its exit, which prevents blood from flowing backward. The valve at each exit opens when the chamber contracts. It closes when the chamber is finished contracting, so blood does not flow backward.

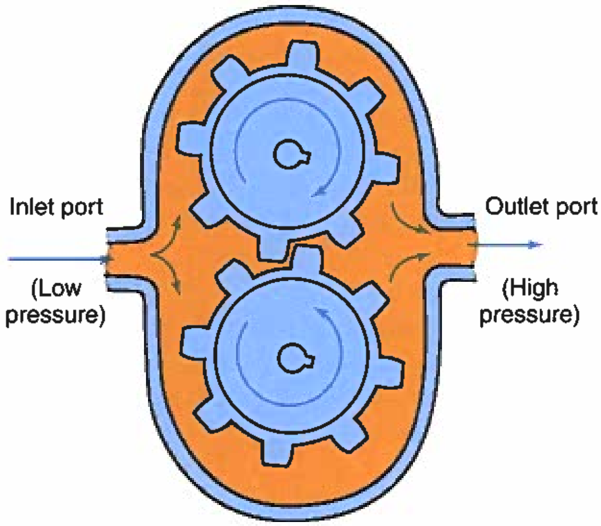


Gear pumps

Gear pumps create the pressure needed to operate many hydraulic systems. In this type of pump, two gears are positioned so they mesh with each other inside a housing. See **Figure 10-8.** One gear is turned by a power source and turns the other gear in the opposite direction. Oil enters the pump through the low-pressure port on one side of the housing. It is drawn through the housing by the two spinning gears. This action forces the oil around the gears and to the other side of the housing, where it exits through the high-pressure port. The oil under pressure is then used to do work.

Gear pump: A pump in which two gears are positioned so they mesh with each other inside a housing.

Figure 10-8. The inside of a gear pump. Two gears, one driven by a power source, pull the fluid into the pump housing and place it under pressure at the outlet port.



Centrifugal pumps

Centrifugal pumps are also used to produce pressure in a hydraulic system. This type of pump uses centrifugal force to move fluids in the system. *Centrifugal force* is the energy that makes objects fly outward when spinning around. It is this force that keeps water in a bucket when you swing it over your head very fast. Centrifugal pumps use a device commonly found in many propulsion systems and other pumps called an *impeller*. An ***impeller*** is a device that has many small blades mounted on a shaft. As the impeller spins inside its housing, it draws liquid through the inlet port from a ***reservoir***, or container. Because the impeller is driven from an outside power source, it can be made to spin very fast. The movement of the impeller forces the liquid outward against the housing, through the outlet port, and to the rest of the system. See **Figure 10-9.**

Centrifugal pump: A pump that uses centrifugal force to move fluids in a system.

Centrifugal force: The energy that makes objects fly outward when spinning around.

Reciprocating pumps

Reciprocating pumps use a piston that moves back and forth in a cylinder to move hydraulic fluid. Each stroke of the piston moves a certain volume of liquid through the system. See **Figure 10-10.** Each time the piston moves in the cylinder, it forces oil out of the cylinder. *Check valves* are needed when using reciprocating pumps to keep fluid from moving backward in the system. A hand water pump is a simple type of reciprocating pump you may have used to move water. See **Figure 10-11.**

Air Compressors

Pneumatic systems use *air compressors* in the same way hydraulic systems use hydraulic pumps. Air compressors convert the mechanical energy put into pneumatic power systems. This conversion creates the necessary flow to make the system work. Compressors are often teamed up with reservoirs or pressure tanks to store and transmit compressed air to the power system whenever it is needed.

The most common air compressor is also the reciprocating type. See **Figure 10-12.** A piston moves up and down (reciprocates) inside a cylinder. The piston is powered by an external power source, such as an electric motor. There are two *valves* at the top of the cylinder that let air pass in only one direction. As the piston moves down, it creates suction in the cylinder that opens the intake valve and lets air into the cylinder. As the piston moves

Figure 10-9. The inside of a centrifugal pump. As the impeller spins, fluid is forced off the vanes and becomes pressurized as it moves out of the pump housing.

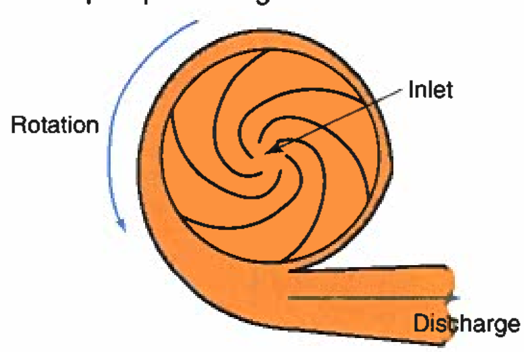


Figure 10-10. A reciprocating pump has a piston driven by a shaft, located off center, on a revolving wheel or crankshaft. Note the action of the intake and delivery valves as the direction of the piston changes.

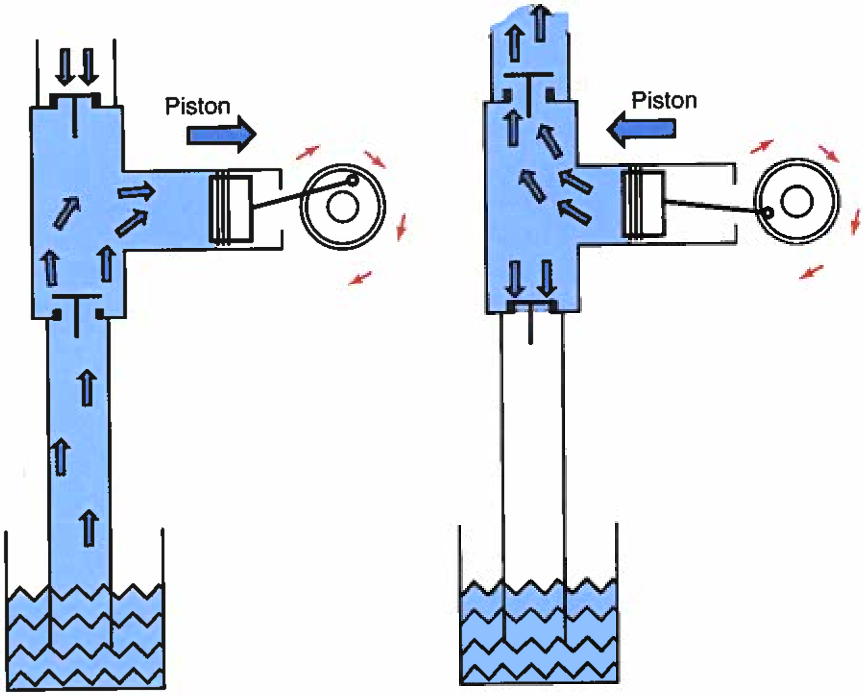
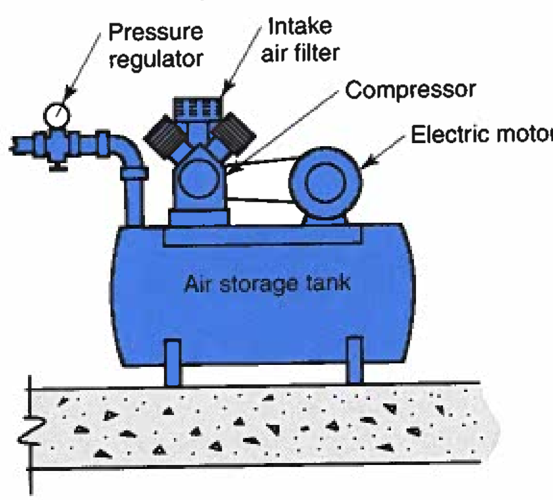


Figure 10-11. A simple hand-operated water pump. You may have used one like it.

Figure 10-12. Air compressors that use a reciprocating-type pump are common in automotive shops.



Impeller: A device that has many small blades mounted on a shaft. It spins inside its housing, drawing liquid through the inlet port from a reservoir.

Reservoir: A container to hold liquids to be used again in a system.

Reciprocating pump: A type of pump with a piston that moves back and forth in a cylinder to move hydraulic fluid.

Check valve: A valve needed when using reciprocating pumps to keep fluid from moving backward in the system.

Air compressor: A device that converts the mechanical energy put into pneumatic power systems creating the necessary flow to make the system work.

Valve: A part of an air compressor at the top of the cylinder that lets air pass in only one direction.

up, the intake valve shuts, and air is compressed in the cylinder until the outlet valve opens. The air then enters the receiver, where it is kept at a constant pressure.

Some compressors are multistage types. This means air passes through more than one piston or cylinder arrangement before it enters the receiver. As air passes between the stages, its pressure is gradually increased. In multistage compressors, air reaches the desired pressure in the last compression stage.

It is important that moisture does not enter a pneumatic power system. This may cause the system's component to rust and corrode. Filters and separators are placed in the system to remove any moisture from the air as it is compressed. These devices are located in the compressor, between the outlet valve and the receiver.

Controlling Fluid Power

In a fluid power system, pressurized fluid is transported by way of transmission lines. Piping or tubing capable of withstanding high pressure is used for this purpose. Transmission lines carry the high-pressure fluids to where they will be used to do work. Components are placed in the system to control pressure, flow, and direction.

All fluid power systems must use control devices to be functional. Valves are devices that control fluid power. They are used for the following:

- Flow control.
- Pressure control.
- Directional control.

Liquids and gases used in fluid systems have many characteristics in common. Therefore, the valves for both hydraulic and pneumatic systems are similar in design. The important difference is that valves for hydraulic systems require different seals to prevent loss of liquid.

Flow-Control Valves

Flow-control valve: A valve used to start or stop the flow of fluid in a system.

Variable-flow restrictor: See *Flow-control valve.*

To start or stop the flow of fluid in a system, a ***flow-control valve*** is used. This type of valve is also known as a ***variable-flow restrictor***. When you turn on the water at a kitchen sink, for example, you are using a flow-control valve. Many times, there are two flow-control valves at a sink—one for hot water and one for cold. Some flow-control valves are made to control both hot and cold water simultaneously. Flow-control valves also control how much fluid passes through a system. If the valve is only partially opened or closed, it does not allow full flow. Flow-control valves can be helpful in controlling the output speed of a fluid motor or in controlling how fast a cylinder is allowed to extend or retract.

Pressure-Control Valves

Pressure-reducing valve: A valve that reduces the pressure within a fluid circuit to levels suitable for use.

Pressure-reducing valves reduce the pressure within a fluid circuit to levels suitable for use. For instance, the pressure coming off a particular pump is 300 psi. Several components within the circuit require high pressure, but a control circuit is comprised of components that operate between

0–30 psi. This is an ideal application for a pressure-reducing valve. The pressure-reducing valve could provide lower pressure for the control circuit, while maintaining the high pressure needed for the rest of the circuit.

A ***pressure-regulating valve*** controls pressure coming from the compressor. This device can vary pressure and is often used in conjunction with lubrication and filtration devices. Such a device is typically referred to as a ***filter, regulator, lubricator (FRL) device***. In addition to regulating pressure, the FRL device also filters harmful moisture from the air and adds lubrication to the air so the wear on pneumatic equipment is minimized. Pressure-regulating valves are also used in hydraulics and are particularly critical, since liquids cannot be compressed within the circuit. Excess pressure could cause component failure. See **Figure 10-13.**

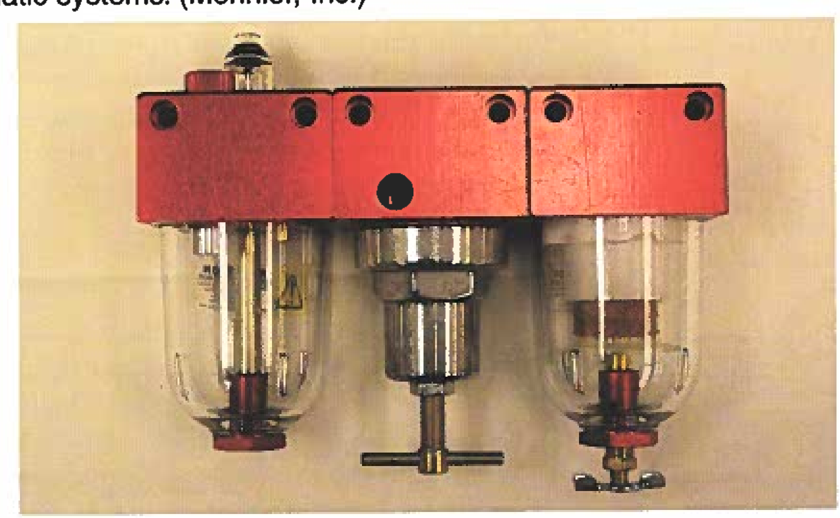
Pressure-Relief Valves

Pressure-relief valves are placed in a system to make sure the pressure does not get too high. If pressure increases to dangerous levels, relief valves automatically open to reduce it. In fluid power circuits, pressure is the primary characteristic of the power that requires protection. Too much effort or pressure built-up may cause damage or entire system failure. In hydraulic systems, the relief valve directs extra liquid to the holding tank, or reservoir. In pneumatic systems, extra air can be released into the atmosphere. Some steam-activated pressure-relief valves, such as those on car radiators and hot water tanks, work this way as well. See **Figure 10-14.**

Directional-Control Valves

Fluid power systems are often designed with more than one path for fluid to travel. A ***directional-control valve*** is used to control which path fluid takes in a circuit. These valves can be operated manually, mechanically, or electrically. Directional-control valves are often referred to as ***spool valves*** because of the way they are constructed. On early models of directional-control valves, the interiors resembled spools that hold thread. Grooves are cut into the interior to guide the fluid to the proper outlet

Figure 10-13. A filter, regulator, lubricator (FRL) device is often installed in pneumatic systems. (Monnier, Inc.)



Pressure-regulating valve: A valve that controls pressure coming from the compressor.

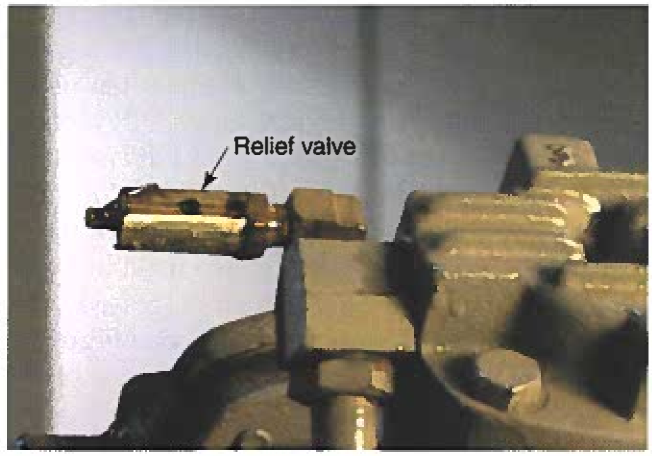
Filter, regulator, lubricator (FRL) device: A device that controls pressure coming from the compressor, filters harmful moisture from the air, and adds lubrication to the air so the wear on pneumatic equipment is minimized.

Pressure-relief valve: A valve placed in a fluid power system to make sure the pressure does not get too high.

Directional-control valve: A valve used to control which path fluid takes in a circuit in a fluid power system.

Spool valve: Another name for a directional-control valve. On early models of directional-control valves, the interiors resembled spools that hold thread.

Figure 10-14. A pressure-relief valve protects the fluid circuit from excessive pressure buildup. This valve is part of a small air compressor.



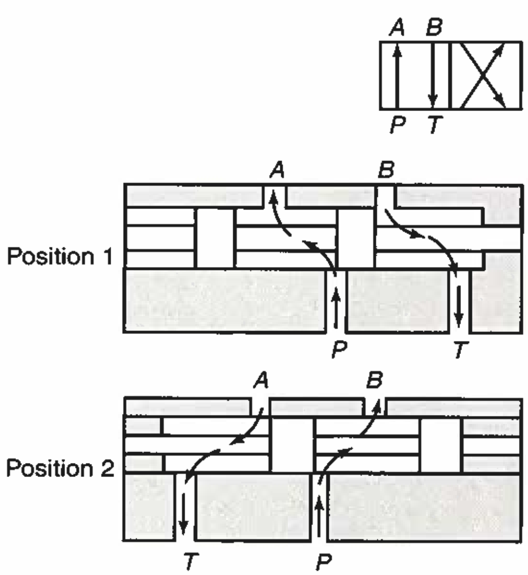
Four-way valve: A common type of spool valve that allows both the pressure and return lines to reverse themselves when the valve is triggered.

Cam-activated valve: An automatically operated valve. When the cam is triggered, the valve shifts its position, allowing another action to occur.

ports. The most common spool valves are a group of valves known as ***four-way valves***. These valves allow both the pressure and return lines to reverse themselves when the valve is triggered. This provides directional-control for fluid cylinders and motors. Many four-way valves also include a neutral position. Neutral allows the pump to run without moving the cylinders or motors that the pump powers. When a neutral position is included in the construction of a valve, neutral is almost always the default position for the valve. See **Figure 10-15.**

Note that, when reading the schematic, the number of boxes that comprise the valve equate to the number of positions the valve can offer. The number of ports indicate the number of hoses that attach to the valve. This is how the proper name of the valves indicated are derived.

Figure 10-15. A four-way spool valve is a common type used for directional control. The labels show where the hoses go: Hose P goes to the pressure, or feed; hose T goes to the tank, or reservoir; and hoses A and B go to the load. The fact that only two boxes are present makes this a two-position valve. It is actually called a *two-position, four-port valve.*



Other Flow-Control Valves

Manually operated valves are the most common valves used. These valves are operated by manually moving a shift lever. Typically, the valve returns to its default state by spring action when the manual lever is released. This type of valve is ideal for use when the control valve is in close proximity to the operation being performed, such as with a hydraulic press or log splitter.

Automatically operated valves can be triggered in a number of ways. A simple, automatically operated valve is the ***cam-activated valve***. Something pushing on the cam causes the valve to shift. Sometimes, a part slides into place and pushes down on the cam. When the cam is triggered, the valve shifts its position. This allows another action to occur. This action may change the direction or pressure of the flow, or it may stop the flow all together. ***Solenoid-operated valves*** are shifted by an electrical signal. The electrical signal may be sent from a switch located remotely on an assembly line or from a programmable control device, such as a programmable logic controller (PLC) or a computer. One great advantage of solenoid-operated valves is that the trigger mechanism may be located a considerable distance from the valve and hydraulic power unit. For instance, a hydraulic bailing unit is attached to a farm tractor. The unit is powered by a small gas engine located on the bailing rig. The rig must be triggered, however, by the driver of the tractor located a considerable distance from the bailing rig. A solenoid-controlled valve allows virtually all the hydraulics to be located in close proximity to the power unit. See **Figure 10-16.** Two light gauge wires can be strung to the cab of the tractor and attached to a push button. When the tractor driver pushes the button, the valve will shift, and the bailing rig will be activated.

Solenoid-operated valve: A valve shifted by an electrical signal.

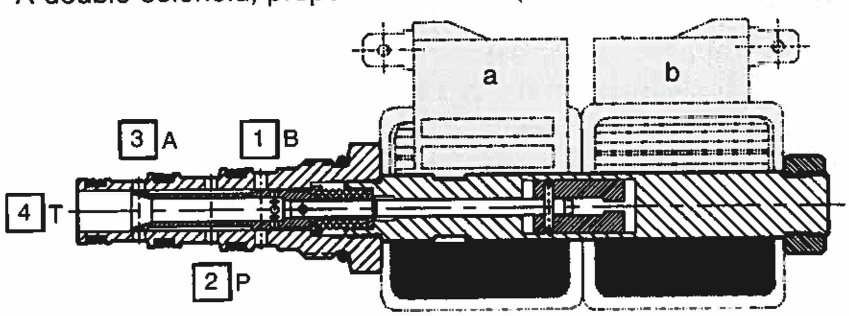
Check valves are another type of directional-control valve that allow fluid to flow in just one direction. If fluid begins to move backward in a system, check valves close and stop the backward movement of fluid. See **Figure 10-17.**

Transmitting Fluid Power

Fluid power may be transmitted through a variety of different devices known as *conductors*. See **Figure 10-18.** Hoses are used to transmit fluid because they allow for both high pressure and tremendous movement and

Figure 10-16. Solenoid-controlled valves. A—A three-position, four-way valve. Solenoids a and b move the spool either in or out from its neutral position to open or close different combinations of the four ports (A, B, P, and T). B—A double-solenoid, proportional valve. (Bosch Automation Technology)

A



B

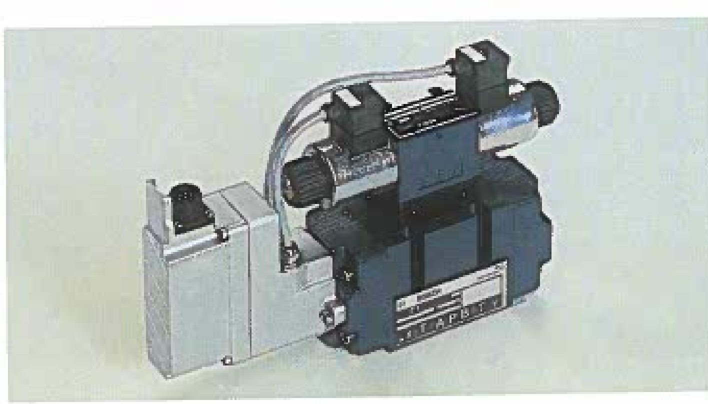
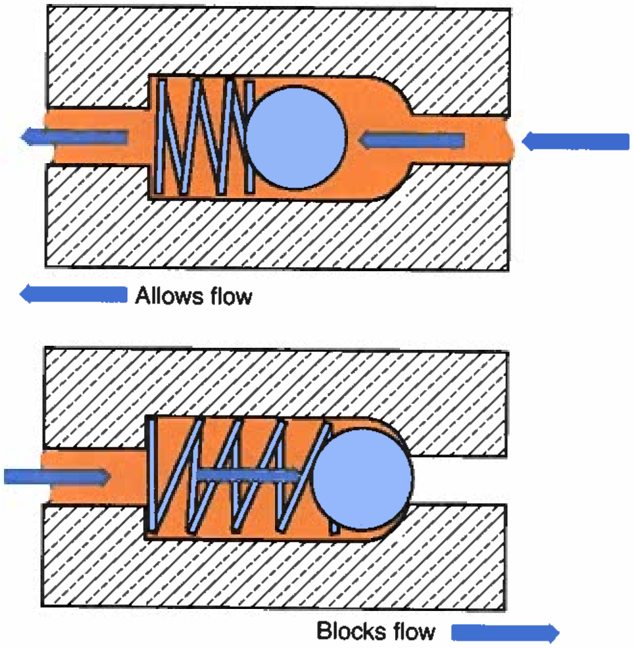


Figure 10-17. The basic construction and action of a check valve in a fluid power system.



flexibility. Movement and flexibility allow hoses to absorb shock very effectively. Rigid pipes are also used to transmit fluid power. Pipes can handle high pressures and are typically used in permanent installations where flexibility is not required. When using pipe to transmit fluid power, it may be necessary to use an accumulator as a shock absorber in the system. The rigidity of pipe cannot absorb shock as well as hose or tubing. Tubing is semi-rigid and provides some of the strength of pipe, as well as allowing for some flexibility. When coiled, tubing can absorb and dissipate shock much better than rigid pipe. Duct work is used to transmit high volumes of gases under relatively low pressures. Ducting is commonly used for climate control applications, such as structural heating, but it is not appropriate for transmitting liquids under pressure.

Sizing Fluid Power Conductors

There are a number of important factors involved in sizing fluid power conductors. The most important factors include the following:

- The volume the conductor must carry.
- The velocity at which the fluid must travel.
- The pressure the conductor is designed to withstand.

Flow Considerations

The flow rate capacity for a particular conductor is primarily determined by the inside diameter of the conductor. The rate increases significantly as the inside diameter is increased even slightly. Consider the flow

Figure 10-18. Examples of fluid power conductors. A—Flexible hoses allow movement of parts in machines operated by fluid power. B—Rigid piping is used in fixed installations, such as this compressed air system in an auto repair shop. C—Ducting is used to transmit large volumes of air or other fluids at low pressure, as in this forced-air heating installation.

capacity a garden hose with a 1″ interior diameter has, compared to a garden hose with only a 1/2″ interior diameter. You may assume that the increased capacity would be twice as much, but that is not correct. The increase in flow capacity is actually four times as much. As the diameter is doubled, the cross-sectional area increases fourfold. See **Figure 10-19.**

Velocity Considerations

Velocity is a measurement of the rate of motion in a particular direction. The velocity of fluid flow is typically measured in feet per second (fps). A measurement of velocity varies directly with the rate of flow. If the rate of flow increases, the velocity also increases. The surface area of a conductor has the opposite effect, however, on velocity. A conductor with a larger diameter allows greater flow capacity, but the velocity decreases because the conductor can now hold more fluid in the larger area available.

A ***nomograph*** is a chart helpful in determining the inside diameter of conductors or for estimating flow or velocity, if two of the three variables are known. This type of chart could be used to determine the required interior diameter of a conductor, if an application such as a pressure washer calls for fluid flow at a rate of 15 GPM and a velocity of 10 fps in order to be effective. Since the desired flow and velocity are known, the diameter of the hose to use can be determined using the nomograph. Similarly, let us say you have a 2″ diameter pipe flowing water at a constant velocity of 5 fps and you would like to calculate the volume of flow. Since the interior diameter of the pipe and the velocity are known, the flow rate can be determined using a nomograph.

Nomograph: A chart helpful in determining the inside diameter of conductors or for estimating flow or velocity, if two of the three variables are known.

Working pressure: The normal operating pressure for which a conductor is designed.

Test pressure: The maximum pressure that a conductor is designed to withstand.

Burst pressure: The pressure at which a conductor will fail by rupturing.

Pressure Considerations

Knowing the amount of pressure a conductor can withstand is critical from an operating safety perspective. Pressure ratings vary, based on the composition of the construction material and the wall thickness of each conductor. Conductors often have three pressure ratings:

- The ***working pressure*** indicates the normal operating pressure for which the conductor is designed.
- The ***test pressure*** indicates the maximum pressure that the conductor is designed to withstand.
- The ***burst pressure*** indicates the pressure at which the conductor will fail by rupturing.

When selecting conductors, it is important to remember that intermittent pressures may significantly exceed normal working pressure, and hoses should be designed to withstand not only working pressure, but also excess pressure. The conductors should also have a large enough diameter to provide adequate flow. Properly sized conductors will prevent pressure drops greater than 10%, which result from excessive friction and turbulence generated inside undersized conductors.

Figure 10-19. As the diameter of a conductor is doubled, the cross-sectional area available for flow increases by four.

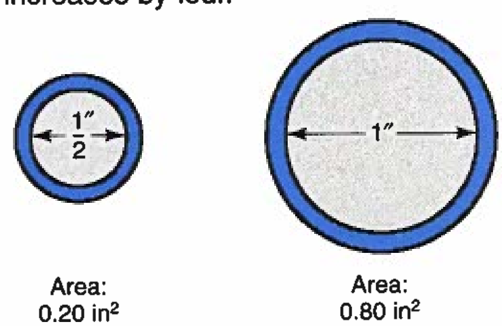
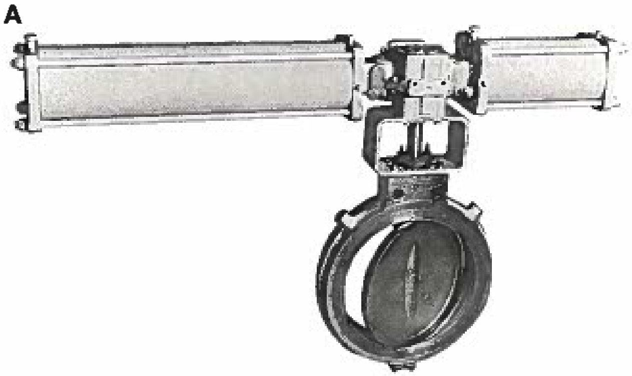


Figure 10-20. Actuators convert fluid power to mechanical power. A—A butterfly valve with a hydraulic piston actuator. The piston moves to close or open the valve. B—This valve has a pneumatically operated diaphragm actuator. (Fisher Controls International, Inc.)

A



B

Making Fluid Power Work

Remember that the purpose of any power system is to perform work. In the previous sections of this chapter, the parts of fluid power systems that control fluid flow and pressure were discussed. This section presents the system components that convert fluid energy to mechanical energy of solid parts.

Actuators

Actuators are devices that convert fluid power to mechanical power in both hydraulic and pneumatic systems. These devices help to make fluid power systems easy to design and use. Fluid power is capable of creating almost any type of mechanical motion. Actuators produce the reciprocating and rotary motion that allows fluid power systems to do work. See **Figure 10-20.**

Cylinders are one type of actuator. They are classified as either single-acting cylinders or double-acting cylinders. Both types contain pistons that reciprocate inside them. ***Single-acting cylinders*** use the force of fluid to move the piston in one direction. The weight of the load then forces the piston to its original position when pressure is not applied to the piston within the cylinder. Other types of single-acting cylinders use an internal spring to return the cylinder to its original position when pressure is not being applied to the cylinder. ***Double-acting cylinders*** use the force of the fluid to move the piston in both directions. Fluid pressure can be exerted on either side of the piston. These cylinders are used where there is a need for complete control.

Hydraulic and pneumatic components are very similar in design. The characteristics of available fluids, liquid or gas, determine which type of system is used. Remember that liquid is not compressible, and gas is. Because of this, hydraulic cylinders are used in systems where quick and precise control of power is needed. The liquids used in these systems act as a solid link between the fluid and the solid parts. Pneumatic cylinders are used in systems in which a certain amount of cushioning is needed, such as with clamping operations where you would not want to crush the material being held.

Actuator: A device that converts fluid power to mechanical power in both hydraulic and pneumatic systems.

Single-acting cylinder: A cylinder that uses the force of a fluid to move the piston in one direction.

Fluid Motors

Fluid motors are devices that convert fluid power into rotary mechanical motion. Two basic types of fluid motors are the gear motor and the vane motor. Gear motors operate like a gear pump, but the process is reversed. Fluid is forced into a housing that contains gears. As the fluid flows around the outside of the gears, against the housing, it forces the gears to spin. One of the gears is connected to an output shaft. The speed of the output shaft depends on the pressure of the fluid in the system.

In a vane motor, a rotor is offset inside a round housing. See **Figure 10-21.** The rotor has spring-loaded vanes, so they always touch the inside of the housing as the rotor spins. Fluid is forced through the housing. The fluid pushes against the vanes as it flows past the rotor, causing the rotor to spin. The speed of the output shaft attached to the rotor depends on the pressure of the fluid in the system.

Double-acting cylinder: A cylinder that uses the force of a fluid to move the piston in both directions.

Fluid motor: A device that converts fluid power into rotary mechanical motion.

Storing Fluid Power

Pneumatic systems store air under pressure in tanks known as ***pressure tanks***. These tanks typically include a pressure-sensitive switch that automatically turns the compressor motor on when the pressure in the tank drops below a preset level. The compressor produces more compressed air and pumps it into the pressure tank until the pressure-sensitive control valve reaches its high-pressure limit and shuts off the compressor motor. This way, a constant amount of pressurized air is maintained within the system. Pressure tanks usually come equipped with a pressure-relief valve, to ensure that excess pressure does not build up in the tank. A bleeder valve at the base of the tank allows any water that condenses inside the tank to drain.

Pressure tank: A tank that stores air under pressure in pneumatic systems.

Accumulator: A device that stores hydraulic liquid under pressure, even when the hydraulic pump is not running.

Normally, hydraulic systems do not store liquid under pressure. The liquid is kept in a storage tank known as the *reservoir*. The reservoir is vented into the atmosphere so pressure does not build up within the reservoir and so a vacuum cannot be created. The reservoir is also equipped with baffles. The baffles deflect fluid entering under high pressure and prevent it from creating turbulence in the reservoir. Turbulence in a reservoir is created similarly to the way a garden hose flowing openly in a bucket creates lots of air bubbles. If the air bubbles get into the hydraulic lines, the entire system will become spongy, or compressible, and the results could be disastrous, given the high-strength applications that typically employ hydraulics. Air can be compressed, but hydraulic fluid cannot be compressed. Imagine air in the brake lines of your car. When you step on the brake, the air could compress, creating a delayed reaction.

GREEN TECH

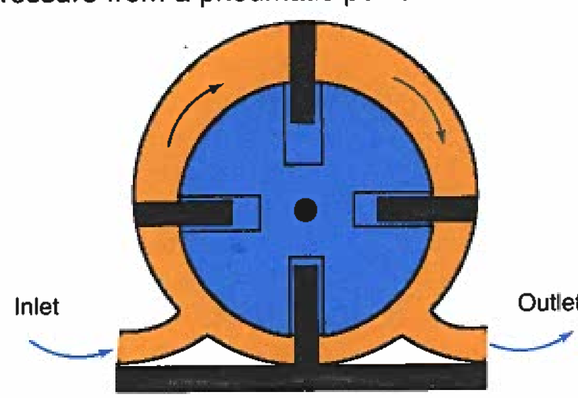
You have already read about the potential dangers hydraulic fluid can pose to the environment. Though hydraulic fluid can be stored, you also have the option of recycling used fluid.

An ***accumulator*** is a device that stores hydraulic liquid under pressure, even when the hydraulic pump is not running. Accumulators serve two purposes in hydraulics:

- To store pressurized fluid, providing it to the circuit on demand.
- To reduce pressure shocks in a hydraulic system.

This device works by allowing hydraulic oil to force a piston to pressurize a gas. Since liquids cannot be compressed, pressure is provided by the force of the expanding gas

Figure 10-21. A vane motor powered by air pressure from a pneumatic power source.



when the control valve is opened. Accumulators allow pressure to be stored so the pump does not run the entire time the hydraulic system is in use. Accumulators are also helpful in providing backup pressure to a system in which pump failure could result in serious injury. An accumulator can store varying amounts of fluid. This allows small actuators to be used as shock absorbers in hydraulic systems.

Working Safely with Fluid Power

There are a number of safety considerations to observe when working with liquids and gases. This is particularly true if the fluids are under pressure. The following safety cautions should be followed when working with fluid power circuits:

- Always adjust pressure-relief valves to provide a safe operating pressure. These adjustments should be made in accordance with the ratings on the components used in the fluid circuit. Many times, pumps and compressors can generate greater pressures than the components in the circuit can actually handle.
- Always wear safety glasses when working with fluid power to protect your eyes from unexpected hazards. Pressurized pneumatic hoses can burst from their fittings, causing hoses to whip violently in the air until the pressure is released or shut down by closing a valve. Hydraulic hoses can burst under high pressure, sending pressurized streams of oil into the work environment.
- Make necessary changes and adjustments to fluid circuits when they are not under pressure.
- Always respect the pressure that fluid power circuits can exert and the speed with which fluid cylinders can extend and retract.

Comparing Liquids and Gases

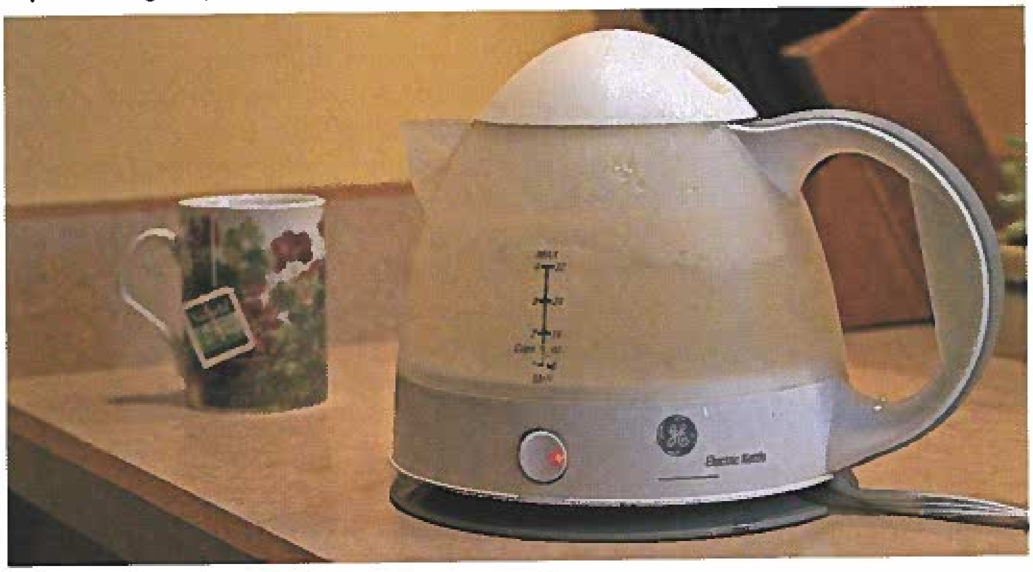
Liquids and gases act differently because the molecules in liquid are closer together than the molecules in gases. This can be observed in boiling water. The high temperature causes the water molecules to speed up and spread further apart, turning water (a liquid) into steam (a gas). See **Figure 10-22.**

Compressibility: The extent to which any substance can be packed down into a smaller size or volume.

Because pressure is involved in doing work with fluid systems, the compressibility of fluids is a factor. ***Compressibility*** is the extent to which any substance can be packed down into a smaller size, or volume. Liquids cannot be compressed much at all, even under enormous pressure. For all practical purposes, liquids are not compressible. Gases, however, may be compressed because of the greater amount of space between the molecules.

Temperature also affects the compressibility of gases. The hotter a gas becomes, the more active its molecules become. Therefore, the molecules have more space between them, which makes the gas more compressible. An English scientist named Robert Boyle studied this relationship between pressure, volume, and temperature. He concluded that if the temperature remains constant, increasing the pressure on a gas reduces its volume. In fact, if the pressure is doubled, the gas is compressed to half its original volume. This concept is an important consideration when designing pneumatic systems.

Figure 10-22. Heating water will cause it to boil and change its state from a liquid to a gas (steam).



Another important difference between hydraulic and pneumatic power systems is that pneumatic power can use an open system, while hydraulic power must be used in a closed system. Pneumatic systems, such as the pneumatic cylinder on a door, can be open because the air put into the system is drawn from the atmosphere and, therefore, can be returned to the atmosphere. See **Figure 10-23.** There is no need for a reservoir to contain the air. A hydraulic system must be closed so the liquids used can be returned to a reservoir to be used again in the system.

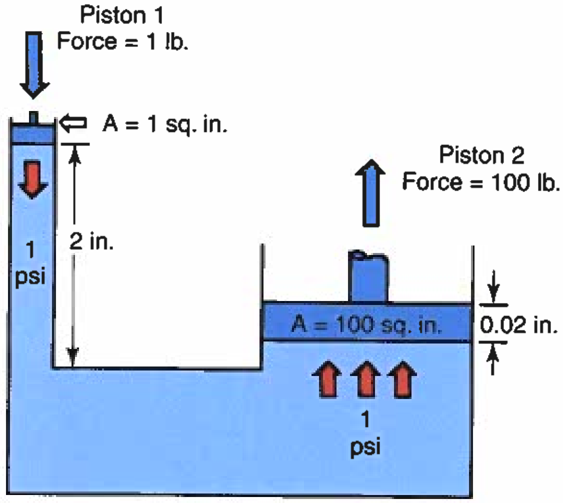
Pascal's law: When there is nothing but liquid in a container, compression applied to any part of the container is distributed equally in all directions. The initial pressure multiplies as it is distributed through a container with a larger diameter.

Blaise Pascal and Mechanical Advantage

In the seventeenth century, a French scientist named Blaise Pascal studied how liquids act while in closed containers. From his findings, Blaise Pascal developed ***Pascal's law***. He found that when there is nothing but liquid in a container, compression applied to any part of the

Figure 10-23. Door closers and air tools are examples of open pneumatic systems, since they use atmospheric air in their systems.

Figure 10-24. Containers representing different sizes of hydraulic cylinders. The force applied to the smaller cylinder is increased 100 times on the large cylinder.



container is distributed equally in all directions. Pascal also noted that this initial pressure multiplies as it is distributed through a container with a larger diameter.

The properties of confined fluids make hydraulic devices capable of increasing mechanical advantage. In **Figure 10-24,** two closed containers are displayed that represent hydraulic cylinders. Assume that one is 100 times smaller than the other. If a force of 1 lb. is exerted on the smaller container, it will transfer the pressure to the larger cylinder. Because the surface area of the other cylinder is 100 times larger and pressure is exerted in all directions, there is 100 times more pressure in the larger cylinder. The force on each square inch of both cylinders is the same. Because the large cylinder spans more square inches, it exerts a larger total force. See **Figure 10-25.**

Using Pascal's Law to Calculate Mechanical Advantage

The formula to apply Pascal's law states that force is equal to pressure multiplied by area. To apply Pascal's law to a real problem, assume we need to know how many pounds of force need to be applied to lift the

Figure 10-25. A backhoe uses hydraulics to control the digging claw and bucket, the lift, and the extension of the bucket.

Technology Link

Medicine: Jaws of Life

Thousands of vehicle accidents occur on a daily basis. Fortunately, only a few of those accidents involve entrapment, which is when the occupants cannot escape the vehicle. These instances are when the jaws of life are dispatched to assist in the rescue. This tool uses mechanical advantage and fluids under pressure to save lives.

The jaws of life is a hydraulically powered, multipurpose tool that can cut or spread metal. It is frequently used to assist in cutting victims out of a mangled vehicle. This tool can also be used as a lift or ram to free people caught under collapsed debris. The jaws of life is one of the most practical applications of the tremendous mechanical advantage that can be created with the use of fluids under pressure.

Liquids under pressure are virtually incompressible. This gives them the strength of solids, yet allows for the flexibility that a liquid can provide. The liquid used in hydraulic circuitry is almost always oil, but the jaws of life use a special liquid known as phosphate ester. This fluid is both fire resistant and nonconductive to electricity. Both of these characteristics make it ideal for use with rescue equipment, in situations where the operators could be working in close proximity to fire or live electricity.

The jaws of life is powered by a small gas engine coupled to a small, but powerful pump, which pressurizes the fluid. The control valve is a typical three-position, four-port valve attached to a double-acting cylinder. The valve can drive the cylinder in or out. The cylinder itself is often coupled to a cutter and spreader device that can spread with more than 15,000 lbs. of force or cut through metal as easily as scissors cut through paper. Rescue personnel operate the valve to drive the cylinder in or out, using it as a cutter or spreader, depending on what the situation warrants. The cutter on the jaws of life can easily snap doorposts on cars right in half to help extricate a person.

Sometimes the rescue situation calls for another type of end effector to do the work. If a dashboard has the legs of a victim trapped, a ram device might be employed to push the dashboard back up, closer to its normal position, so the victims can be extricated. The ram is another double-acting cylinder, but it is only coupled to a metal plate and not to a cutter or spreader. This plate can be used to lift heavy loads or to bend crushed metal. There are many practical applications for using liquids under pressure, but perhaps none are as vital as the jaws of life.

side of a 3000-lb. car. Since the jack must only lift half the car, we can estimate the load to be 1500 lbs. The input, or drive, cylinder is .25″ in diameter, and the output, or driven, cylinder is 1.25″ in diameter. Pascal's law can be applied to either the input or the output side of the jack, but two of the three pieces of information are required to work this type of formula. In this example, we will apply Pascal's law to the output (right) side of the jack, where more information is provided:

- Pascal's law says that force (lbs.) / area (in^2) = pressure (psi)
- area = πr^2
- 1500 lbs. / [(3.14 × .625″ × .625″) = 1.23 in^2] = 1220 psi

Pressure is the same throughout a hydraulic circuit because liquids under pressure exert pressure evenly in all directions when they are not flowing. Therefore, if we solve for pressure on the output (right) side of the circuit, we have also solved for pressure on the input (left) side of the circuit. Once pressure is determined, Pascal's law can be applied to the other side of the jack because two out of three pieces of information are now available to work the formula.

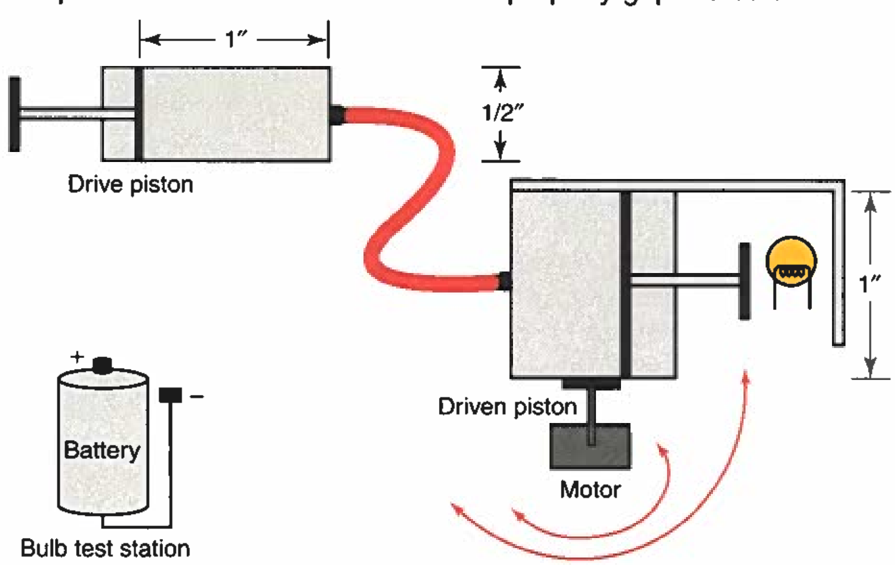
- Pascal's law says that area × pressure = force
- .049 in^2 × 1220 psi = 59.8 lbs. of force is required to lift the car

This represents an approximate 25:1 mechanical advantage, which can be determined by dividing the output force (1500 lbs.) by the input force (59.8 lbs.). If a jack handle is placed on the input side of the jack, it creates an additional 3:1 mechanical advantage. This is because the jack handle is actually a first-class lever that multiplies force by 3:1. The input force required is only about 20 lbs., which results in a total mechanical advantage of 75:1.

Sizing Actuators

Pascal's law can also be helpful in sizing cylinders and determining the stroke length of a cylinder for specific applications. In **Figure 10-26,** a lightbulb will be picked up from a tester by a clamping device and then rotated away for packaging if it is good. Generating a big mechanical advantage for this application is important because it requires very little force to lift the bulb. The distance the driven piston moves, however, is obviously very critical. Overextending the piston could easily crush the lightbulb. If the driven cylinder is underextended, the gripper will not pick up the lightbulb. A cam will provide intermittent motion to power the drive cylinder in and out.

Figure 10-26. The driven cylinder has to move out only 1/4″ to properly grip the bulb. If the drive cylinder has a 1/2″ diameter, what diameter must the driven cylinder be in order to extend only 1/4″ when the drive cylinder is inserted 1″? Remember that if the diameter of a cylinder is doubled, volume will be quadrupled. If the diameter of the driven piston was exactly double that of the drive piston, the driven piston would extend only 1/4″ for every inch the drive piston is pushed in. Therefore, the driven piston should be 1″ in diameter to properly grip the bulb.



Summary

Fluid power systems use the power of pressurized liquids and gases to do work. Systems that use liquid are called hydraulic, and those that use gas are called pneumatic. Both types of fluids have similar characteristics that let the systems work with very little wear on mechanical parts. The basic difference, which must be considered when designing the systems, is the compressibility of the fluids. Liquids cannot be compressed, while gases may be compressed into as much as half their original volume.

Like any power system, fluid power systems require several components to perform work. Pumps and compressors are devices that convert mechanical energy to fluid power and supply the pressure and flow needed to operate the system. Fluid pressure is sent through conductors, such as pipes and hoses, to other parts of the system. Valves are devices within the fluid circuit that control flow, pressure, and direction of fluid power. Actuators and fluid motors are components of a fluid power system that convert fluid power back to mechanical power for end use. These are the parts of the system that usually do the actual work.

Key Words

All the following words have been used in this chapter. Do you know their meanings?

accumulator
actuator
air compressor
burst pressure
cam-activated valve
centrifugal force
centrifugal pump
check valve
compressibility
directional-control valve
double-acting cylinder
filter, regulator, lubricator (FRL) device
flow-control valve
flowmeter
fluid motor
four-way valve
gear pump
hydraulic pump
hydraulic system
impeller
laminar flow
nomograph
Pascal's law
pounds per square inch absolute (psia)
pounds per square inch gauge (psig)
pressure gauge
pressure-reducing valve
pressure-regulating valve
pressure-relief valve
pressure tank
reciprocating pump
reservoir
single-acting cylinder
solenoid-operated valve
spool valve
test pressure
turbulence
valve
variable-flow restrictor
viscosity
working pressure

Test Your Knowledge

Write your answers on a separate sheet of paper. Do not write in this book.

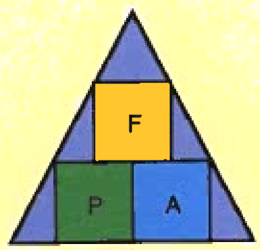
1. Fluid power systems involve the transfer of _____ energy.
2. What are the advantages of using fluid power systems?
3. Fluids exert pressure in all _____.
4. Fluids try to reach balanced pressure by flowing from an area of _____ pressure to an area of _____ pressure.
5. Fluid flow rate is measured with a(n) _____.
6. Summarize the difference between gauge pressure and absolute pressure.
7. The term _____ is used to describe smooth fluid flow.
8. Two types of hydraulic pumps are _____ and _____.
9. What is an impeller? How is it used in hydraulic pumps?
10. Two types of air compressors are _____ and _____.
11. _____ are devices that control fluid power within transmission lines.
12. A(n) _____ valve protects a fluid circuit from excessive pressure buildup.
13. If asked to create a fluid circuit that can provide both forward and reverse motion, use a(n) _____ valve.
14. How is the operation of a solenoid-operated valve different from the operation of a cam-activated valve?
15. _____ are devices that transmit power in both hydraulic and pneumatic systems.
16. A(n) _____ is a chart helpful in determining the interior diameter of fluid conductors when a flow rate is specified.
17. Describe the differences between how single-acting and double-acting cylinders operate.
18. A storage device used in pneumatic systems is a(n) _____.
19. Identify three safety concerns that should be considered when dealing with fluids under pressure.
20. Of the two types of fluids used in power systems, _____ can be compressed, and _____ cannot be compressed.
21. Explain the difference between an open fluid power system and a closed fluid power system.
22. Identify three common applications each for both hydraulic power circuits and pneumatic power circuits.

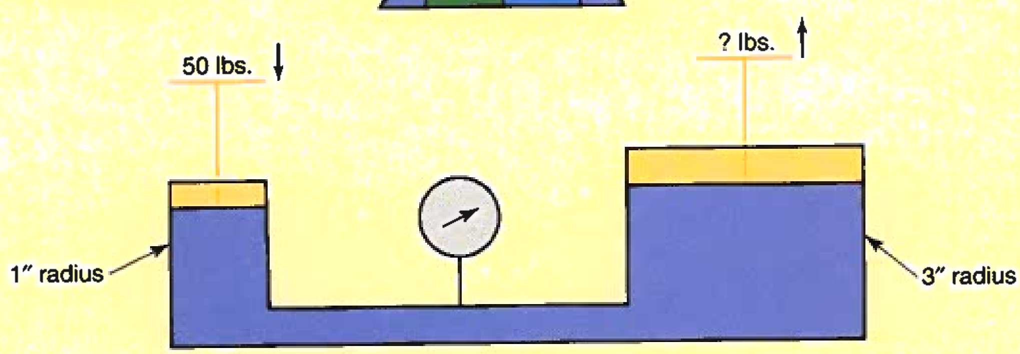
Matching questions: For Questions 23 through 29, match the phrases on the right with the correct term on the left.

23. _____ Oil.
24. _____ Atmospheric air.
25. _____ Robert Boyle.
26. _____ Viscosity.
27. _____ Working pressure.
28. _____ Accumulator.
29. _____ Blaise Pascal.

A. A type of fluid used in hydraulic power systems.
B. Studied the relationship between temperature, volume, and pressure.
C. A device that can store liquid under pressure.
D. A gas used in pneumatic power systems.
E. Described how hydraulic cylinders are able to increase mechanical advantage.
F. The term used to describe the ease with which liquid flows.
G. A term that describes the normal operating pressure for a conductor.

30. Write two or three sentences explaining how hydraulic cylinders increase mechanical advantage.
31. Calculate the amount of force that can be generated on the driven cylinder in the circuit below.





32. Calculate the mechanical advantage created in the circuit in Question 31.
33. Calculate the distance that the drive cylinder must be inserted in order to achieve 1/2″ of lift on the driven cylinder in the circuit in Question 31.
34. You are asked to create a hydraulic circuit that will lower the landing gear on an aircraft. The landing gear is located a considerable distance from the cockpit of the airplane. What type of valve will you use?

STEM Activities

1. Connect two clear, 2-liter bottles with a length of clear plastic hose. Clamp the hose that connects the two bottles and fill one of the bottles with water. Release the clamp and observe the water levels in both bottles reach a balance.
2. Research the fluid clutch system used in many vehicles. Write a short essay on how a fluid clutch system operates and provide a sketch of a common fluid clutch system.
3. Construct a model door opener out of some large syringes connected by a fish tank tube. Glue the tube between the two syringes. Inserting the drive syringe should make the driven syringe extend. Retracting the drive syringe should pull the driven syringe back in. Use popsicle sticks or scrap wood to represent the door and attach the door to the end of the driven syringe to create the model.