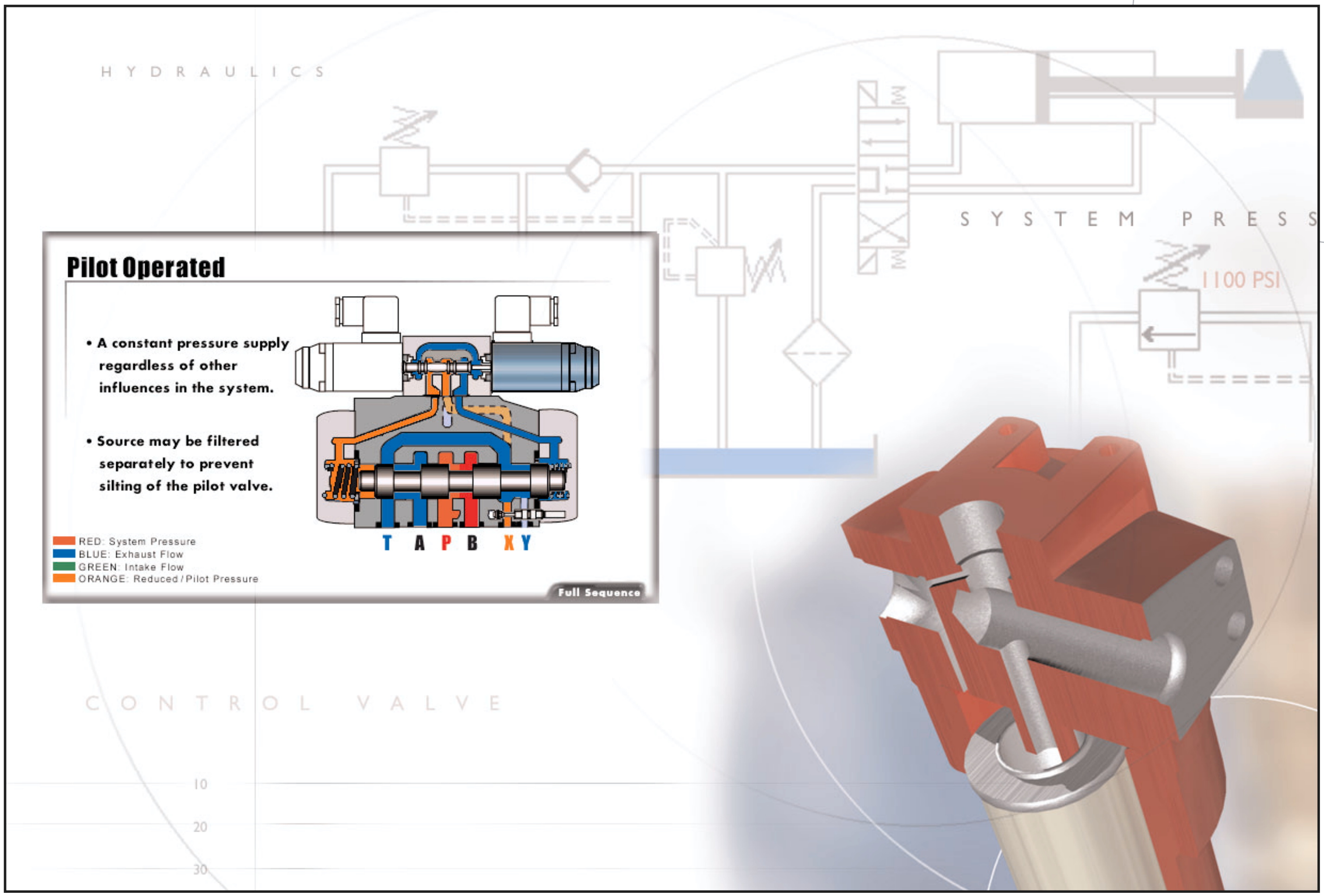
NATIONAL FLUID POWER ASSOCIATION

FLUID POWER TRAINING

Basic Hydraulics



NFPA
Solutions through motion technology

NFPA is pleased to present the Basic Hydraulics Interactive Training Course.

From its inception in 1953, NFPA has dedicated its efforts to fostering a better understanding of fluid power. Whether you're a student, employee, customer—or just curious about this fascinating technology—Basic Hydraulics Interactive Training will unlock the door to learning about key hydraulic concepts and principles.

Once you have completed this course, you should understand various basic physics laws as they apply to fluid power, as well as understand schematics and system design. You will also study the various components found in a typical hydraulics system and how these components function and interact with each other. And, if your computer can access the Internet, you will be able to link to NFPA's web site which offers additional information about fluid power as well as a product locator and links to the web sites of our member companies.

From the main menu, you can select from any of the course topics listed on the right hand side of your screen. Although you can work through these topics in any order, we recommend that you start at the top of the list with Fluid Power Physics and continue through the subjects from top to bottom. These topics are presented in this order to aid in your understanding of the material presented. While using this program, you can return to the main menu screen at any time.

Notice the buttons that allow you to quit the program and adjust the volume. These buttons are accessible throughout the program.

The interactive nature of this program will allow you to study and learn at your own pace. You will also find it helpful to review this information from time to time, even after you've completed the course.

NOTE: This workbook is not a supplement to your computer based training. It has been provided only to give each individual a place to compile notes and work additional exercises. The workbook contains all of the software narration and some animation screens to further assist in study.

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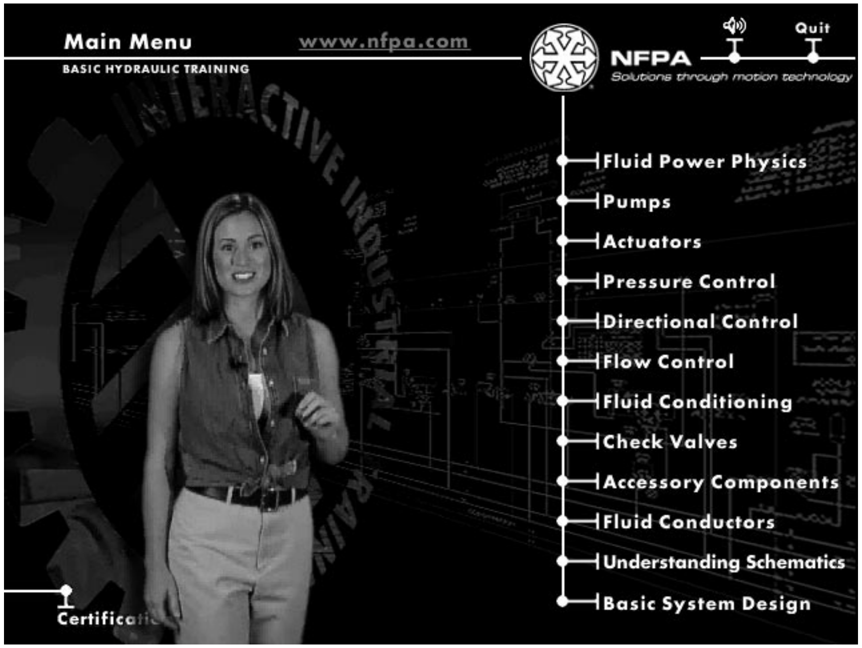
Loading Instructions

Insert CD into CD ROM Drive. This CD has a built in auto-run feature. If the program does not automatically start up then follow these instructions. **Double click on "My Computer", double click on the NFPA icon which will show contents of CD ROM drive, double click on NFPA.exe.**



After a brief introduction you will be presented with the screen you see at your left. This is the main menu of your Basic Hydraulics CD. Your options appear to the right. Also take a moment to notice the other global navigation that will be present throughout this training course.

Although you may skip through to any particular topic, we recommend that you begin with Basic Physics, and work sequentially through the training. Some concepts are built upon previous subjects and all interactive learning labs require studying the related material first.

Additional notes have been included in this manual to help increase your understanding of the principles taught.

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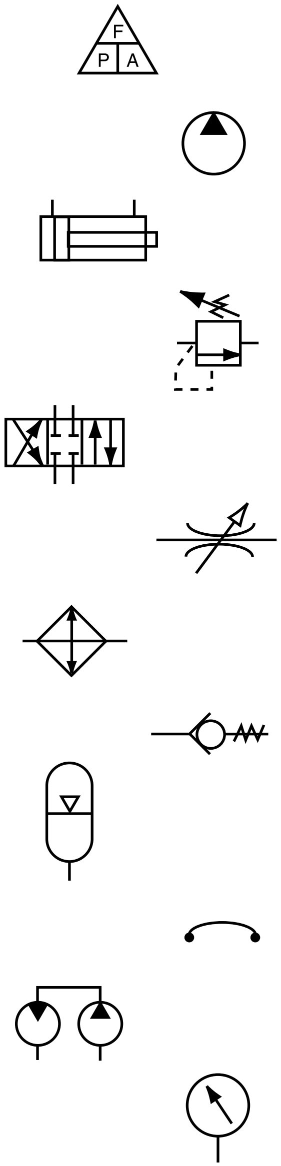


Introduction

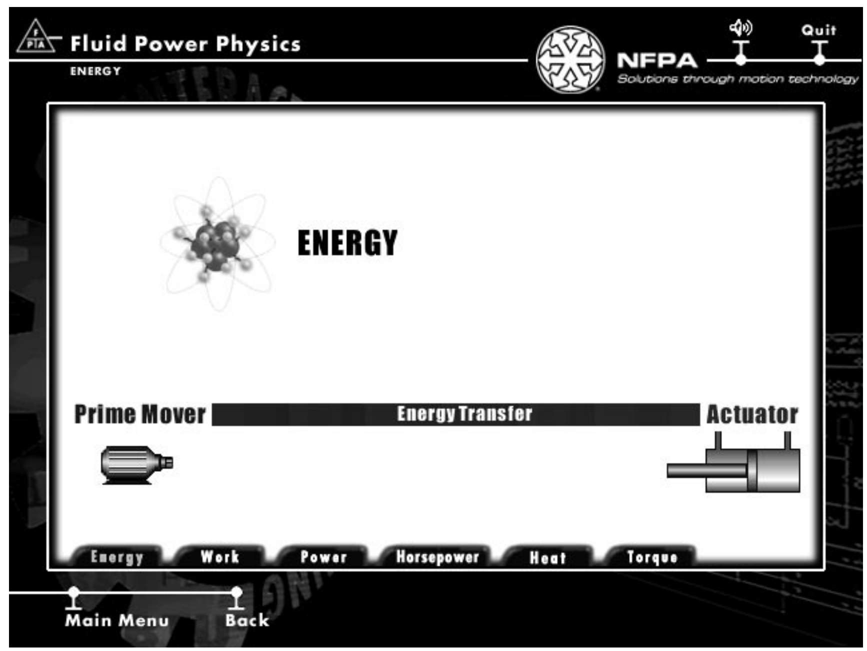
After completing the lessons and exercises in this section you will better understand the basic physics principles that govern fluid power. These principles are timeless, and understanding them well will provide you with a solid foundation on which to learn much more about fluid power. Within these sections, as well as throughout the program, you will be given the option to take a short quiz. The results of these quizzes are not recorded and are given only for you to test your own progress. In fact, you will even be given the answers.

Energy

Energy: As we begin our study of basic hydraulics we must first recognize that fluid power is another method of transferring energy. This energy transfer is from a prime mover, or input power source, to an actuator or output device. (figure 1). This means of energy transfer, although not always the most efficient, where properly applied may provide optimum work control. Energy may be defined as the ability to do work.

Work: Work is defined as force through distance. If we move 1000 pounds a distance of two feet we have accomplished work. We measure the amount of work in foot pounds. In our example, we have moved 1000 pounds two feet, or have accomplished 2000 foot pounds of work.

Power: Power may be defined as the rate of doing work, or work over time in seconds. If we lift 1000 pounds two feet in two seconds we have accomplished 1000 units of power, or 1000 times two, divided by two seconds. To give us relative meaning for measuring power, we must convert this to horsepower which is a unit for measuring energy.



(figure 1)

NOTES

Hydraulics is a means of power transmission.

Work (in • lbs.) = force (lbs) x Distance (in)

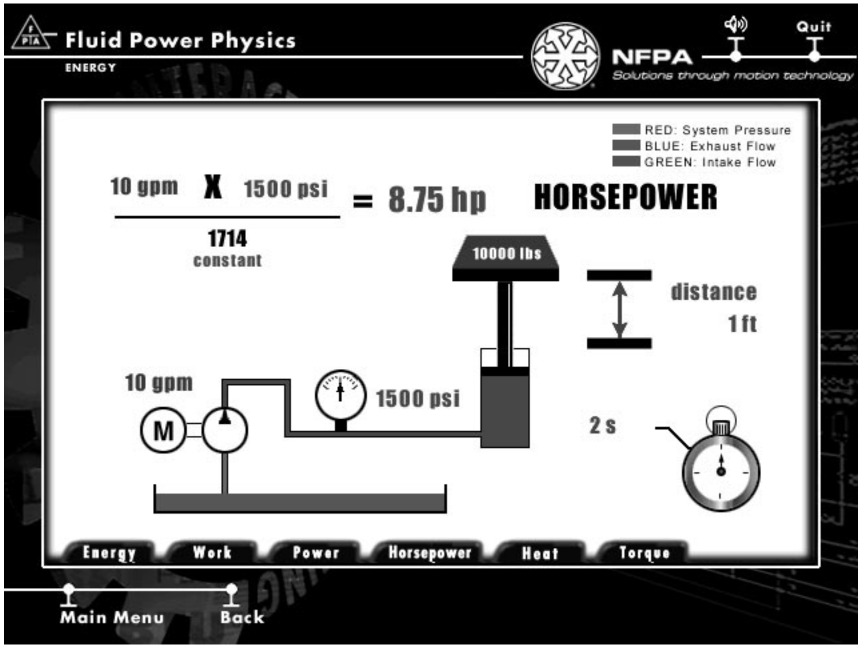
$$\text{Power} = \frac{\text{Force x Distance}}{\text{Time}}$$

Important:
As all systems are less than 100% efficient an efficiency factor must be added to the calculated input horsepower.
Example:

$$\text{Input hp} = \frac{\text{10 gpm x 1500 psi}}{\text{1714 (constant)}} = \frac{\text{8.75 hp}}{\text{.85 (efficiency)}} = \text{10 hp}$$

Rule of Thumb: 1 gpm @ 1500 psi = 1 Input hp

Horsepower: Mathematically, hydraulic horsepower is expressed as follows: horsepower equals flow, in gallons per minute (gpm), times pressure, in pounds per square inch (psi), divided by 1714, a constant. In our illustration we are lifting 10,000 pounds (this is our force) a distance of 1 foot (this is the work to be accomplished). If we lift our load in two seconds we have defined a power requirement. This may be expressed as hydraulic horsepower. To lift our 10,000 pounds a distance of one foot in two seconds we must have a required flow rate at a specific pressure, based on cylinder size and the pump flow discharge. In this illustration a 10 gpm pump is required to extend the cylinder in two seconds. The pressure requirement to lift the 10,000 pounds is 1500 psi (based on cylinder diameter). Based on our formula our theoretical horsepower requirement would be 8.75 (figure 2).



(figure 2)

Heat: The law of conservation of energy states that energy can neither be created nor destroyed, although it can change its form. Energy in a hydraulic system that is not used for work takes the form of heat. For example, if we have 10 gpm going through a relief valve which has a pressure setting of 1500 psi, we can calculate the energy being converted to heat.

Torque: Torque is a twisting force. It can be measured in foot pounds. In this illustration we are producing 10 foot pounds of torque when we apply 10 pounds of force to a foot-long wrench. This same theory applies to hydraulic motors. Hydraulic motors are actuators that are rated in specific torque values at a given pressure. The twisting force, or torque, is the generated work. A motor's rotations per minute (rpm) at a given torque specifies our energy usage or horsepower requirement.

Learning Lab

This learning lab will demonstrate the effect of flow and pressure requirements on theoretical input horsepower required. Clicking on the arrows labeled 'gpm' will increase or decrease the pump flow output, while clicking on the arrows labeled 'load' will increase or decrease the load on the cylinder. Clicking on the 'extend' or 'retract' will shift the valve and operate the circuit. Observe the changes in horsepower required.

NOTES

1 hp = 33,000 ft • lbs Per min or 33,000 lbs raised 1 ft in 1 min

1 hp = 746 W

1 hp = 42.4 Btu per min

Quiz

1. If a 500 pounds weight is lifted two feet, 1000 ft pounds of work has been accomplished.
   a) True
   b) False
2. Power is defined as the rate of doing work.
   a) True
   b) False
3. Wasted energy in a hydraulic system
   a) makes the system more efficient.
   b) is destroyed.
   c) is changed to heat.
   d) is used to do work.

Energy Formulas

1 kw = 1.3 hp

1 hp = 550 ft • lbs /s

$$\text{Hydraulic hp} = \frac{\text{gpm x psi}}{1714}$$

$$\text{Torque (in • lbs.)} = \frac{\text{psi x disp. (in}^3\text{/rev)}}{6.28}$$

$$\text{Torque (in • lbs.)} = \frac{\text{hp x 63025}}{\text{rpm}}$$

$$\text{hp} = \frac{\text{Torque (ft • lbs) x rpm}}{5252}$$

Btu (per hour) = Δpsi x gpm x 1.5

NOTES

To determine the volume (in^3) required to move a piston a given distance, multiply the piston cross sectional area (in^2) by the stroke (in)
Volume = AXL

The speed of a cylinder piston is dependent upon its size (piston area) and the flow rate into it.

$$\text{Velocity (in/min)} = \frac{\text{Flow (} in^3\text{/min)}}{\text{Area (}in^2\text{)}}$$

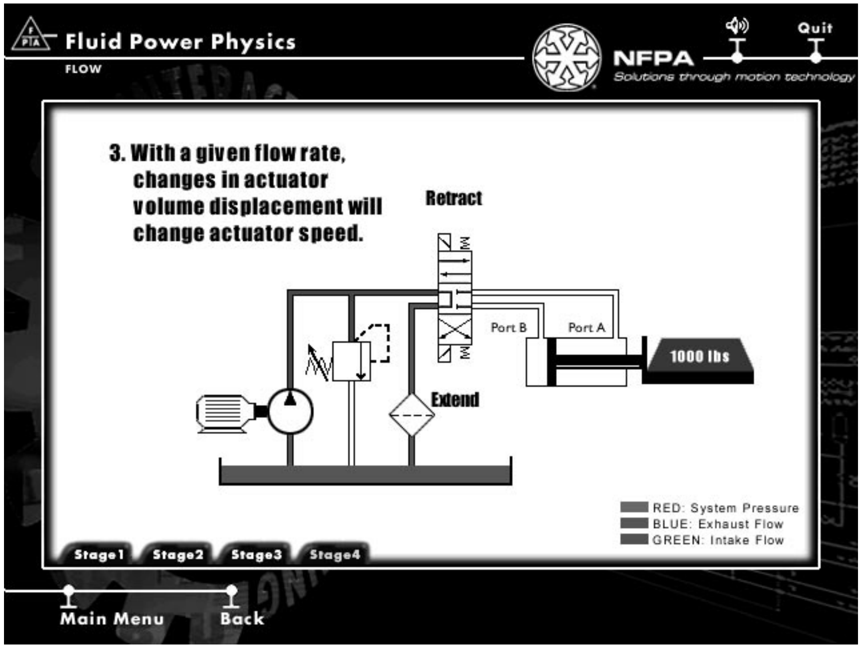
Flow

Stage 1: Flow in a hydraulic system is produced from a positive displacement pump. This is different from a centrifugal pump, which does not produce positive displacement. There are 3 important principles that must be understood relating to flow in a hydraulic system.

Stage 2: Principle one: Flow makes it go. For anything to move in a hydraulic system the actuator must be supplied with flow. This cylinder is retracted. It can extend only if there is flow into port B. Shifting the directional control valve will send flow to either extend or retract the cylinder.

Stage 3: Principle two: Rate of flow determines speed. Rate of flow is usually measured in gpm. Flow is generated by the pump. Changes in pump output flow will change the speed of the actuator.

Stage 4: Principle three: With a given flow rate, changes in actuator volume displacement (figure 3) will change actuator speed. With less volume to displace, the actuator will cycle faster. For example, there is less volume to displace when we retract, because the cylinder rod occupies space, diminishing the volume to be displaced. Notice the difference in speed between extend and retract.



(figure 3)

Learning Lab

In this learning lab you will learn how flow gives us actuator speed based on a specific pump output and actuator displacement. First, click on “extend” or “retract” to begin flow to the actuator. Use arrows to adjust pump size, gpm (flow rate), and actuator size. Notice the speed of the actuator as the gpm (flow rate) and/or actuator size is adjusted.

NOTES

Quiz

1. Changing the flow rate to an actuator will have no effect on the actuator speed.
   a) True
   b) False

2. If a cylinder is replaced with a larger diameter cylinder, the speed at which the new cylinder extends and retracts will:
   a) not change.
   b) increase.
   c) decrease.

Flow Formulas

1 gal = 231 in^3

Cylinder speed (ft/min) = $\frac{\text{gpm x 19.25}}{\text{Effective Area (in}^2\text{)}}$

Volume required (gpm) = $\frac{\text{Volume Displaced x 60}}{\text{Time (s) x 231}}$

Volume required (Hyd. Motor) = $\frac{\text{rpm x disp. (in}^3\text{)}}{231}$

(Cylinder) Volume displaced = Stroke x Effective Area

gpm (theoretical) = $\frac{\text{Pump rpm x in}^3\text{ /rev}}{231}$

NOTES

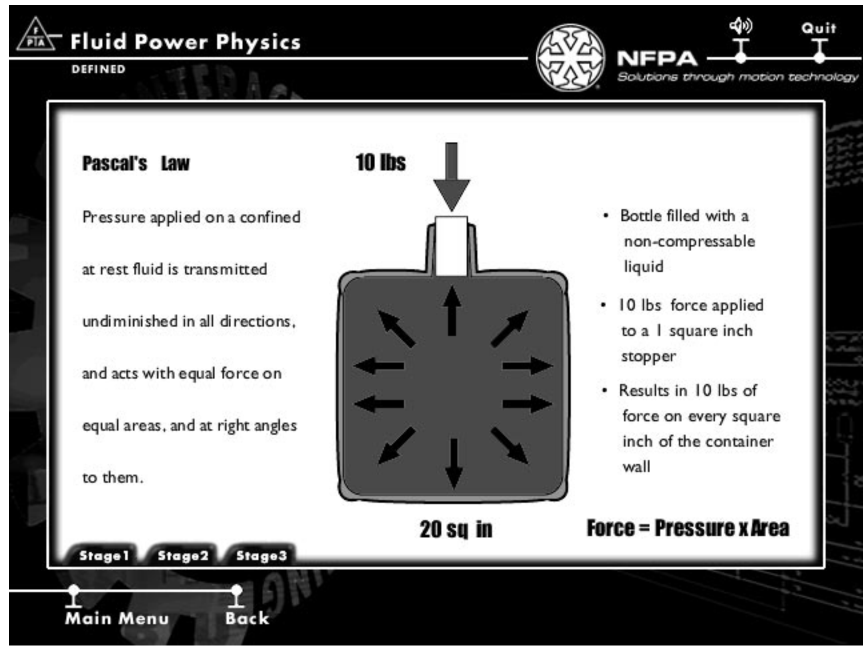
Note: *Hydraulic fluids are slightly compressible, however, for simplicity we will consider them to be non-compressible*

Pressure Defined

Stage 1: Pressure in a hydraulic system comes from resistance to flow. To further illustrate this principle, consider the flow produced from a hydraulic pump. The pump is producing flow, not pressure. However, if we begin to restrict the flow from the pump, pressure will result. This resistance to flow is load induced from the actuator and also generated as the fluid is passed through the various conductors and components. All points of resistance, such as long runs of pipe, elbows, and various components, are accumulative in series and contribute to total system pressure.

Stage 2: Pascal's law forms the basis for understanding the relationship between force, pressure, and area. The relationship is often expressed with the following symbol: Mathematically we express this relationship as: Force is equal to pressure times area; pressure is equal to force divided by area; and we can calculate the area by dividing force by pressure.

Stage 3: Pascal's law is expressed as follows: Pressure applied on a confined fluid at rest is transmitted undiminished in all directions and acts with equal force on equal areas and at right angles to them. In the following illustration we have a vessel filled with a non-compressible liquid. If 10 pounds of force is applied to a one square inch stopper, the result would be 10 pounds of force on every square inch of the container wall. If the bottom of the container was 20 square inches total, the resultant force would be 10 psi times 20 square inches, or 200 pounds of total force, since force equals pressure times area (figure 4).



(figure 4)

NOTES

The force (lbs) exerted by a piston can be determined by multiplying the piston area (in^2) by the pressure applied (psi).

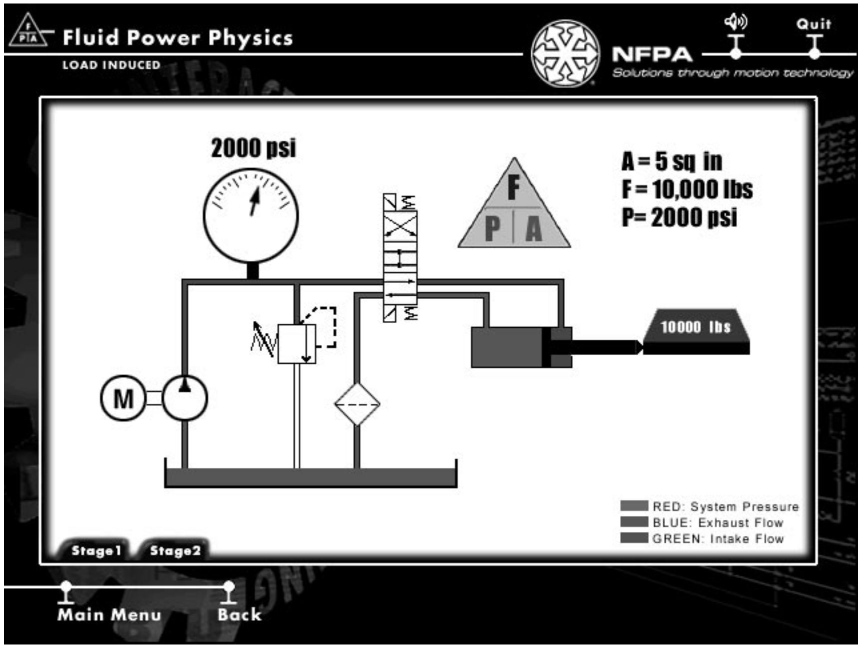
To find the area, square the diameter and multiply by .7854 $A = d^2 \times .7854$ *or* $d = \sqrt{\frac{A}{.7854}}$

Learning Lab

In this learning lab you will directly see the effects of Pascal's law. By pulling down the lever you will put equal pressure on the fluid within the system. Note the pressure gauges read the same pressure throughout the system.

Load-Induced

Stage 1: Load-induced pressure is defined as pressure generated from the load, or force, on the actuator. The effective area of the cylinder piston is the area available for force generation. In our illustration a 10,000 pound force gives us a load-induced pressure of 1,000 psi, based on our formula. When the cylinder is extended, the required pressure to move the 10,000 pound load is 1,000 psi less frictional forces.
Stage 2: During retraction, the effective area is only 5 square inches. This increases the required pressure to 2,000 psi needed to retract the load (figure 5).



(figure 5)

Learning Lab:

In this learning lab we will learn that as we increase the load on a cylinder the required pressure to maintain that load must increase. This is accomplished by stacking and unstacking the provided weights, increasing the load on the cylinder.

Pressure Drop

Stage 1: Pressure that is not directly used to provide work may be defined as pressure drop or resistive pressure. It is the pressure required to push the fluid through the conductors to the actuator.
Stage 2: This energy takes the form of heat. Excessive pressure drop may contribute to excessive heat buildup in the hydraulic system. This resistive pressure is accumulative and must be added to the overall system pressure requirements.

NOTES

Learning Lab

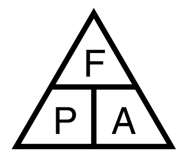
In this learning lab you will pick and place the elbows, reducers and pipe lengths to the system. As you add these elements to the system notice that the pressure increases. When we reach a pressure of 1000 psi, heat will be coming from all areas of the system. (The value of 1000 psi is used for illustration purposes only.)

Quiz

1. Increasing the load on an actuator will cause a decrease in system pressure.
    a) True
    b) False

2. Pressure is a result of flow.
    a) True
    b) False

3. Pressure is measured in inch/pounds.
    a) True
    b) False



Pressure Formulas

1 Bar = 14.5 psi

Force (lbs) = Pressure (psi) x Area (in^2)

$$\text{Pressure (psi)} = \frac{\text{Force (lb)}}{\text{Area (in}^2\text{)}}$$

$$\text{Area (in}^2\text{)} = \frac{\text{Force (lb)}}{\text{Pressure (psi)}}$$

$$\text{Area} = d^2 \times .7854$$

$$\text{Diameter} = \sqrt{\frac{\text{Area}}{.7854}}$$

$$\text{psi} = \frac{\text{lbs}}{\text{in}^2} = \text{Pounds per square inch}$$

NOTES

Hydraulic fluid types vary according to applications. The four most common types are:

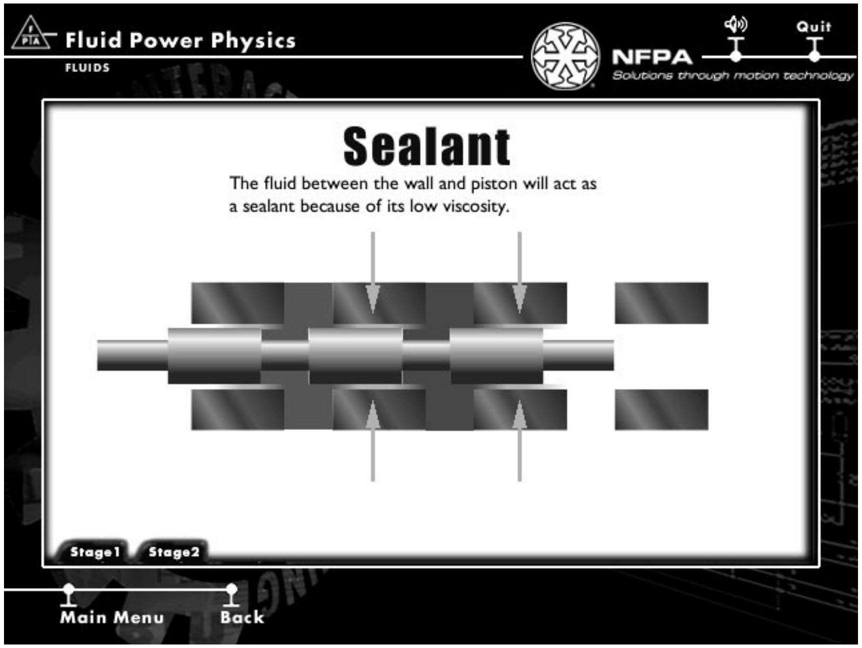
1. *Petroleum base- most common and best application where fire resistance is not required.*
2. *Water glycol- used where a fire resistant fluid is required. Most pumps must be derated or require special bearings when using water glycol.*
3. *Synthetic- used where applications require fire resistance or nonconductivity. Synthetic fluids are typically not compatible with most common seal compounds.*
4. *Enviromentally friendly- Fluids that will have a minimal effect on the environment in the event of a spill.*

Hydraulic fluids are slightly compressible. The amount of compressibility depends on the type of fluid. For this training program we will consider fluids to be basically non-compressible.

Fluids Overview

Stage 1: The study of fluid power deals with understanding energy transmission through a confined liquid. The hydraulic fluid may well be considered the most important component in a hydraulic system. It serves as a lubricant, a heat transfer medium, as well as a means for transferring energy, and as a sealant.

In our example of lubrication, hydraulic fluid as a lubricant allows this block to glide with less friction and wear on the parts. In our example of a heat transfer medium, the heated fluid enters and radiates its energy out and leaves the system cooler. In our example of energy transfer, hydraulic fluid will transfer energy from the input side to the output side because fluid is basically non-compressible. In our example of sealant the hydraulic fluid between the wall and the piston will act as a sealant because of its viscosity (figure 6).



(figure 6)

Stage 2: Hydraulic fluid is basically non-compressible and can take the shape of any container. Because of this, it exhibits a certain advantage in the transmission of force.

Examples

Using a positive displacement pump we transmit energy from the prime mover (our input source), to the actuator (our output), through the medium of a non-compressible fluid. As the fluid passes through the conductors and components, certain considerations must be given to ensure maximum efficiency of energy transfer. These considerations include the understanding and proper application of fluid velocity and viscosity.

NOTES

Maximum Recommended Oil Velocity in Hydraulic Lines:

Pump suction line 2-4 ft/s
Pressure lines to 500 psi 10-15 ft/s
Pressure lines to 3000 psi 15-20 ft/s
Pressure lines over 3000 psi 25 ft/s

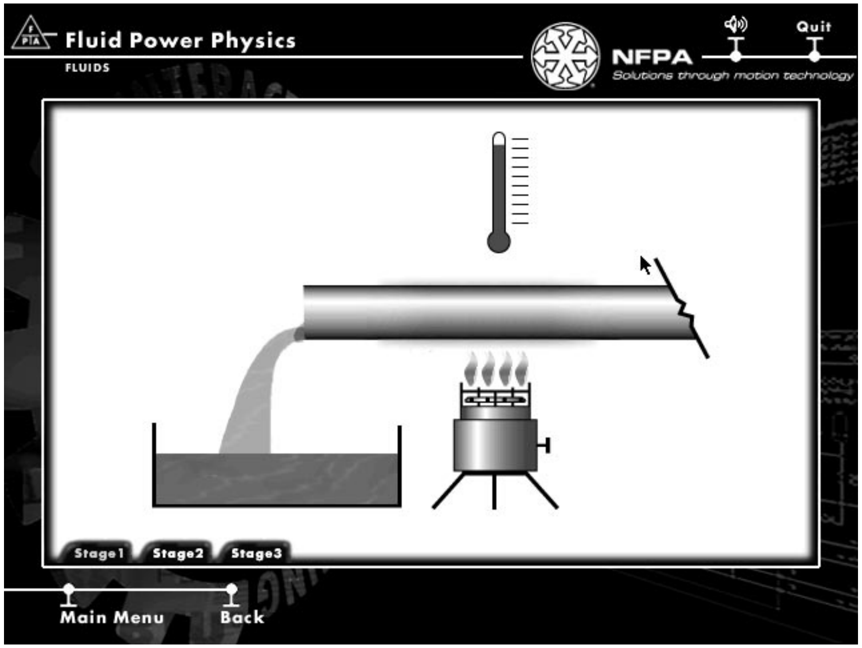
The most important characteristic of a fluid is its viscosity.

Velocity

Stage 1: Velocity is the distance fluid travels per unit of time. With a fixed volume of fluid going through a conductor, the velocity of the fluid will depend upon the inside diameter of the conductor.

Stage 2: If the diameter of a conductor is increased, the velocity of the fluid will decrease. Conversely, if the diameter of the conductor is decreased, the fluid's velocity will increase.

Stage 3: To better illustrate this principle we have two simple systems in which two pumps of equal displacement of 30 gpm move fluid through conductors of different sizes. The displacement remains equal while the velocity of the fluid varies with the size of the conductor. The fluid turning fly wheel 2 is moving four times faster than the fluid turning fly wheel 1 because the inside diameter of the pipe for fly wheel 1 is twice the size of the inside diameter of fly wheel 2. However, the fly wheels turn at the same rate because the volume displacement is equal in both systems.



(figure 7)

Viscosity

Stage 1: Viscosity is a measure of a liquid's resistance to flow. A thicker fluid has more resistance to flow and a higher viscosity. Viscosity is affected by temperature. As a hydraulic fluid's temperature increases, its viscosity or resistance to flow decreases (figure 7).

Stage 2: A viscosimeter, the device used to measure a liquid's viscosity, consists of a small reservoir surrounded by a water bath used to heat and maintain the liquid at a constant temperature. There is a small orifice below the reservoir through which the liquid can pass once it is heated to a specified temperature. A stopwatch is used to determine how much time it takes to fill a 60 milliliter. flask. The number of seconds that it takes to fill the flask at a given temperature is the liquid's viscosity at that temperature.

Stage 3: As illustrated, the fluid on the right has a lower viscosity number than the fluid on the left.

NOTES

The following applies to petroleum based hydraulic fluids.

Hydraulic oil serves as a lubricant and is practically non-compressible. It will compress approximately .5% at 1000 psi.

The weight of hydraulic oil may vary with a change in viscosity, however, 55 to 58 lbs/ft^3 covers the viscosity range from 150 SUS to 900 SUS @ 100 degrees F.

Pressure at the bottom of a one foot column of oil will be approximately .4 psi. To find the pressure at the bottom of any column of oil, multiply the height in feet by .4.

Atmospheric pressure equals 14.7 psia at sea level psia (pound per square inch absolute).

Gauge readings do not include atmospheric pressure unless marked psia.

Quiz

1. Viscosity is affected by the diameter of the fluid conductor.
   a) True
   b) False

2. At a given flow rate, to increase the diameter of the fluid conductor would cause the fluids velocity to increase.
   a) True
   b) False

3. Pressure drop in a fluid conductor is due to leakage.
   a) True
   b) False

Fluids Formulas

$$\text{Flow rate (gpm)} = \frac{\text{Velocity (ft/sec)} \times \text{area (in}^2\text{)}}{0.3208}$$

$$\text{Conductor area (in}^2\text{)} = \frac{\text{gpm} \times 0.3208}{\text{Velocity (ft/s)}}$$

$$\text{Fluid velocity (ft/sec)} = \frac{\text{gpm} \times 0.3208}{\text{Area (in}^2\text{)}}$$

NOTES

Fluid is pushed not drawn into a pump.

Pumps do not pump pressure, their purpose is to create flow. (Pressure is a result of resistance to flow).

To determine the required pump capacity:

$$gpm = \frac{speed\ (rpm) \times disp\ (in^3/rev)}{231}$$

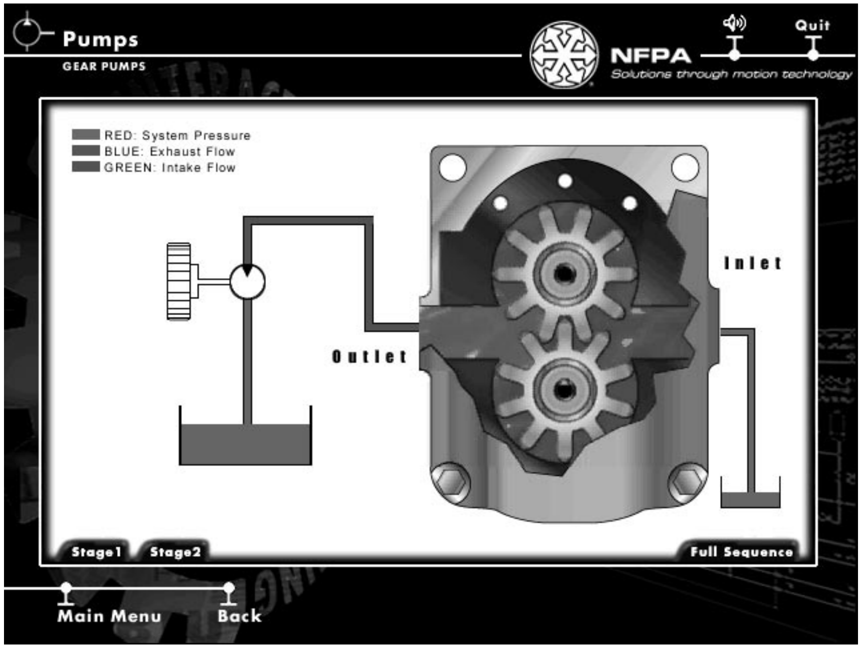
Introduction

Although various types of hydraulic pumps exist, the sole purpose of pumps is to provide flow for the hydraulic system. In this section you will learn more about the three basic types of hydraulic pumps: gear pumps, vane pumps, and piston pumps. It is important to understand the differences and similarities between these pumps, their fluid displacement capabilities, and their proper application in a hydraulic system.

Gear Pumps

Stage 1: Pumps are fluid power components which transform mechanical energy transmitted by a prime mover into fluid power energy. Gear pumps are compact, relatively inexpensive, and have few moving parts. External gear pumps consist of two gears, usually equal in size, that mesh with each other inside a housing. The driving gear is an extension of the drive shaft. As it rotates, it drives the second gear. As both gears rotate, fluid is drawn in through the inlet. This fluid is trapped between the housing and the rotating teeth of the gears where it travels around the housing and is pushed through the outlet port (figure 8).

Stage 2: The pump creates flow and, under pressure, transfers energy from our input source, which is mechanical, to a fluid power actuator. Now that you have seen the pumps operate in segments, click on "full sequence" to watch the whole animation uninterrupted and see how the pump creates flow within the system.



(figure 8)

NOTES

Quiz

1. Gear pump displacement increases with increased input rpm.
   a) True
   b) False

2. Gear pumps
   a) trap fluid between the teeth and the housing.
   b) have many moving parts.
   c) are used to control pressure control valves.

Unbalanced Vane Pumps

Stage 1: The rotating portion of the pump, or rotor assembly, is positioned off-center of the cam ring, or housing. The rotor is connected to a prime mover by means of a shaft. As the rotor is turned, the vanes are thrown out by centrifugal force and contact the ring, or housing, forming a positive seal.

Stage 2: Fluid enters the pump and fills the large volume area formed by the offset rotor. As the vanes push the fluid around the cam the volume decreases, and the fluid is pushed out the outlet port.

Now that you have seen the pump operate in segments, click on "full sequence" to watch the whole animation uninterrupted. This will illustrate how the pump actually creates flow within the system.

NOTES

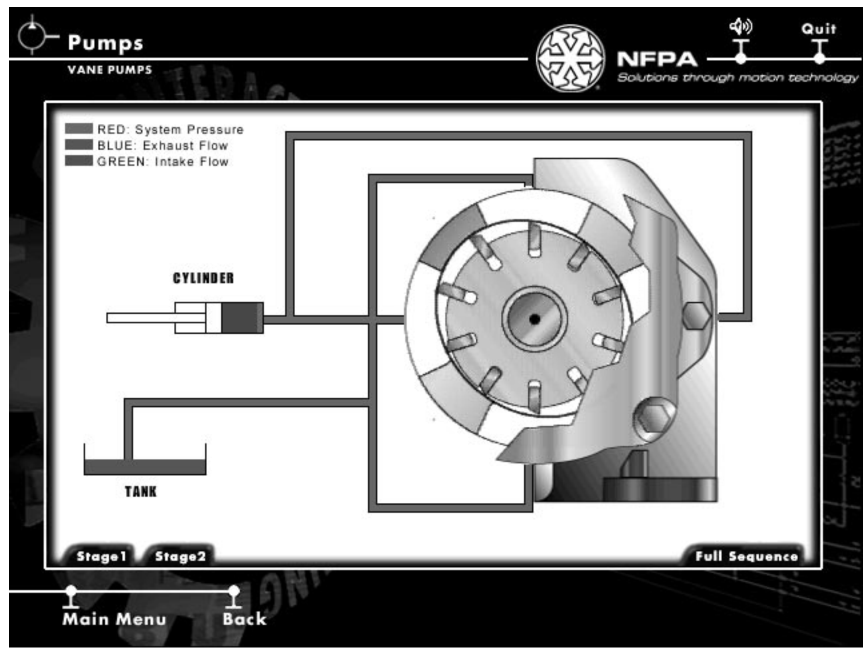
Balanced Vane Pumps

Stage 1: It is important before viewing this animation to understand the unbalanced vane pump. If you need to review it, go back and click on unbalanced vane pumps. With the unbalanced vane pump, which has been previously illustrated, one half of the pumping mechanism is at less than atmospheric pressure; the other half is subjected to full system pressure. This results in side loading on the shaft while under high pressure conditions. To compensate for this, the ring in a balanced vane pump is cam-shaped instead of circular. With this arrangement, the two pressure quadrants oppose each other. Two ports take fluid in and two pump fluid out. The two inlet ports and the two outlet ports are connected inside the housing. Because they are on opposite sides of the housing, excessive force or pressure buildup on one side is canceled out by equal but opposite forces on the other side. With the forces balanced, the shaft side load is eliminated (figure 9).

Stage 2: Flow is created in the same manner that you have seen illustrated in the unbalanced vane pump, the only difference being that there are two discharge and two suction cavities rather than one. It is notable that constant volume, positive displacement vane pumps used in industrial systems are generally of the balanced design.

Learning Lab

In this learning lab you will learn to identify the components that make up a vane pump. Use your mouse to drag the labeled tiles at the bottom of the screen to the corresponding boxes above.



(figure 9)

NOTES

Quiz

1. Vane pumps
    a) may be balanced or unbalanced.
    b) are not positive displacement.
    c) use a rotor for pumping.

2. A balanced vane pump uses an elliptical cam ring for opposing pressure quadrants.
    a) True
    b) False

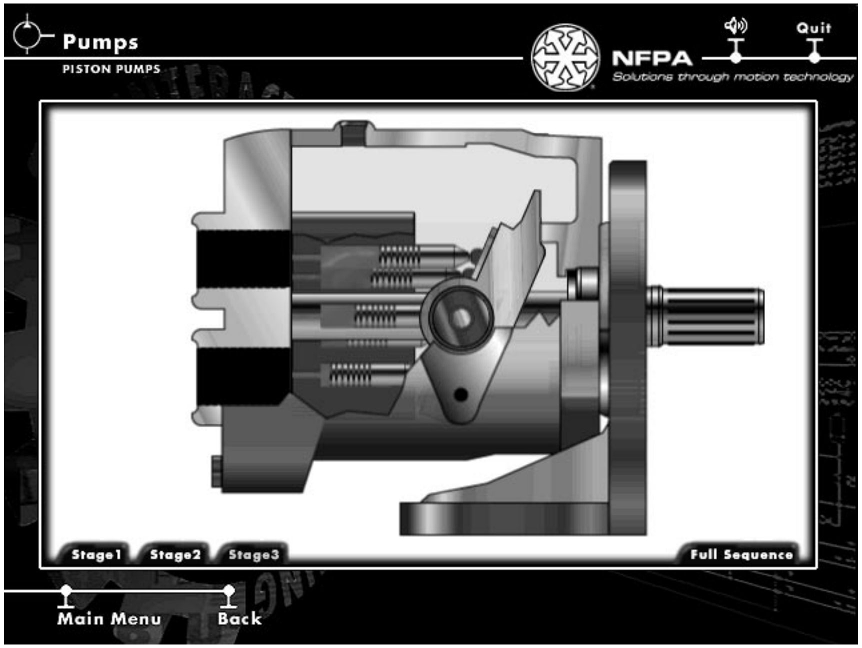
3. Which is not a part of a vane pump?
    a) Vane
    b) Rotor
    c) Cam Ring
    d) Barrel

NOTES

Piston Pumps

Stage 1: Axial piston pumps convert the rotary motion of an input shaft to an axial reciprocating motion, occurring at the pistons. This is accomplished by a swash plate that is either fixed or variable in its degree of angle. As the piston barrel assembly rotates, the pistons rotate around the shaft with the piston slippers in contact with and sliding along the swash plate surface. For simplicity of illustration, we have animated only one piston.

Stage 2: With swash plate vertical, no displacement occurs because there is no reciprocating motion. As the swash plate increases in angle, the piston moves in and out of the barrel as it follows the angle of the swash plate.



(figure 10)

Stage 3: In actual design the cylinder barrel is fitted with many pistons. During one half of the circle of rotation, the piston moves out of the cylinder barrel and generates an increasing volume. In the other half of the rotation the piston moves into the cylinder barrel and generates a decreasing volume. This reciprocating motion draws fluid in and pumps it out (figure 10). Now that you have seen the pump's operation in segments, click on “full sequence” to watch the whole animation uninterrupted and watch how the pistons draw fluid in and force fluid out.

NOTES

Quiz

1. Increasing the angle of the swashplate in a piston pump
   a) increases the pistons displacement.
   b) allows the pump to rotate faster.
   c) increases the pumps outlet pressure.

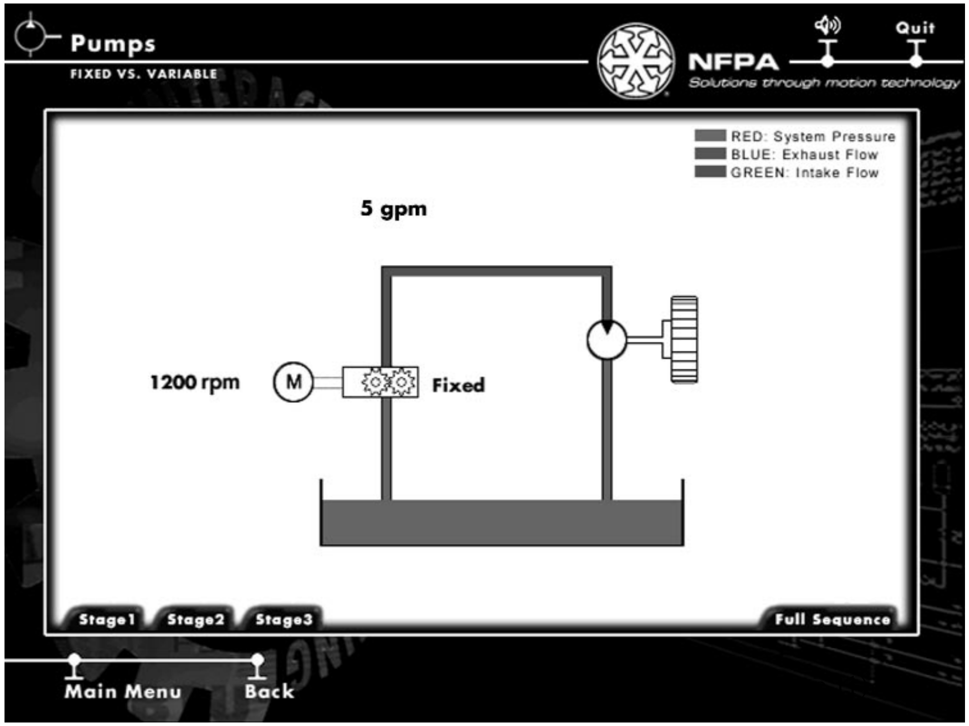
2. Axial piston pumps utilize a rotating swashplate.
   a) True
   b) False

NOTES

Fixed vs. Variable Pumps

Stage 1: There are two types of positive displacement hydraulic pumps. A fixed pump, which produces a fixed flow (gpm) based on the speed (rpm) of the prime mover or electric motor, and a variable pump, which can vary its rate of flow (gpm) while the input speed (rpm) remains constant. Although displacement is typically measured in volume displaced per revolution, output is measured in gpm.

Stage 2: In this example a motor turning at 1200 rpm is driving a fixed displacement gear pump producing 5 gpm flow. The flow (gpm) can be changed if the speed (rpm) of the motor changes (figure 11).



(figure 11)

Stage 3: When a variable displacement pump is used in the system, the flow (gpm) can be varied in two ways. As with fixed displacement pumps, the flow (gpm) will be changed if the speed (rpm) of the motor is changed. The second way is to vary the displacement of the pump. For example, the displacement of an axial piston pump is determined by the distance the pistons are stroked in and pushed out of the cylinder barrel. Since the swashplate angle controls this distance in an axial piston pump, we need only to change the angle of the swash plate to alter the piston stroke and pump volume. Several means of varying the swash plate angles are used. They may include hand levers, mechanical stops, or more sophisticated, hydraulically positioned devices. If the pump produces 5 gpm flow with 1200 rpm and maximum displacement, the flow (gpm) can be varied by moving the swashplate in the upright position or de-stroking the pump. This will vary the flow from 5 – 0 gpm.

NOTES

Learning Lab

Click on the ‘fixed’ or ‘variable’ button to change the type of pump in the system. Then, experiment with varying the flow (gpm) discharge and the speed of the flywheel by clicking on the different speed (rpm) settings. If you choose the variable pump, you can also vary the output by adjusting the displacement of the pump by moving the handle on the pump. The outlet flow (gpm) or discharge of fixed displacement pumps can only be changed by increasing or decreasing the speed of the electric motor, or prime mover.

Quiz

1. Gear pumps
   a) may be variable.
   b) are usually not used in hydraulics.
   c) change displacement with changes in rpm.
   d) give constant output with constant rpm.

2. Variable displacement pumps change the output flow by
   a) changing either the pumps rpm and/or swashplate anlge.
   b) only changing the swashplate angle.
   c) only changing the pump’s rpm

3. Variable volume pumps may also be pressure compensated.
   a) True
   b) False

4. Piston pumps
   a) increase flow by increasing the angle of the swash plate.
   b) decrease flow with increase in swash plate angle.
   c) are at full displacement when the rotating group is turning.

NOTES

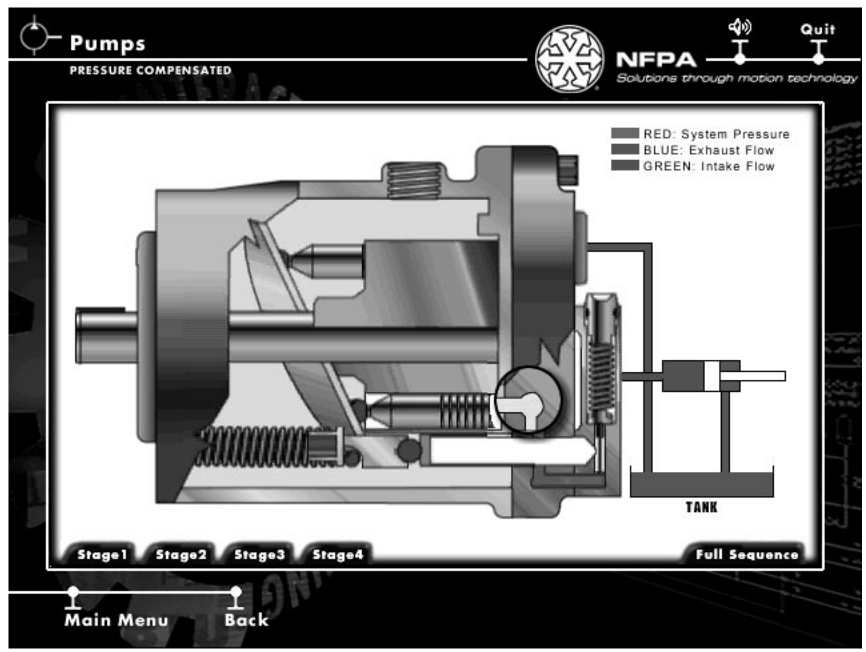
Pressure Compensated Pumps

Stage 1: Before beginning this section, you should understand the difference between fixed and variable pumps. If you need to review the concept return to the pumps menu and click on “Fixed vs. Variable”. Variable volume pumps can also be pressure compensated. A pressure compensated piston pump de-strokes, or moves to zero output, at a predetermined pressure. This is accomplished by hydraulically positioning the pumping chambers to zero output while maintaining compensator pressure at the outlet of the pump. In this example we have used a pressure compensated piston pump. It is helpful to understand the functionality of a piston pump.

Stage 2: As the pistons rotate around the shaft and follow the angle of the swash plate, they are pumping fluid out the outlet, which provides flow to move a component such as a cylinder. When the cylinder reaches the end of its stroke, pressure rises at the outlet of the pump as the fluid’s flow path is blocked (figure 12).

Stage 3: This pressure forces the compensating spool up, allowing the pressurized fluid to energize the de-stroking piston and push against the swash plate, forcing it to a vertical position. With the swash plate vertical the pump is now de-stroked and the pressure at the outlet port is maintained at a constant level. A very slight amount of flow is produced to maintain de-stroke pressure. This flow is bypassed into the case and carried back to the reservoir through the pump’s case drain outlet.

Stage 4: Of the three types of hydraulic pumps discussed, (gear, vane and axial piston), only the vane and piston types may be pressure compensated.



(figure 12)

NOTES

Quiz

1. When an axial piston pump is destroked or fully compensating
   a) the swash plate is at a 19º angle.
   b) the swash plate is at a 0º angle.
   c) there is no pressure.
   d) there is maximum flow.

2. A pressure compensated axial pump will de-stroke when flow is blocked
   a) True
   b) False

3. When a pressure compensated pump is on stroke, we have flow at operating pressure.
   a) True
   b) False

NOTES

Introduction

The actuator is the interface component that converts hydraulic horsepower back into mechanical horsepower. An actuator may either be a cylinder giving linear motion or a hydraulic motor giving rotating motion. After completing this section, you should have a good understanding of how actuators work in a hydraulic system.

Cylinders

Types
Stage 1: Cylinders are linear actuators. Their output force, or motion, is in a straight line. Their function is to convert hydraulic power into linear mechanical power. Their work applications may include pushing, pulling, tilting, and pressing. Cylinder type and design are based on specific applications.

Stage 2: A ram is perhaps the most simple of the actuators. It has only one fluid chamber and exerts force in only one direction. It is used in applications where stability is needed on heavy loads. A single acting cylinder is pressurized on one end only. The opposite end is vented to the tank or atmosphere. They are designed so that the load or a device, such as an internal spring, retracts them.

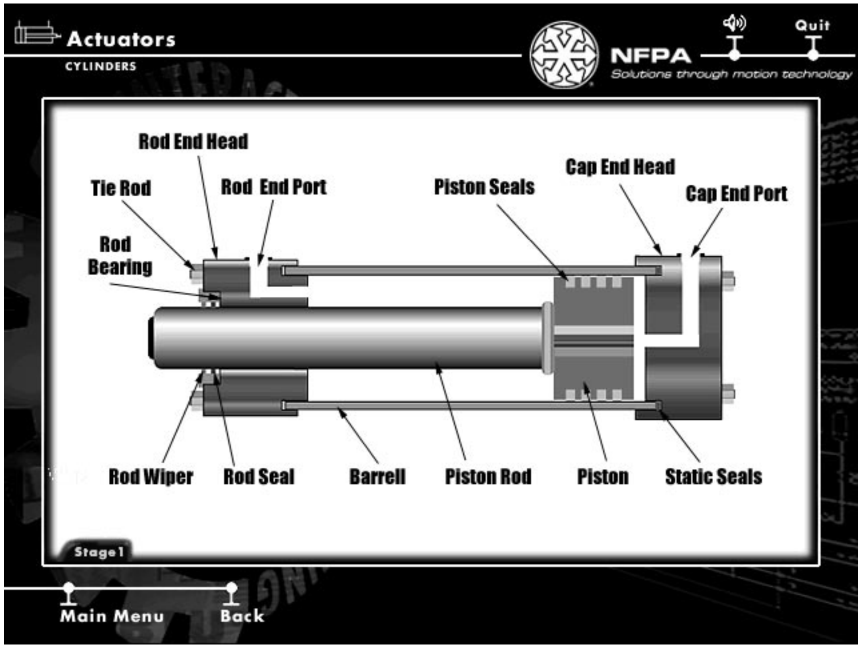
Stage 3: The double acting cylinder is the most common cylinder used in industrial hydraulics. We can apply pressure to either port, giving power in both directions. These cylinders are also classified as differential cylinders because of their unequal exposed areas during extend and retract. (In other words because the areas that are subjected to pressure during extend and retract differ in size.) The difference in effective area is caused by the area of the rod that reduces the piston area during retraction. (In other words the effective area of the rod side of the actuator is equal to the piston area minus the rod area. The effective area of the piston side of the actuator is equal to the piston area.) Extension is slower than retraction because more fluid is required to fill the piston side of the cylinder. However, more force can be generated on extension because of the greater effective area. On retraction, the same amount of pump flow will retract the cylinder faster because of the reduced fluid displaced by the rod. Less force, however, will be generated due to less effective area. A double rod cylinder is considered a non-differential type cylinder. The effective areas on both sides of the piston are equal, thus providing equal force in both directions. An application for such cylinders would be where it is advantageous to couple a load to both ends or where equal speed is needed in both directions.

NOTES

Mill type cylinders are more robust in design than tie rod cylinders. Applications for the mill type cylinders include presses, cranes, iron works and rolling mills.

Design

The cylinder assembly is constructed of a steel cap end head, a steel barrel assembly, a rod end head, a rod bearing, a piston, and piston rod. Tie rods and nuts are used to hold the heads and barrel assembly together. Static seals keep the joint pressure tight. A rod wiper is provided to prevent foreign material from entering the bearing and seal area. Sealing of the moving surfaces is provided by the rod seal, which prevents fluid from leaking past the rod and by the piston seals, which prevents fluid from bypassing the piston. Fluid is routed to and from the cylinder through the rod end port and the cap end port (figure 13).



(figure 13)

Motors

Types

Stage 1: Hydraulic motors are classified as rotary actuators. Motors very closely resemble pumps in construction. However, instead of pushing on the fluid as the pump does, the fluid pushes on the internal surface area of the motor, developing torque. Resistance from the load is encountered and pump flow provides a continuous rotating motion. Since both inlet and outlet ports may be pressurized, most hydraulic motors are externally drained.

Stage 2: The four most common types of hydraulic motors are gear, vane, piston, and bent axis piston.

NOTES

Hydraulic motors are typically classified as high speed motors (500-10,000 rpm) or low speed motors(0-1,000 rpm).

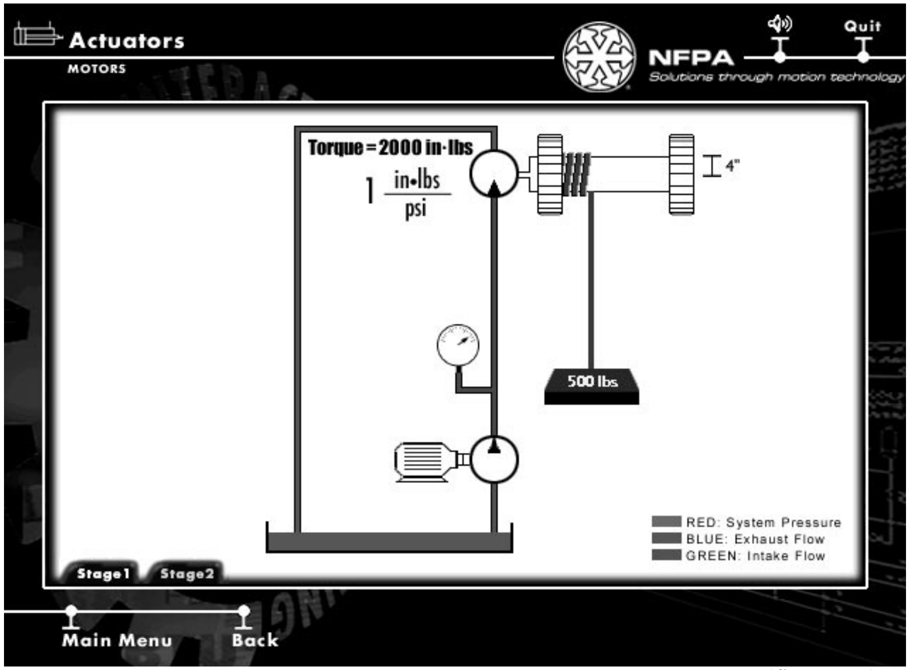
$$\text{Torque (in} \bullet \text{lbs)} = \frac{63025 \times hp}{rpm}$$

$$hp = \frac{\text{Torque (in} \bullet \text{lbs)} \times rpm}{63025}$$

Application

Stage 1: Hydraulic motors are primarily rated according to displacement and torque. The first consideration should be torque. Hydraulic motors are rated in foot-pounds or inch-pounds of torque per given psi, typically inch-pounds per 100 psi. Torque is equal to load times radius. Large displacement motors usually have a greater radius for the hydraulic fluid to push against. Therefore, they create more torque at a specific pressure.

Stage 2: A hydraulic motor with a specific torque of one inch-pound per psi is rotating a winch with a radius of four inches. Our load is 500 pounds. The required torque is 2000 inch-pounds. Based on the torque rating of our motor, our operating pressure would be 2000 psi. The second consideration would be displacement. This is necessary to determine the amount of flow required to rotate the hydraulic motor at the required speed (rpm) (figure 14).



(figure 14)

NOTES

Quiz

1. The purpose of an actuator is to convert hydraulic energy to mechanical energy.
   a) True
   b) False

2. Cylinders can be used to
   a) push or pull a load.
   b) tilt a load.
   c) press.
   d) all of the above.

3. At the same pressure, a single rod cylinder will produce more force on extend than on retract.
   a) True
   b) False

4. Hydraulic motors are rated according to displacement and torque capacity.
   a) True
   b) False

5. Hydraulic motors are only built in two designs: vane and piston.
   a) True
   b) False

NOTES

IMPORTANT !

The primary function of a pressure relief valve is to protect the system from excessive pressure. The valve should not be used to direct excess pressure to the tank, as this may cause the system to overheat.

Introduction

This section is designed to give you an understanding of the basic concept of manipulating force through a hydraulic system, using pressure control valves. The two basic design types of these valves are direct acting and pilot operated. This section will illustrate the operating principles of these two types of valves, and from within the learning lab you'll be able to simulate how different pressures and settings control the operation of these valves.

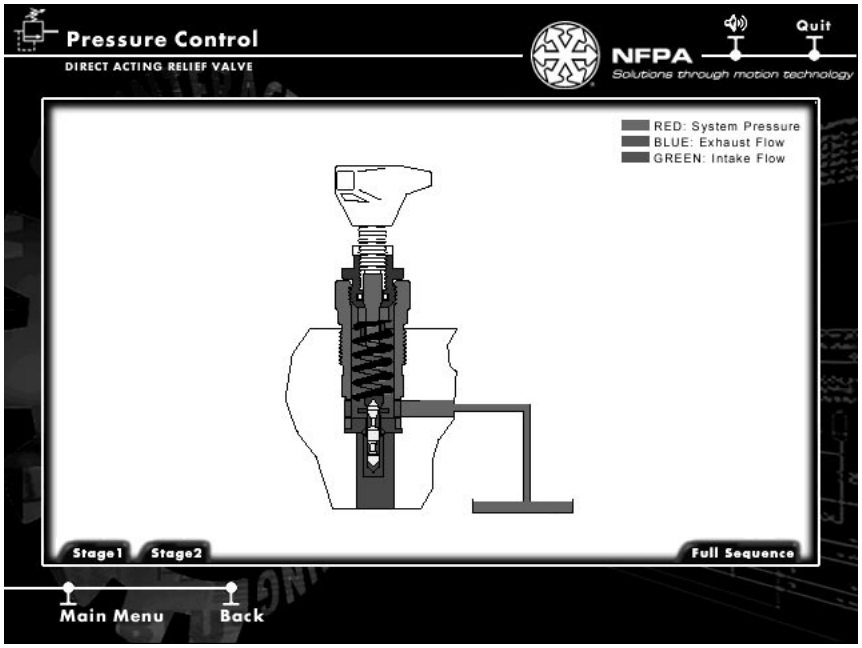
Overview

A primary concern in fluid power circuits is to either control the rate of flow or the pressure level. One misconception has been that pressure may be controlled with an orifice or flow control device. This is never accomplished with any degree of accuracy. For accurate control of force, six types of pressure controls have been developed. They are: relief valve, unloading valve, sequence valve, reducing valve, counterbalance valve, and brake valve. The symbols for each of these valve types closely resemble one another. Often only their location in the hydraulic circuit will designate what type of pressure valve they are.

Direct Acting Relief Valve

Stage 1: Maximum system pressure can be controlled with the use of a normally closed pressure valve. With the primary port of the valve connected to system pressure, and the secondary port connected to the tank, the poppet is actuated by a predetermined pressure level, at which point primary and secondary passages are connected, and flow is diverted to the tank. This type of pressure control is known as a relief valve.

Stage 2: A direct acting relief valve is one in which the poppet is held closed by direct force of a mechanical spring which is usually adjustable. Spring tension is set on the knob adjustment to keep the poppet closed until system pressure working against the poppet reaches the desired cracking pressure. When the system pressure reaches full relief value, all fluid is passed across the poppet to the tank passage (figure 15). It should be noted, that direct acting relief valves are usually available in only relatively small sizes. Because it is difficult to design a strong enough spring to keep the poppet closed at high pressure and high flow.



(figure 15)

NOTES

High flow valves require larger springs to facilitate larger valve assemblies. Larger springs contribute to higher pressure override in the valve. Pressure override is the difference in cracking pressure and the pressure needed to completely open the valve.

Quiz

1. The secondary port of a direct acting relief valve is connected back to the tank.
    a) True
    b) False

2. Direct acting relief valves only come in large sizes because they have to utilize a large spring directly against a poppet.
    a) True
    b) False

3. A direct acting relief valve can be used to control maximum system pressure.
    a) True
    b) False

NOTES

*Although **pilot operated relief valves** characteristically have less pressure override than **direct acting relief valves**, their response time is slower.*

***"Pressure override"** occurs when flow through the relief valve increases after the cracking pressure has been reached. Due to the compression of the spring, the pressure will rise above, or "override" the setting of the valve.*

Note: *All pressure valves are designed as either direct acting or pilot operated.*

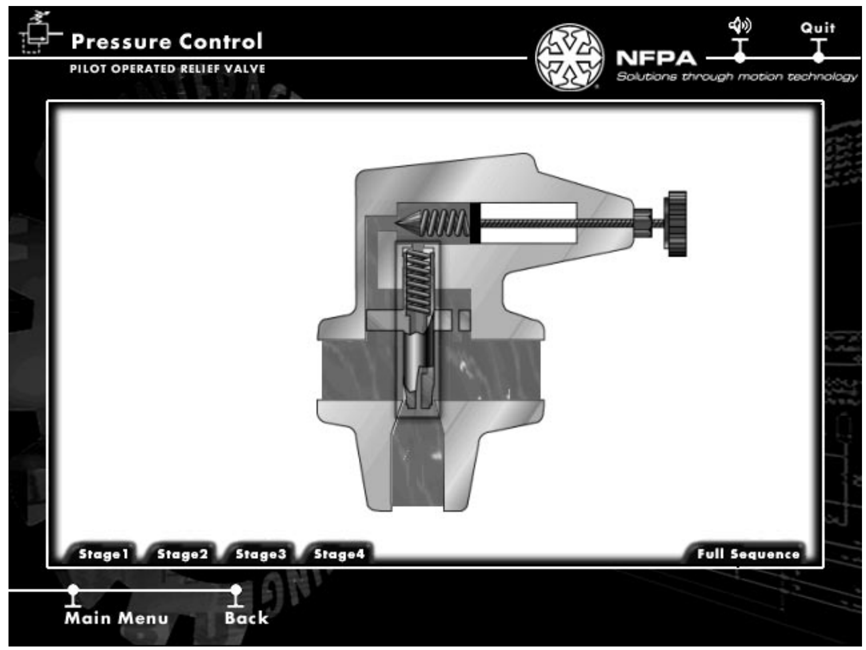
Pilot Operated Relief Valve

Stage 1: Pilot operated relief valves are designed to accommodate higher pressures with higher flows, while allowing a smaller frame size than a direct acting relief valve with the same rate of flow capacity. The valve is built in two stages. The second stage includes the main spool held in a normally closed position by a light, non-adjustable spring. The second stage is large enough to handle the maximum flow rating of the valve. The first stage is a small, direct acting relief valve usually mounted as a cross head on the main valve body, and includes a poppet, spring, and adjustable knob. The second stage handles full rate of flow to the tank. The first stage controls and limits pilot pressure level in the main chamber.

Stage 2: Relieving action through the main spool is as follows: As long as the system pressure is less than relieving pressure set on the control knob, pressure in the main spring chamber is the same as pump line pressure, because there is no flow through the control orifice. Consequently, there is no pressure drop from one side of the orifice to the other.

Stage 3: When pump line pressure rises higher than the adjustment set on the control knob the pilot relief poppet moves off its seat. This starts oil flow from the pump line, through the orifice, across the pilot relief poppet, and to the tank.

Stage 4: This restricted flow caused by the orifice creates a pressure difference between the pump line and the area across the pilot orifice. This pressure imbalance causes the main poppet to move off its seat. This will discharge enough of the pump flow to prevent any further rise in the pump line pressure. When pump line pressure drops below the control knob setting, the pilot relief closes, flow through the orifice ceases, and the main spring can re-seat the main poppet (figure 16).



(figure 16)

NOTES

Poppet Relief Valve

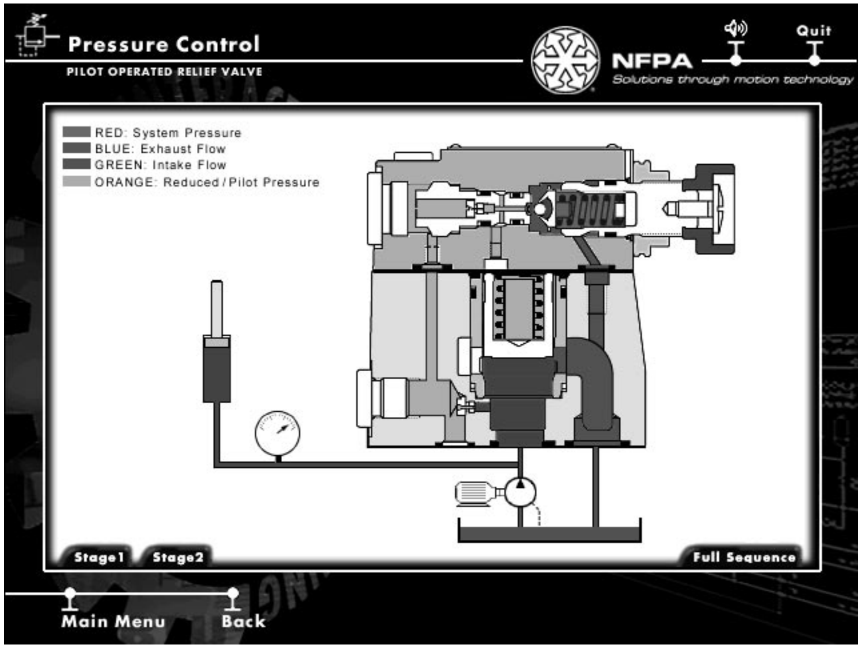
Stage 1: The pilot operated pressure relief valve comprises a valve body, a main spool cartridge, and a pilot valve with a pressure-setting adjustment (figure 16a).

Stage 2: The pressure present in the primary port acts on the bottom of the main spool and, at the same time, the pressure is fed to the spring-loaded side of the main spool via the control lines and containing orifices. The pressure is also present at the ball of the pilot valve. If the pressure increases to a level above the spring setting of the pilot valve, the ball opens against the spring.

The pilot oil on the spring side of the main spool cartridge now flows into the spring chamber of the pilot valve and is directed internally to the secondary port and back to the tank.

Due to the orifices in the control line between the primary port and the pilot valve, a pressure drop, or pressure differential, exists between the bottom of the main spool and the spring side of the main spool. This pressure differential lifts the main spool off its seat and connects the primary pressure port of the valve to the secondary, or tank port.

Fluid now flows to the tank, maintaining the set operating pressure of the valve.



(figure 16a)

NOTES

Quiz

1. By design, a pilot operated relief valve has a larger flow capacity than a direct operated relief valve of the same frame size.
   a) True
   b) False

2. A pilot operated relief valve utilizes a small orifice in the main spool for the purpose of creating a pressure differential across the spool when the pilot poppet is open.
   a) True
   b) False

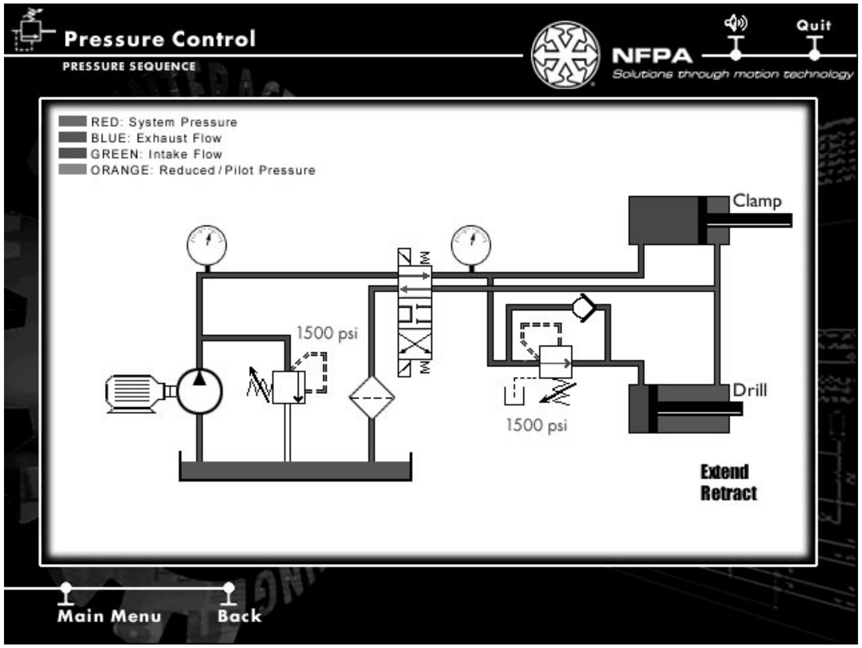
3. The first stage of a pilot operated relief valve is actually a small direct acting relief valve.
   a) True
   b) False

NOTES

Pressure Sequence Valve

A sequence valve is a normally closed pressure control valve that insures that one operation will occur before another, based on pressure. In our clamp and drill system we want the clamp cylinder to extend completely before the drill cylinder extends. To accomplish this we place a sequence valve just before the drill cylinder. We set the valve to 500 psi (figure 17).

This will ensure that the drill will not extend before we have reached 500 psi on the clamp cylinder. Notice that once the drill cylinder has extended, pressure will continue to rise to the system relief setting of 1500 psi. Push the “extend” or “retract” button to watch the function of the valve.



(figure 17)

NOTES

Quiz

1. A sequence valve is a flow control valve.
    a) True
    b) False

2. A sequence valve is normally open.
    a) True
    b) False

3. The pressure downstream of a sequence valve is limited to the sequence valve's settings.
    a) True
    b) False

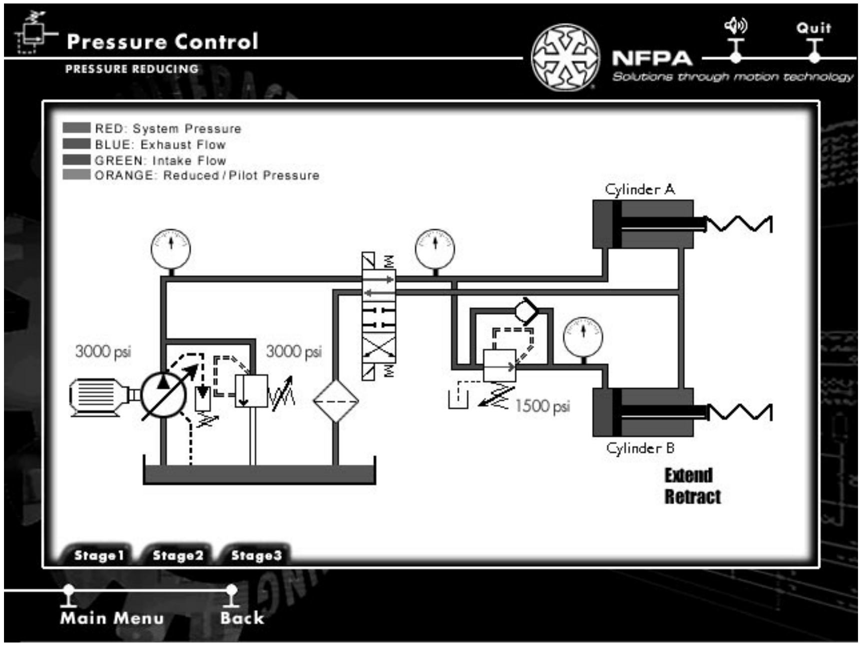
NOTES

Pressure Reducing Valve

Stage 1: A pressure reducing valve is a normally open pressure control valve used to limit pressure in one or more legs of a hydraulic circuit. Reduced pressure results in a reduced force being generated. A pressure reducing valve is the only pressure control valve that is normally open. A normally open pressure control valve has primary and secondary passages connected. Pressure at the bottom of the spool is sensed from the pilot line which is connected to the secondary port. Remember, a pressure reducing valve is normally open.

Stage 2: Now let's place our pressure reducing valve in an actual circuit to see its application. The illustrated clamp circuit requires that clamp cylinder B apply a lesser force than clamp cylinder A. A pressure reducing valve placed just before the clamp cylinder B will allow flow to go to the cylinder until pressure reaches the setting of the valve (figure 18).

Stage 3: At this point, the valve begins to close off, limiting any further buildup of pressure. As fluid bleeds to the tank through the valve drain passage, pressure will begin to decay and the valve will again open. The result is a reduced modulated pressure equal to the setting of the valve. Push the 'extend' or 'retract' button to watch the function of the valve.



(figure 18)

NOTES

Quiz

1. A pressure reducing valve is the only normally open pressure control valve.
   a) True
   b) False

2. Pressure reducing valves are used to limit maximum system pressure.
   a) True
   b) False

3. Unlike other pressure control valves, the pressure reducing valve senses its pilot from the secondary port of the valve.
   a) True
   b) False

NOTES

*A **High-Low pump** system provides a high volume flow at low pressure and a low volume flow at high pressure. These circuits are used to extend and retract work loads at low pressure high flow, followed by a high pressure, low volume flow to do work. Inasmuch as the power required is the product of pressure and flow, a Hi-Low system allows components and input motors to be kept small which increases operating efficiency by sizing the system to load requirements.*

(Hydraulic hp= Pressure x flow rate ÷ 1714)

*A **High-Low pump** circuit which incorporates an 18 gpm pump which unloads at 1000 psi and a 10 gpm pump which is relieved at 3000 psi. What is the maximum **theoretical** input hp required?*

A. 8.5 hp
B. 17.5 hp
C. 12.5 hp
D. 20 hp

Solution
Just prior to unloading, the system will supply 28 gpm (18 gpm + 10 gpm) @ 1000 psi. Based on our theoretical input horsepower formula, the required hp = 16.3. With the 18 gpm pump unloading we supply only 10 gpm at 3000 psi. Again, using our formula, we calculate 17.5 hp required.
Answer: *17.5 hp (theoretical)*

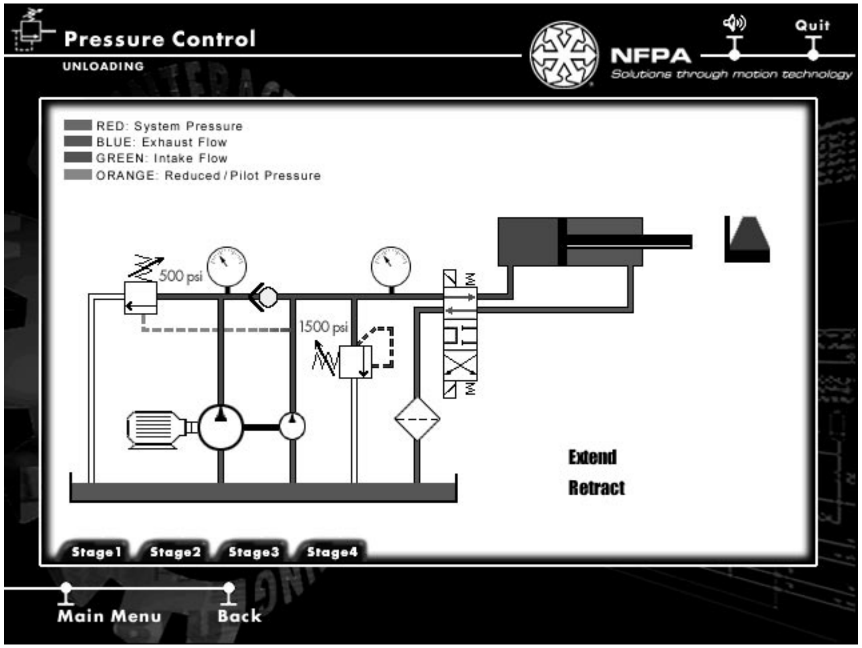
Unloading Valve

Stage 1: An unloading valve is a remotely piloted, normally closed pressure control valve that directs flow to the tank when pressure at that location reaches a predetermined level. A good example of an unloading valve application would be a High-Low system. A High-Low system may consist of two pumps: one high volume pump (high flow), the other a low volume pump (low flow). The system is designed to give a rapid approach or return on the work cylinder. The total volume of both pumps is delivered to the work cylinder until the load is contacted.

Stage 2: At this point the system pressure increases, causing the unloading valve to open. The flow from the large volume pump is directed back to the tank at a minimal pressure. The small volume pump continues to deliver flow for the higher pressure requirement of the work cycle (figure 19).

Stage 3: Both pumps join again for rapid return of the cylinder. This application allows less input horsepower for speed and
force requirements.

Stage 4: Now that you understand the application of an unloading valve push the "extend" or "retract" button to watch the function of the valve.



(figure 19)

NOTES

Quiz

1. When an unloading valve opens, it directs flow directly back to the tank.
   a) True
   b) False

2. Since the unloading valve is remotely piloted, it can allow flow to return to the tank at minimal pressure.
   a) True
   b) False

3. Flow dictates when an unloading valve will open.
   a) True
   b) False

NOTES

***Counterbalance valves** may prevent a loaded cylinder from falling. Pilot check valve circuits also hold loaded cylinders in place. Both types of circuits have unique applications. Counterbalance valves may not be leak free. For example, manufacturers commonly give the leakage rate across a counter-balance spool in drops per minute. If a cylinder must be locked in place with a valve that allows no leakage across the spool, the valve must be designed to do so.*

***Counterbalance valves** may also incorporate external piloting for smoother, "non hunting" performance. When the manufacturer utilizes both internal and external pilots you have the best of both worlds. The internal pilot lowers the load with countered pressure, while the external pilot drops all back pressure when performing work.*

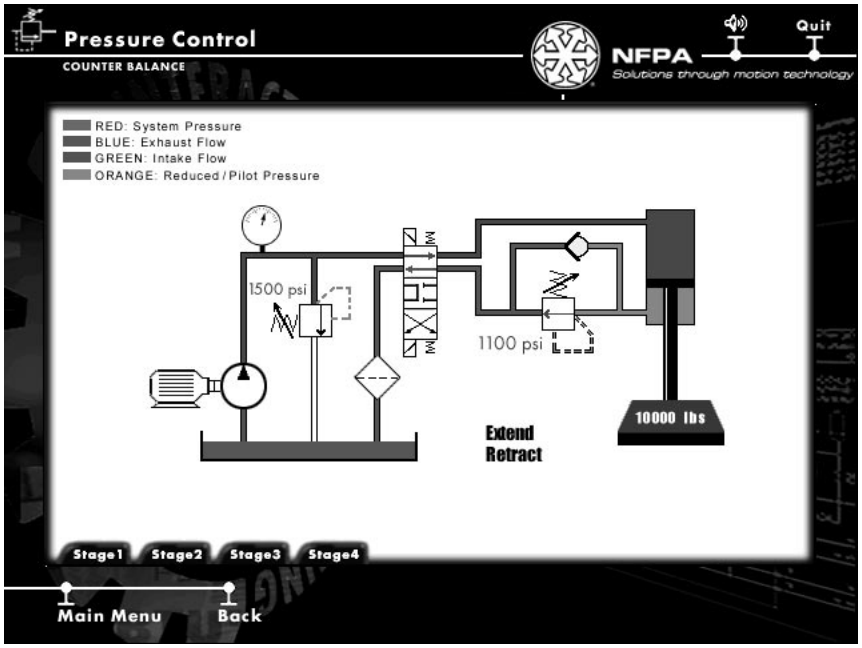
Counterbalance Valve

Stage 1: A counterbalance valve is a normally closed pressure valve used with cylinders to counter a weight or potentially overrunning load. In this circuit, without a counterbalance valve the load would fall uncontrolled or overrun, and pump flow would not be able to keep up. To avoid the uncontrolled operation, we place a counterbalance valve just after the cylinder.

Stage 2: The pressure setting of the counterbalance valve is set slightly above the load-induced pressure of 1000 psi. This counters the load. As we extend the cylinder, pressure must slightly rise to drive the load down.

Stage 3: See Illustration on CD (figure 20).

Stage 4: Now that you understand the application of a counterbalance valve, push the “extend” and “retract” buttons to watch the function of the valve.



(figure 20)

NOTES

Quiz

1. A counterbalance valve is a normally open flow control valve.
   a) True
   b) False

2. A counterbalance valve is used to control a cylinder with a negative or overrunning load to move at a controlled rate.
   a) True
   b) False

3. The counterbalance valve should be set at a pressure slightly higher than the load induced pressure caused by the weight on the cylinder.
   a) True
   b) False

NOTES

*A **brake circuit** utilizing a brake control valve is necessary on a rotary actuator where speed (rpm) control and stopping capacity are required.*

This is also a remote piloted counterbalance valve. Brake valve usually implies that it is used with a motor circuit.

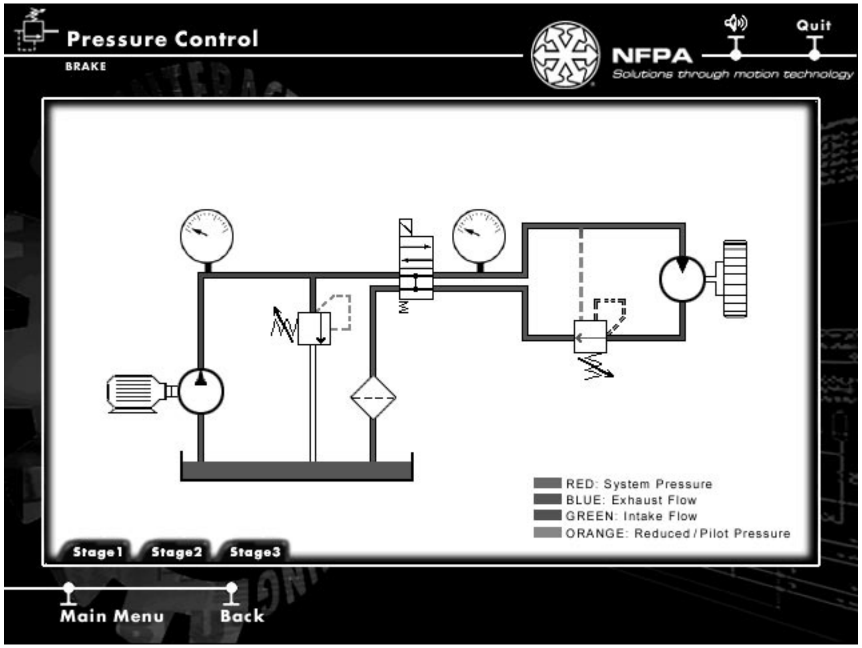
Brake Valve

Stage 1: A brake valve is a normally closed pressure control valve with both direct and remote pilot connected simultaneously for its operation. This valve is frequently used with hydraulic motors for dynamic braking.

Stage 2: Because any downstream resistance will add to the load on the hydraulic motor, we pilot remotely, using working pressure to keep the valve open during running. This eliminates back pressure on the motor (figure 21).

Stage 3: When we de-energize the directional valve, remote pilot pressure is lost, allowing the valve to close. The inertia of the load will now drive the valve open via the internal pilot, giving us dynamic braking.

Stage 4: Now that you understand the application of a brake valve, push “energize,” then “stop,” to see the valve function.



(figure 21)

NOTES

Quiz

1. The brake valve uses a remote pilot to maintain a constant back pressure on the motor.
   a) True
   b) False

2. The brake valve has two pilots for the purpose of allowing the installer more plumbing options.
   a) True
   b) False

3. When the directional control valve is centered, the brake valve allows a controlled amount of back pressure to build in the line between the motor and the brake valve to achieve dynamic braking.
   a) True
   b) False

Learning Lab

In this learning lab you will learn to identify pressure valves in a schematic. Match the proper valve with the proper name by dragging the appropriate name over the appropriate valve. If you are correct, a brief explanation of the valve and its application will follow.

Brake valve: The brake valve serves two purposes. It prevents a load from overrunning the motor, and when the directional control valve is centered, it brings the motor to a stop at a controlled rate of speed.

Unloading valve: When the system pressure reaches the unloading valve setting, the valve opens, diverting flow from the pump back to the tank at minimum pressure.

Pressure relief valve: This valve limits the maximum system pressure.

Sequence valve: If properly adjusted, the sequence valve assures that the cylinder will fully extend before the motor starts.

Counterbalance valve: Counterbalance valves are used to aid a cylinder in lowering a load at a controlled rate.

Pressure reducing valve: The reducing valve will limit the pressure to the motor, thus limiting the output torque of the motor.

NOTES

Directional control valves may also be of the “poppet” design. They have seating elements in the form of balls, poppets or plates. The advantages of the poppet design are zero leakage and no sticking under high pressure.

Introduction

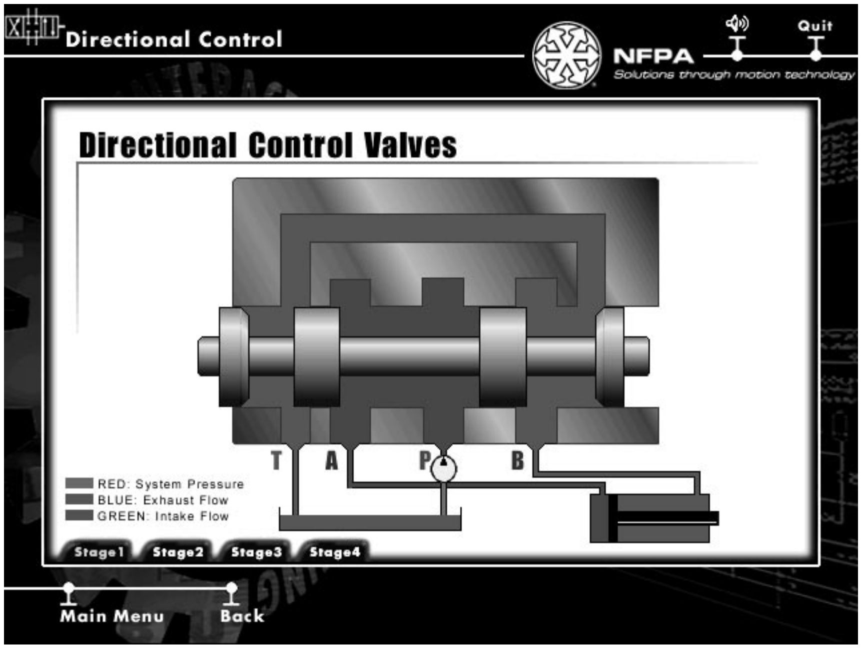
The directional control valve is the component that starts, stops, and changes the direction of the fluid flowing through a hydraulic system. In addition to this, the directional control valve actually designates the type of hydraulic system design: either open or closed. The exercises in this section will give you a hands-on opportunity to see how these valves actually operate and the importance that they play in proper system function.

Overview

Stage 1: Directional control valves are used to start, stop, and change the direction of flow in a hydraulic circuit. Although they may be designed as rotary or poppet style, the spool type directional control is the most common. This design consists of a body with internal passages that are connected or sealed by a spool that slides along the land of the valve. Directional spool valves are sealed along the clearance between the moving spool land and the housing. The degree of sealing depends on the clearance, the viscosity of the fluid, and the pressure. Because of this slight leakage, spool type directional valves alone cannot hydraulically lock the actuator (figure 22).

Stage 2: Directional control valves are primarily designated by their number of possible positions, port connections or ways, and how they are actuated or energized. For example, the number of porting connections are designated as ways or possible flow paths. A four-way valve would have four ports: P, T, A, and B. A three position valve is indicated by a symbol of three connected boxes. There are many ways of actuating or shifting the valve. They are: push button, hand lever, foot pedal, mechanical, hydraulic pilot, air pilot, solenoid, and spring.

Stage 3: Directional control valves may also be designated as normally opened or normally closed. These designations would accompany two-position valves such as the following:



(figure 22)

NOTES

*Single and double **solenoid control valves** are available with DC solenoids or AC 50/60 Hz 120 volt solenoids.*

Most solenoid actuated valves are equipped with manual overrides, allowing the spool to be shifted by hand. This is accomplished by depressing the pin located in the end of the push pin tube located at each end of the valve.

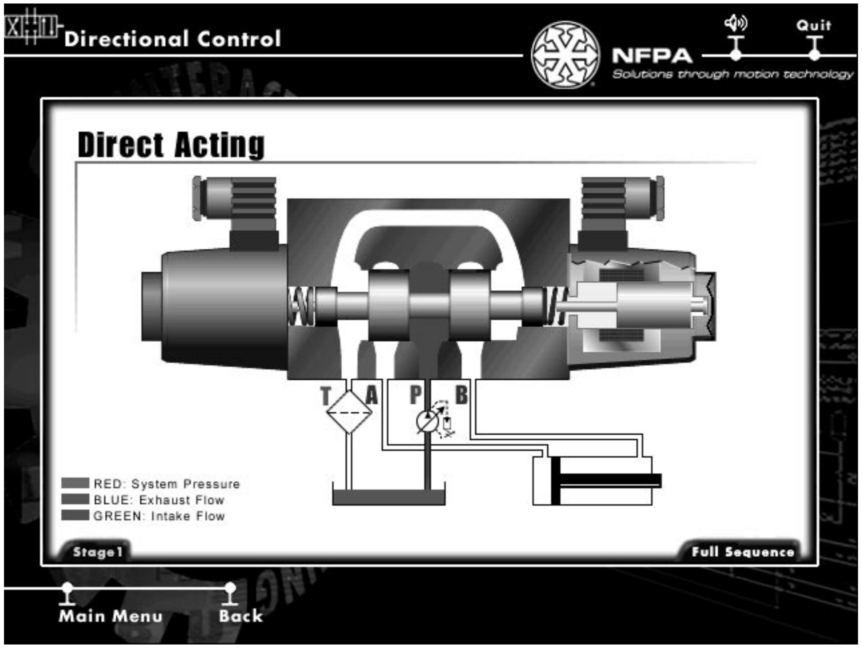
***Pilot operated directional control valves** must have a provision to drain the pilot oil at the opposite end of the spool in order for the valve spool to shift. Blocking the drain or “Y” port of an externally drained valve will prevent the spool from shifting.*

spring offset, solenoid operated, two-way valve normally closed; spring offset, solenoid operated, two-way valve normally open; spring offset, solenoid operated, three-way valve normally closed; spring offset, solenoid operated three-way valve normally open.

Stage 4: The spool type directional control valves in industrial applications are sub-plate or manifold mounted. The porting pattern is industry standard and designated by valve size. Directional control valve sizing is according to flow capacity, which is critical to the proper function of the valve. Flow capacity of a valve is determined by the port sizes and the pressure drop across the valve. This mounting pattern and size is designated as a DO2 nominal flow 5 gpm, DO3 nominal flow 10 gpm, DO5 nominal flow 20 gpm, DO5H nominal flow 25 gpm, DO7 nominal flow 30 gpm, DO8 nominal flow 60 gpm, D10 nominal flow 100 gpm,

Direct Acting

A direct-acting directional control valve may be either manual- or solenoid-actuated. Direct acting indicates that some method of force is applied directly to the spool, causing the spool to shift. In our illustration, energizing the solenoid or coil creates an electromagnetic force which wants to pull the armature into the magnetic field. As this occurs, the connected push pin moves the spool in the same direction while compressing the return spring. As the spool valve shifts, port P opens to port A, and port B opens to port T or tank. This allows the cylinder to extend. When the coil is de-energized, the return springs move the spool back to its center position (figure 23).



(figure 23)

Pilot Operated

Stage 1: For control of systems requiring high flows, usually over 35 gpm, pilot operated directional control valves must be used due to the higher force required to shift the spool. The top valve, called the pilot valve, is used to hydraulically shift the bottom valve, or the main valve.

Stage 2: To accomplish this, oil is directed from either an internal or an external source to the pilot valve. When we energize the pilot valve, oil is directed to one side of the main spool. This will shift the spool, opening our pressure port to the work port and directing return fluid back to the tank.

NOTES

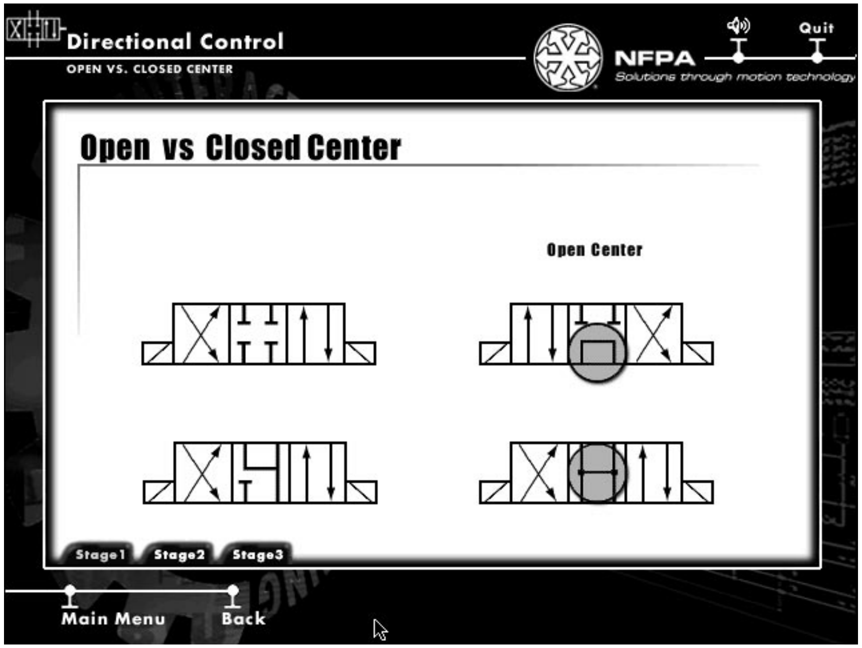
All "spool" type directional control valves have some leakage by the spool. This slight leakage may cause a cylinder to extend under pressure or drift down under load. The application may require the use of a pilot operated check valve in conjunction with a float center.

Stage 3: It is often required to externally pilot, or send fluid to the pilot valve, from an external source. The advantages to external piloting are constant pressure supply, regardless of other influences in the main system, and the source may be filtered separately to prevent silting of the pilot valve. In addition to externally piloting, we may also externally or internally drain the valve. If the pilot valve is internally drained, oil flows directly into the tank port of the main valve. Pressure or flow surges occurring in the tank port when operating the main control spool may affect the unloaded side of the main spool, as well as the pilot valve. To avoid this, we may externally drain the pilot valve by feeding pilot oil flow back to the tank.

Stage 4: Pilot operated directional control valves may be field changed from internal to external pilot and drain.

Open vs. Closed Center

Stage 1: We can categorize most hydraulic circuits into two basic types: open center or closed center (figure 24). The directional control valve actually designates the type of circuit. Open center circuits are defined as circuits which route pump flow back to the reservoir through the directional control valve during neutral or dwell time. This type of circuit typically uses a fixed volume pump, such as a gear pump. If flow were to be blocked in neutral or if the directional control valve is centered, it would force flow over the relief valve. This could possibly create an excessive amount of heat and would be an incorrect design. A closed center circuit blocks pump flow at the directional control valve, in neutral or when centered. We must utilize a pressure compensated pump, such as a piston pump, which will de-stroke, or an unloading circuit used with a fixed volume pump.



(figure 24)

Stage 2: A three-position directional control valve incorporates a neutral or center position which designates the circuit as open or closed, depending on the interconnection of the P and T ports, and designates the type of work application depending on the configuration of the A and B ports. The four most common types of three position valves are: open type, closed type, float type, and tandem type.

NOTES

Stage 3: This open type configuration connects P, T, A, and B together, giving us an open center and work force that drain to the tank. This configuration is often used in motor circuits to allow freewheeling in neutral.

This closed type configuration blocks P, T, A, and B in neutral, giving us a closed center. This center type is common in parallel circuits where we want to stop and hold a load in mid-cycle.

This float type configuration blocks P while interconnecting A and B ports to T. Because P is blocked, the circuit becomes closed center. This center type is commonly used in parallel circuits where we are freewheeling a hydraulic motor in neutral. (and must be used as the pilot valve in any large three position valve).

This tandem type configuration connects P to T while blocking work ports A and B. With P and T connected, we have an open center circuit. This center type is used in connection with a fixed displacement pump. Because A and B are blocked, the load can be held in neutral.

When specifying a directional control valve type, one must consider the type of circuit required and the work application.

Learning Lab

In this learning lab you'll learn the correct combination of directional control valves and pumps used within a system. Choose the correct directional valve and pump from the choices below by dragging and dropping them in place. Press the "operate" button to see if you are correct.

NOTES

Quiz

1. A closed center system maintains constant flow, but no pressure when the directional control valve is centered.
    a) True
    b) False

2. The type of pump (fixed vs. pressure compensated) designates whether we have an open or closed center system.
    a) True
    b) False

3. In an open center system, flow passes through the valve center and back to tank at low pressure when the valve is centered.
    a) True
    b) False

NOTES

Flow control valves, when metering, add resistance to the circuit, which adds heat load to the system. Fixed displacement pump circuits must force excess flow over the relief valve to meter. This creates much more heat than variable displacement pumps, which partially de-stroke the pump from the valve closure, rather than force excess flow over a relief valve.

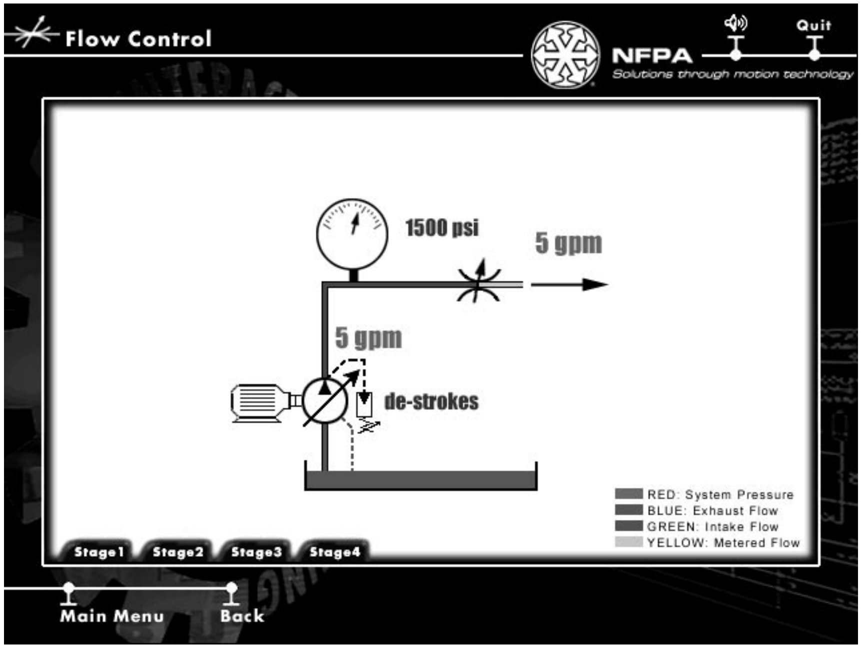
Introduction

Flow control valves are used to regulate the volume of oil supplied to different areas of hydraulic systems. In this section you will be given an overview of the two types of flow control valves, as well as their applications and locations in a hydraulic system. Because a proper placement of these devices is critical to optimum system performance, a section has been provided to help you learn why and where flow control devices should be used. Remember, you can review this section as many times as necessary.

Overview

Stage 1: The function of the flow control valve is to reduce the rate of flow in its leg of the circuit. Flow reduction will result in speed reduction at the actuator. A flow control valve builds added resistance to the circuit, increasing pressure, resulting in a partial bypass of fluid over the relief valve or de-stroking of a pressure of a compensated pump. This reduces flow downstream of the flow control valve.

Stage 2: This circuit uses a fixed volume pump system. To reduce flow to the actuator, we must bypass a portion of the fluid over the relief valve. As we close the needle valve, pressure increases upstream. As we approach 1500 psi the relief valve begins to open, bypassing a portion of fluid to the reservoir (figure 25).



(figure 25)

Stage 3: With flow control used in a pressure compensated pump, we do not push fluid over the relief valve. As we approach the compensator setting of 1500 psi, the pump will begin to destroke, reducing outward flow.

Stage 4: Flow control valves may be fixed, non-adjustable, or adjustable. In addition, they may also be classified as throttling only or pressure compensated. The amount of flow through an orifice will remain constant as long as the pressure differential across the orifice does not change. When the pressure differential changes, the flow changes. Changing load or upstream pressure will change the pressure drop across the valve.

NOTES

A pressure compensated flow control valve may also be temperature compensated as well. Temperature compensation allows for changes in fluid viscosity due to temperature changes in the hydraulic oil.

Throttling vs. Pressure Compensating

Needle Valves

Stage 1: Needle valves may be designated as non-compensated flow control or throttling valves. They are good metering devices as long as the pressure differential across the valve remains constant. We will show you how the speed of the cylinder is affected by the different loads when we use a non-compensated flow control. First, we place a 1000 pound load on the cylinder. Watch the speed indicator to see how the cylinder responds (figure 26).

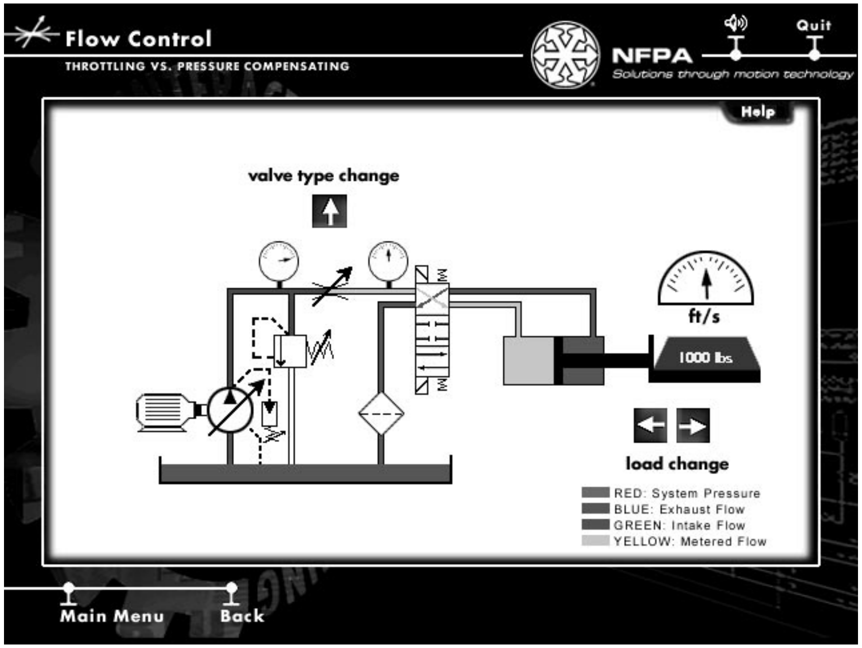
Stage 2: Now, we will place a 5000 pound load. Watch the speed indicator to see how the cylinder responds.

Stage 3: Now, let's place a 500 pound load. Watch the speed indicator to see how the cylinder responds.

Stage 4: A pressure compensated flow control valve is designed to make allowances for pressure changes ahead of or after the orifice. The pressure compensated flow control valve symbol adds a pressure arrow to the orifice. Notice that with a pressure compensated flow control valve, the speed of the cylinder does not change with the change in load.

Learning Lab

In this learning lab you will see how the throttling valve differs from the pressure compensated flow valve. Choose the different weights and valves to see how the speed of the cylinder changes.



(figure 26)

NOTES

Quiz

1. Flow controls are always adjustable.
    a) True
    b) False

2. Flow controls are often used to control the speed of an actuator.
    a) True
    b) False

3. Flow through a throttling valve will vary if the differential pressure across the valve varies.
    a) True
    b) False

4. A pressure compensated flow control valve maintains a constant flow by maintaining a constant pressure upstream from the valve.
    a) True
    b) False

NOTES

Cavitation: A localized gaseous condition within a hydraulic fluid causing the rapid implosion of a gaseous bubble.

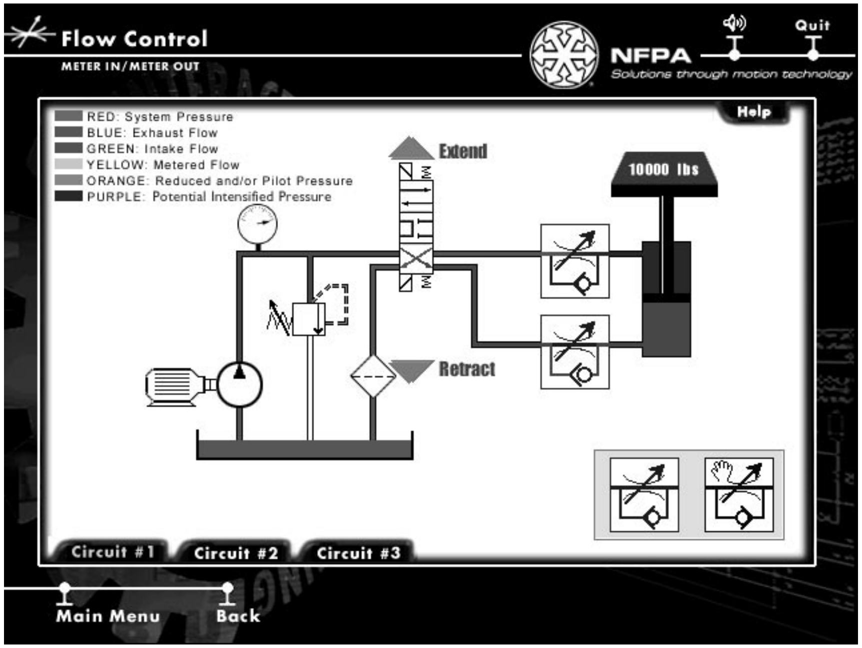
Meter-In, Meter-Out

Stage 1: Meter-in is the method of placing a flow control valve in such a way that fluid is restricted to the actuator. In this circuit, without a flow control valve the cylinder extends and retracts at an unrestricted rate. When we place a flow control valve into the circuit this flow control valve will restrict flow to the cylinder, slowing the extend rate of the cylinder. The check valve allows return flow to bypass the flow control when the direction of flow is reversed. When we move the flow control to the other line, the cylinder extends at an unrestricted rate. We can restrict the flow to the cylinder so that it will retract at a reduced rate.

Stage 2: The advantage to meter-in is that it is very accurate with a positive load. However, when the load goes over center, the load becomes negative or overruns. The load is no longer being controlled by the cylinder. As the load overruns, it causes the cylinder to cavitate.

Stage 3: Although meter-in is usually the best placement for controlling a constant speed, because it also dampens flow and pressure transients, it may be required in some applications to meter-out. To meter-out we simply change the direction that the flow is allowed to pass through the reverse check. This will cause the fluid to be metered as it leaves the actuator, which is opposite of meter-in (figure 27).

Stage 4: An advantage of meter-out is that it will prevent a cylinder from overrunning and consequently cavitating. A disadvantage of meter-out can be pressure intensification. This can occur with a substantial differential area ratio between the rod and piston. When we meter-out on the rod side of the cylinder without a load, the pressure is intensified on the rod side. This may damage the rod seals. Meter-in or meter-out has advantages and disadvantages. The application must determine the type of flow control valve placement.



(figure 27)

NOTES

Learning Lab

In this learning lab you will learn to place the flow control valve correctly in the circuit that will give the proper meter-in and meter-out result. Study the circuit carefully and choose from the two flow control valves in the lower right hand corner and place them in the circuit. Press the "extend" and "retract" buttons to see the circuit work, giving your configuration. When you have completed circuit one, select circuit two and circuit three.

Quiz

1. Meter-in should only be used with a positive load.
   a) True
   b) False

2. When metering-in one must always use a pressure compensated flow control.
   a) True
   b) False

3. Meter-in refers to controlling the flow going to the actuator.
   a) True
   b) False

NOTES

Ingression is defined as the rate at which external contaminants enter the system from the cylinder rods, air breathers, shaft seals and other possible points of entry.

Introduction

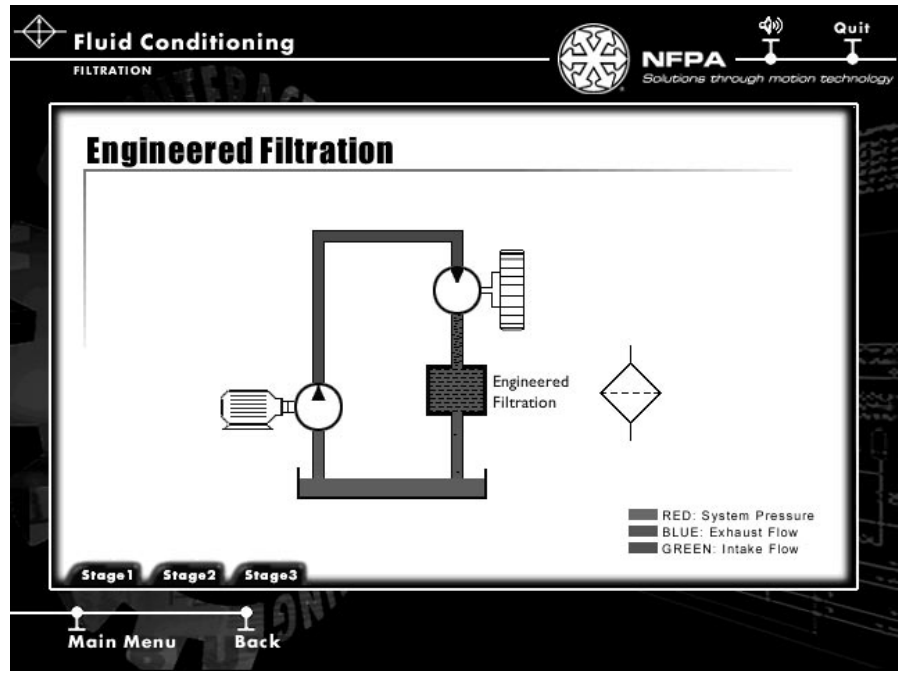
Fluid conditioning is critical in maintaining proper operation of a hydraulic system. In this section, you will learn about different types of filters, their locations, and how they keep hydraulic fluid clean. You will also learn about the importance of regulating the temperature of hydraulic fluid with devices like heat exchangers. For example, fluid that is too hot or too cold can have a negative impact on system performance.

Filtration Overview

Stage 1: Cleanliness of hydraulic fluid has become critical in the design and operation of fluid power components. With pumps and valves designed to closer tolerances and finer finishes, fluid systems operate at ever increasing pressures and efficiencies. These components will perform as designed as long as the fluid is clean. Oil cleanliness results in increased system reliability and reduced maintenance.

Stage 2: As particles are induced or ingressed into a hydraulic system, they are often ground into thousands of fine particles. These tiny particles are tightly packed between valve spools and their bores, causing the valve to stick. This is known as silting.

Stage 3: To prevent silting, early component wear, and eventual system failure, engineered filtration is required. Engineered filtration includes: understanding required micron rating, application of the beta ratio, maintaining proper ISO code cleanliness levels, filter location specific to the system design, and environment (figure 28).



(figure 28)

NOTES

*To convert **beta ratio** into percentage, take the reciprocal of the beta ratio (1÷ß) and subtract it from 100%. Formula: 100%-(1÷ß)= % efficiency.*

Terminology

Micron (µm)

Stage 1: Micron (µm-official name is micrometer) is the designation used to describe particle sizes or clearances in hydraulic components. A µm is equal to 39 millionths of an inch. To put this into perspective the smallest dot that can be seen by the naked eye is 40 µm.

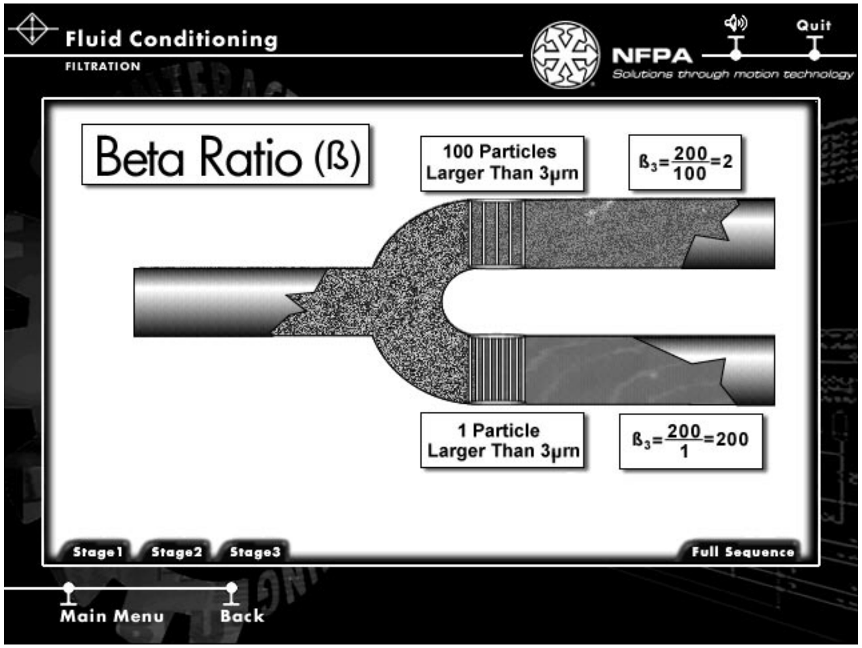
Stage 2: Consider the following illustration. If we looked at a human hair magnified 100 times the particles you see next to the hair are about 10 µm. Industrial hydraulic systems usually filter in the 10 µm range. This means that filters are filtering particles that cannot be seen by the naked eye.

Beta ratio

Stage 1: Filtration devices are used to filter particles out of the system's fluid. A filter's efficiency is expressed as a beta ratio. The beta ratio is the number of particles upstream from the filter that are larger than the filter's µm rating divided by the number of particles downstream larger than the filter's µm rating. In this example there are 200 particles upstream which are larger than three µm. These flow up to and through the filters.

Stage 2: A filter that allows more particles through or in other words, one that is less efficient, has a low beta ratio. You can see that the filter at the top allowed 100 particles through. The filter on the bottom allowed only one particle through (figure 29).

Stage 3: If we apply these numbers to the beta ratio formula, we can see that the filter at the top has a lower, or less efficient beta ratio, and the filter at the bottom has a higher, or more efficient beta ratio.



(figure 29)

NOTES

ISO Code

To specify the cleanliness level of a given volume of fluid we refer to what is known as an ISO code, or ISO solid contamination code. This code, which applies to all types of fluid, provides a universal expression of relative cleanliness between suppliers and users of hydraulic fluid. Based on a milliliter of fluid, a particle count is analyzed using specific sizes of particles; 4 µm, 6 µm, and 14 µm. These three sizes were selected because they gives an accurate assessment of the amount of silt from 4 µm particles and 6 µm particles while the number of particles above 14 µm reflects the amount of wear type particles in the fluid. To interpret the meaning of these results a graph like the one shown would have been consulted. In this example, a rating of 22/18/13 indicates the following: The first number 22 indicates the number of particles greater than or equal to 4µm in size is more than 20,000 and less than or equal to 40,000 per milliliter. The second number 18 indicates the number of particles greater than or equal to 6µm in size is more than 1,300 and less than or equal to 2,500 per milliliter. The third number 13µm indicates the number of particles greater than or equal to 14µm in size is more than 40 and less than or equal to 80 per milliliter (figure 30).

This ISO code is meaningful only if we can relate it to the required cleanliness level of our hydraulic system. This is usually based on a manufacturer's requirement for cleanliness levels in which a component may operate. For example: Most servo valves require an ISO code of 15/13/12 or better, while gear pumps may operate adequately in fluids with 18/16/15 ISO.

Number of particles per 1.0 ml

ISO 4406 Code

Scale No.	More than	& up to	Scale No.	More than	& up to
0	[illegible]	[illegible]	15	[illegible]	[illegible]
1	[illegible]	[illegible]	16	[illegible]	[illegible]
2	[illegible]	[illegible]	17	[illegible]	[illegible]
3	[illegible]	[illegible]	18	1.3k	2.5k
4	[illegible]	[illegible]	19	[illegible]	[illegible]
5	[illegible]	[illegible]	20	[illegible]	[illegible]
6	[illegible]	[illegible]	21	[illegible]	[illegible]
7	[illegible]	[illegible]	22	20k	40k
8	[illegible]	[illegible]	23	[illegible]	[illegible]
9	[illegible]	[illegible]	24	[illegible]	[illegible]
10	[illegible]	[illegible]	25	[illegible]	[illegible]
11	[illegible]	[illegible]	26	[illegible]	[illegible]
12	[illegible]	[illegible]	27	[illegible]	[illegible]
13	40	80	28	[illegible]	[illegible]
14	[illegible]	[illegible]	>28	[illegible]	

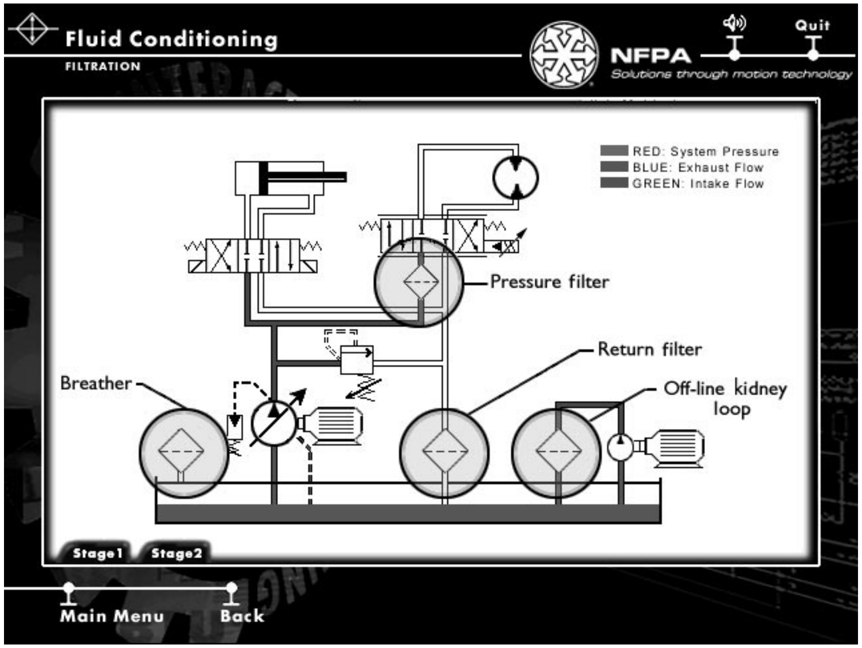
(figure 30)

NOTES

Placement

Stage 1: Filter placement is critical for maintaining acceptable fluid cleanliness levels, adequate component protection, and reducing machine downtime (figure 31).

Stage 2: Filter breathers are critical in prevention of airborne particulate ingression. As the system operates, the fluid level in the reservoir changes. This draws in outside air and with it, airborne particulates. The breather filters the air entering the reservoir. Pressure filters are often required to protect the component immediately downstream of the filter, such as a sensitive servo valve, from accelerated wear, silting, or sticking. Pressure filters must be able to withstand the operating pressure of the system as well as any pump pulsations. Return filters best provide for maintaining total system cleanliness, depending on their µm rating (beta ratio). They can trap very small particles before they return to the reservoir. They must be sized to handle the full return flow from the system. A kidney loop or off-line filtration is often required when fluid circulation through a return filter is minimal. Being independent of the main hydraulic system, off-line filters can be placed where they are most convenient to service or change. Off-line filtration normally runs continuously.



(figure 31)

Learning Lab

In this learning lab you will learn the proper placement of filters. A description explaining the filter's placement will appear at the right side of your screen. Click and drag the description to the proper filter area.

NOTES

Quiz

1. The beta ratio of 75
   a) is less efficient than beta 100.
   b) is more efficient than beta 100.
   c) indicates the µm size.
   d) is none of the above.

2. Filter breathers are critical in prevention of airborne particulate ingression.
   a) True
   b) False

NOTES

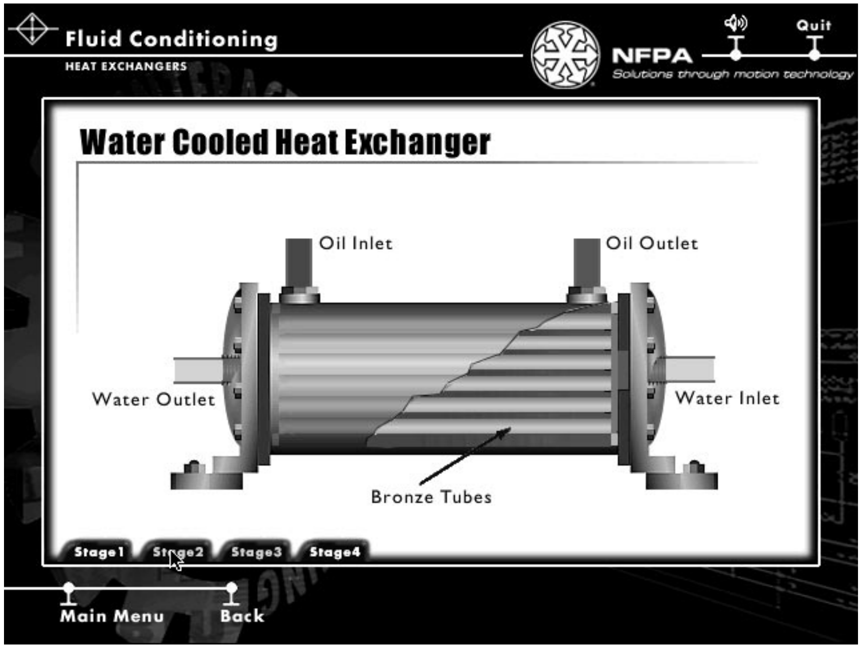
Heat Exchangers

Types

Stage 1: Temperature control is critical in hydraulic systems. Even with the best circuit design, there are always power losses in converting mechanical energy into fluid power. Heat is generated whenever fluid flows from high to low pressure without producing mechanical work. Heat exchangers may be required when operating temperatures are critical or when the system cannot dissipate all the heat that is generated.

Stage 2: There are two basic types of heat exchangers. Each is based on a different cooling medium: water cooled heat exchangers and air cooled heat exchangers.

Stage 3: If cooling water is available, a shell and tube heat exchanger may be preferred (figure 32). Cooling water is circulated through a bundle of bronze tubes from one end cap to the other. Hydraulic fluid is circulated through the unit and around the tubes containing the water. The heat is removed from the hydraulic fluid by the water. There are advantages to this type of cooler. They are the least expensive, they are very compact, they do not make noise, they provide consistent heat removal year round, and they are good in dirty environments. The disadvantages are: water costs can be expensive; with rupture, oil and water may mix; and these exchangers usually require regular maintenance from mineral buildup.



(figure 32)

Stage 4: Air cooled heat exchangers consist of a steel radiator core through which oil flows while a strong blast of air passes across the core. In industrial applications the air is pushed by an electric motor driven fan. The advantages of this type of air cooled heat exchanger are: they eliminate problems associated with cooling water, they have low installed costs, and the dissipated heat can be reclaimed. The disadvantages are: there is a higher installation cost, noise levels range from 60 to 90 decibels, and they are larger in size than comparable water cooled equipment.

NOTES

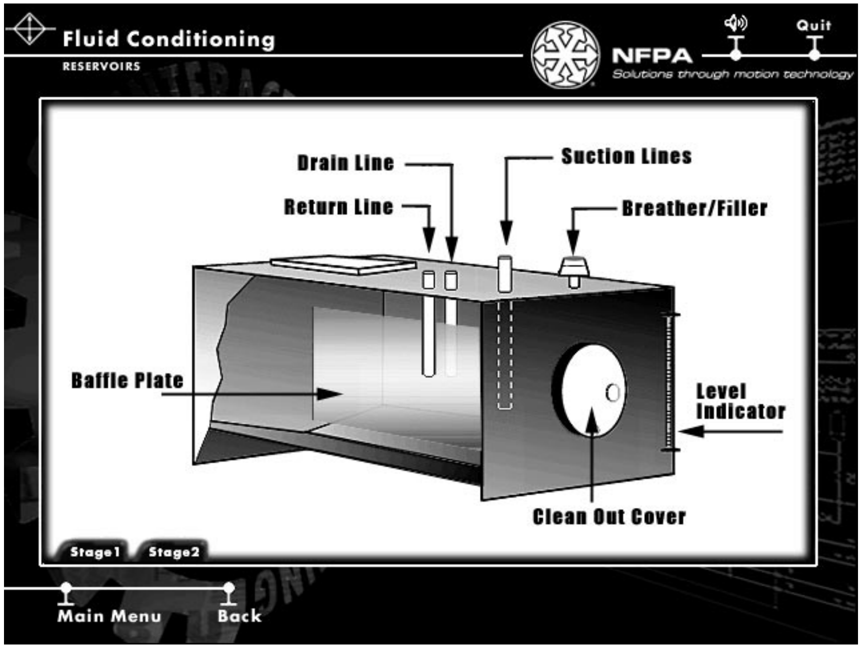
Reservoirs may be classified as vented or pressurized. Vented reservoirs are open to the atmosphere. Pressurized reservoirs offer several advantages over vented: contaminants and condensation are reduced, and pressurized reservoirs help force fluid into the pump inlet.

Reservoirs

Stage 1: In addition to holding the system's fluid supply, the reservoir (tank) serves several other important functions. It cools the hydraulic fluid. This is accomplished by dissipating excess heat through its walls. It conditions the fluid. As oil waits to leave the reservoirs solid contaminants settle while air rises and escapes. The reservoir may provide mounting support for the pump or other components.

Stage 2: A well designed hydraulic system always includes a properly designed reservoir (figure 33). An industrial reservoir should include the following components: a baffle plate to prevent returning fluid from entering the pump inlet, a cleanup cover for maintenance access, a filter breather assembly to allow air exchange, a filler opening well protected from contaminant ingression, a level indicator allowing upper and lower limits of the fluid level to be monitored, and adequate connections and fittings for suction lines, return lines, and drain lines.

It is often stated that the hydraulic fluid is the heart of the system or the most important component. The reservoir serves a critical role in maintaining the efficiency of fluid transfer and conditioning.



(figure 33)

NOTES

Quiz

1. Reservoirs help to condition hydraulic fluid, as well as store the fluid.
    a) True
    b) False

2. Hydraulic fluid returning to the reservoir may contain entrained air and solid contaminants.
    a) True
    b) False

3. All fluid conductor lines entering the reservoir terminate below the fluid level.
    a) True
    b) False

NOTES

Pilot operated check valves *may be piloted to open or piloted to close. This is determined by the application.*

Introduction

Check valves are a simple but important part of a hydraulic system. Simply stated, these valves are used to maintain the direction that fluid flows through a system. And since check valves are zero leakage devices we can use them to lock hydraulic fluid from the cylinders. This section has been designed to help you understand how the different valves function and their application within a hydraulic system.

In-line

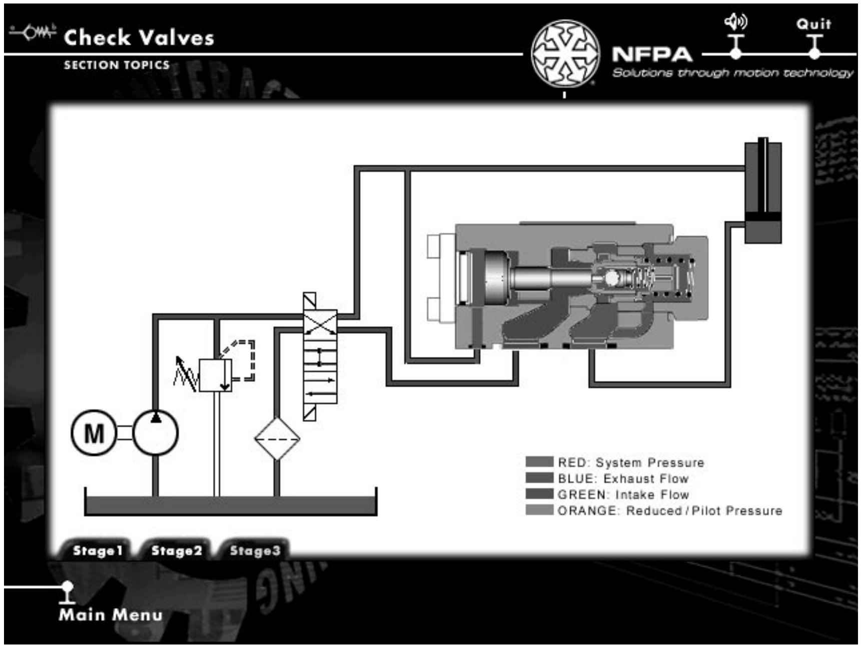
In-line check valves are classified as directional control valves because they dictate the direction flow that can travel in a portion of the circuit. Because of their sealing capability many designs are considered to have zero leakage. The simplest check valve allows free flow in one direction and blocks flow from the opposite direction. This style of check valve is used when flow needs to bypass a pressure valve during return flow, as a bypass around a filter when a filter becomes clogged, or to keep flow from entering a portion of a circuit at an undesirable time.

Pilot Operated

Stage 1: Because of slight spool leakage on standard directional control valves, we must add a check valve to the circuit if we need to hydraulically lock a cylinder. This type of check valve is referred to as a pilot operated check valve.

Stage 2: Unlike a simple check valve, reverse flow is required through the valve to retract the cylinder. This is accomplished by allowing pilot pressure to act on a pilot piston, thus opening the check valve and retracting the cylinder (figure 34).

Stage 3: To extend the cylinder, the check valve allows fluid to flow freely in one direction and blocks flow in the opposite direction.



(figure 34)

NOTES

Learning Lab

In this learning lab you will learn the proper places and proper type of valve to be used within a system by placing the correct valve in the correct space.

Quiz

1. Check valves are classified as
    a) pressure control valves.
    b) flow control valves.
    c) directional control valves.
    d) bypass valves.

2. Pilot operated check valves use an external pilot to allow reverse flow to pass through the valve.
    a) True
    b) False

3. Check valves are considered to have
    a) much leakage.
    b) zero leakage.
    c) little leakage.
    d) moderate leakage.

NOTES

Safety is an important consideration in working with accumulators. Caution must be taken not to overcharge the accumulator.

Accumulator circuits *should be equipped with a unloading valve. This valve allows the accumulators to be isolated and discharged to the tank prior to system maintenance.*

Introduction

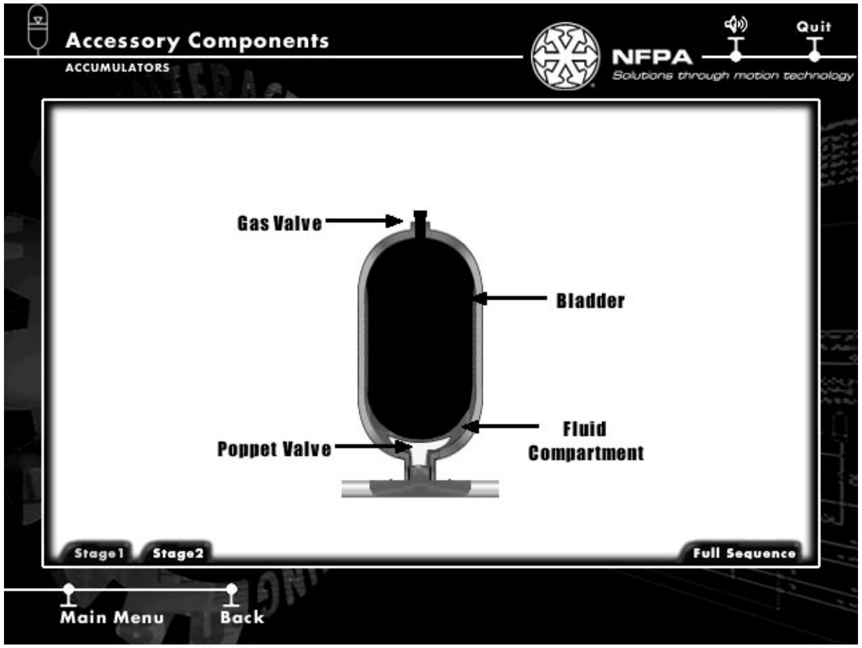
In this section you will be given an overview of several accessory components that are used in most hydraulic systems. You'll learn about accumulators, pressure switches, gauges, flow meters, and manifolds. These components are vital to proper system operation, and understanding how they are used in a system is an important part of this basic hydraulic course.

Accumulators

Stage 1: Accumulators are devices that store energy in the form of fluid under pressure. Because of their ability to store excess energy and release it when needed, accumulators are useful tools for improving hydraulic efficiency. Industrial hydraulic accumulators are typically classified as hydropneumatic. This type of accumulator applies a force to a liquid by using compressed gas.

The two most common types of hydropneumatic accumulators are the bladder type accumulator and the piston accumulator. The name of each type indicates the device separating gas from liquid.

A hydra-pneumatic accumulator has a fluid compartment and a gas compartment, with a element such as a bladder separating the two. The bladder is charged through a gas valve at the top of the accumulator, while a poppet valve at the bottom prevents the bladder from extruding into the pressure line. The poppet valve is sized so that maximum volumetric flow cannot be exceeded (figure 35).



(figure 35)

To operate, the bladder is pre-charged with nitrogen to a pressure specified by the manufacturer, according to the operating conditions. When the system pressure exceeds the gas's pre-charged pressure, the poppet valve opens and hydraulic fluid enters the accumulator. The changing gas volume in the bladder determines the useable volume or useful fluid capacity.

Stage 2: Now that our accumulator is charged with stored energy, watch it discharge and use the stored energy to accomplish work.

NOTES

Learning Lab

In this learning lab you will see how an accumulator functions within a system. Accumulators store energy that can be used during power failure or when additional energy is needed. Click the “motor on” button to charge the accumulator.

Once the accumulator is charged click “motor off” to turn the motor off and simulate a power outage. Notice how the fluid is stored within the system. When the valve is shifted, the stored energy will be released. This creates enough flow to raise the cylinder. Depending on the size of the accumulator, operations like this can be performed several times before the energy in the accumulator is expended. To discharge the accumulator, click on the “shift valve” button.

In certain situations additional flow may be needed. An accumulator can be used to supplement the flow rate of a pump. Click the “motor on” button to charge the accumulator.

Now that our accumulator is charged and the pump is running, notice that it has de-stroked. Click on the “shift valve” button to see the accumulator discharge, combining with pump discharge to increase the flow in the system. Notice how this additional flow will speed up the extension of the cylinder.

NOTES

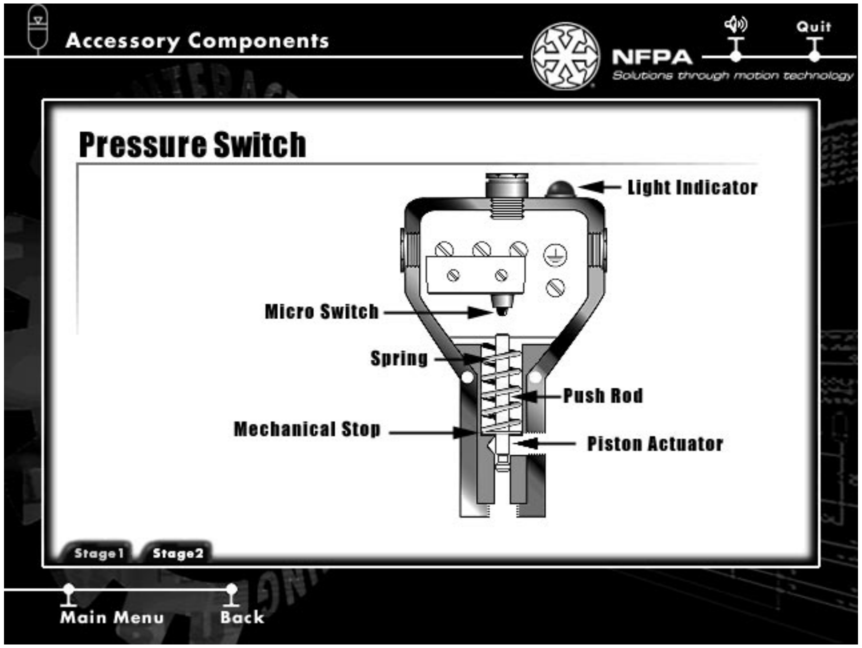
***Bourdon tube** pressure gauges are most accurate in the center half of the scale.*

Even with the gauge properly sized, shock loading or pressure spikes will damage the gear mechanism. Dampening devices help prevent this from happening.

Pressure Switches

Stage 1: There are two types of pressure switches: the bourdon tube switch and the piston switch, shown here (figure 36). This pressure switch consists of a micro switch, a spring, a mechanical stop, a push rod, and a piston actuator. External lights are often used to indicate that the switch has been activated.

Stage 2: When pressure builds in the system, it enters the device, applying force to the piston actuator. This energy is transferred to the mechanical stop, compressing the spring, driving the push rod up until it activates the micro switch. Pressure switches are used to open or close an electrical circuit when a predetermined pressure has been reached.



(figure 36)

Pressure Gauges

Stage 1: Bourdon tube pressure gauges measure the pressure in a system and display it on a calibrated dial. The units of calibration are displayed in psi, bar, and psia.

Stage 2: The bourdon tube is a coiled metal tube. It is connected to system pressure. Any increase in pressure within the system causes the tube to straighten out.

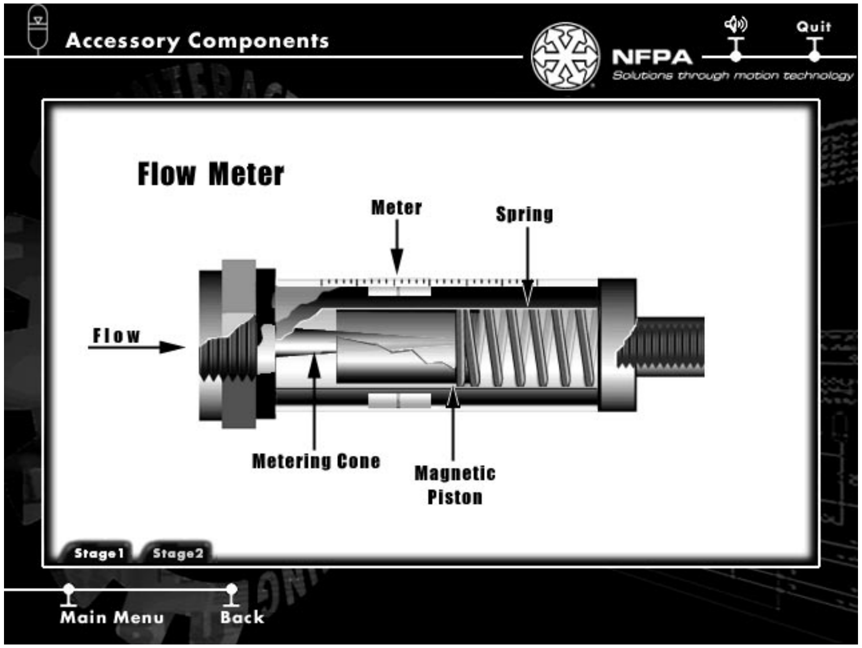
The end of the tube is connected to a mechanical linkage which turns a gear. This gear in turn meshes with a gear, driving the pointer needle. Watch now as the tube is pressurized, causing the needle to turn and give the new system pressure.

NOTES

Flow Meters

Stage 1: The purpose of a flow meter is to measure flow. It is not bi-directional and acts as a check valve blocking flow in the reverse direction. The main components consist of: a metering cone and a magnetic piston which is held in the no-flow position by a tempered spring.

Stage 2: Fluid first enters the device, flowing around the metering cone, putting pressure on the magnetic piston and spring. As flow increases in the system, the magnetic piston begins to compress the spring, indicating the flow rate on the graduated scale (figure 37).



(figure 37)

Manifolds

As the number of connections in a hydraulic system increases, so does the possibility of leakage. Hydraulic manifolds drastically reduce the number of external connections required (for example fittings).

Manifolds used for modular valve stacking incorporate a common pressure and return port. With individual A and B work ports for each valve station, at each station additional control valving may be added by sandwiching or stacking the valves vertically. This is accomplished without any external connections. Manifolds are specified according to system pressure, total flow, number of work stations, and valve size or pattern.

NOTES

Quiz

1. A flow meter controls the amount of flow in a circuit.
   a) True
   b) False

2. A pressure gauge measures pressure in a system and displays it on a calibrated dial.
   a) True
   b) False

3. Pressure switches are used to open or close an electrical circuit when a predetermined pressure has been reached.
   a) True
   b) False

4. Manifolds reduce the number of connections, but increase the number of potential leak points.
   a) True
   b) False

5. Two common applications for accumulators are to store energy in a hydraulic circuit and to supplement pump flow.
   a) True
   b) False

NOTES

Hoses should not be installed with a twist. A slight twist in the hose can significantly reduce hose life. Twisting a hose 10º could shorten its service life as much as 90%.

The bending radius of a hose is the curvature of a hose from a straight line beginning at the radius of the bend. The bending radius of a hose is measured to the external cover of the hose on the inside turn.

The minimum bending radius of a hose is determined by the manufacturer and typically illustrated by charts.

The bending radius increases as the diameter of the hose increases. It must also increase with an increase in pressure.

Hose life is greatly reduced with system temperature increase.

Introduction

Fluid conductors are those parts of the system that are used to carry fluid to all of the various components in the hydraulic circuit. These types of conductors include hydraulic hose, steel tubing, and steel pipe. This section will help you understand the benefits of these different conductors and where they are best used in a hydraulic system.

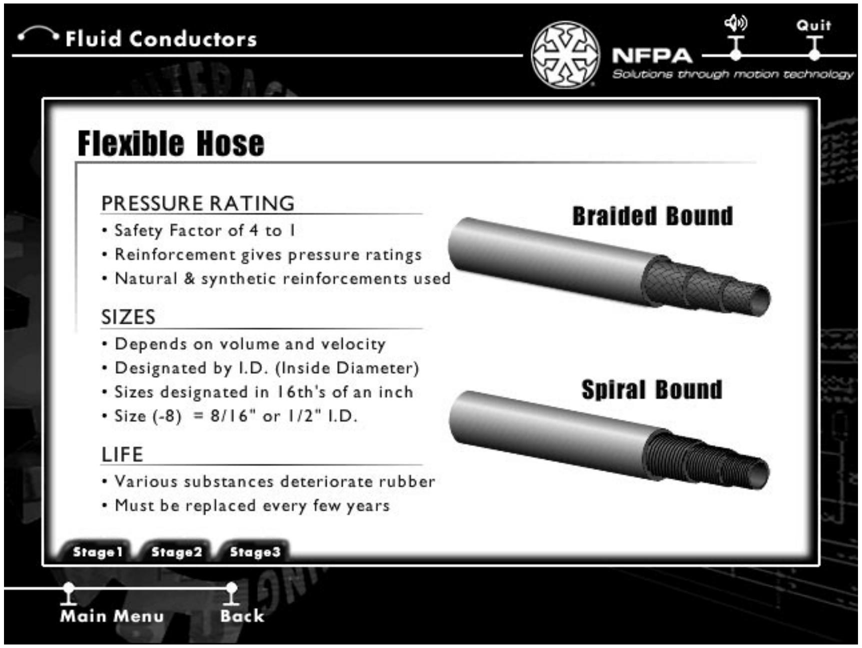
Overview

Transmitting power from one location to another is a key element in system design and performance. Fluid conductors describe the different types of conducting lines that carry hydraulic fluid between components. The three principle types of plumbing materials used in hydraulic systems are steel pipes, steel tubing, and flexible hose. A safety factor of 4 to 1 is recommended on the pressure rating of the plumbing material. To determine the pressure rating of the conductor, we must take the burst pressure and divide by the safety factor of 4.

Hose

Stage 1: Hydraulic hoses are used in applications where lines must flex or bend. In considering the use of hoses, one must first look at system pressure, pressure pulses, velocity, fluid compatibility, and environmental conditions (figure 38). Hose construction has been standardized by the Society of Automotive Engineers. (SAE J517-R series), for example, 100R2 or 100R4. This designation describes the cover, construction, pressure rating and application.

Stage 2: Hoses are usually pressure rated with a safety factor of 4 to 1. Different types and amounts of reinforcement give the hose specific pressure ratings. The reinforcement may be a natural or synthetic fiber or metal wire. The reinforcement may be braided or spiral bound. Required hose size depends on the volume and velocity of the fluid flow. Unlike pipe and tubing, hose sizes are designated by the inside diameter.



(figure 38)

NOTES

Remember:
As inside diameter or I.D. is increased to reduce velocity, maximum system working pressure is decreased. This is due to the increase in surface area. A thicker wall (heavier schedule) may be required.

In standard pipe, the actual I.D. is usually larger than the nominal size quoted. A standard conversion chart should be used.

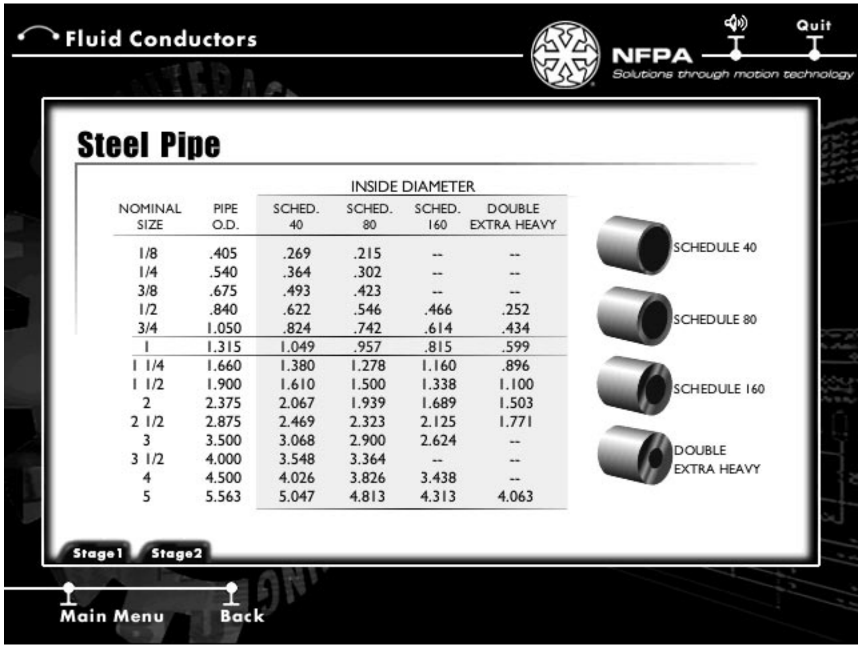
Sizes are designated in 16ths of an inch by using a dash and a number equivalent to the numerator of the fraction. Example: dash 8 (-8) is 8/16" or half inch inside diameter. Hose life can last a long time, but all rubber slowly deteriorates with contact from various substances, such as solvents, water, sunlight, heat, etc. Hoses are not as permanent as metal conductors and should be replaced every few years.

Stage 3: Proper hose installation is critical. Improper bends, twisting, or lack of proper anchoring may lead to hose failure.

Pipe

Stage 1: Steel pipe is often a preferred conductor from the standard points of performance and cost. However, it is often difficult to assemble, because welding is required to give maximum leak protection. It also requires costly flushing to ensure a contaminant-free system at startup.

Stage 2: Pipe is specified by its nominal outside diameter, but its actual flow capacity is determined by its inside area. For example, schedules 40, 80, 160, and double extra have the same outside diameter, and can be threaded by the same pipe die. The difference is the inside diameter and area. Schedule 40 pipe is standard and has the thinnest wall, with more flow area but lower pressure rating (figure 39).



NOMINAL SIZE	PIPE O.D.	INSIDE DIAMETER SCHED. 40	SCHED. 80	SCHED. 160	DOUBLE EXTRA HEAVY
1/8	.405	.269	.215	--	--
1/4	.540	.364	.302	--	--
3/8	.675	.493	.423	--	--
1/2	.840	.622	.546	.466	.252
3/4	1.050	.824	.742	.614	.434
1	1.315	1.049	.957	.815	.599
1 1/4	1.660	1.380	1.278	1.160	.896
1 1/2	1.900	1.610	1.500	1.338	1.100
2	2.375	2.067	1.939	1.689	1.503
2 1/2	2.875	2.469	2.323	2.125	1.771
3	3.500	3.068	2.900	2.624	--
3 1/2	4.000	3.548	3.364	--	--
4	4.500	4.026	3.826	3.438	--
5	5.563	5.047	4.813	4.313	4.063

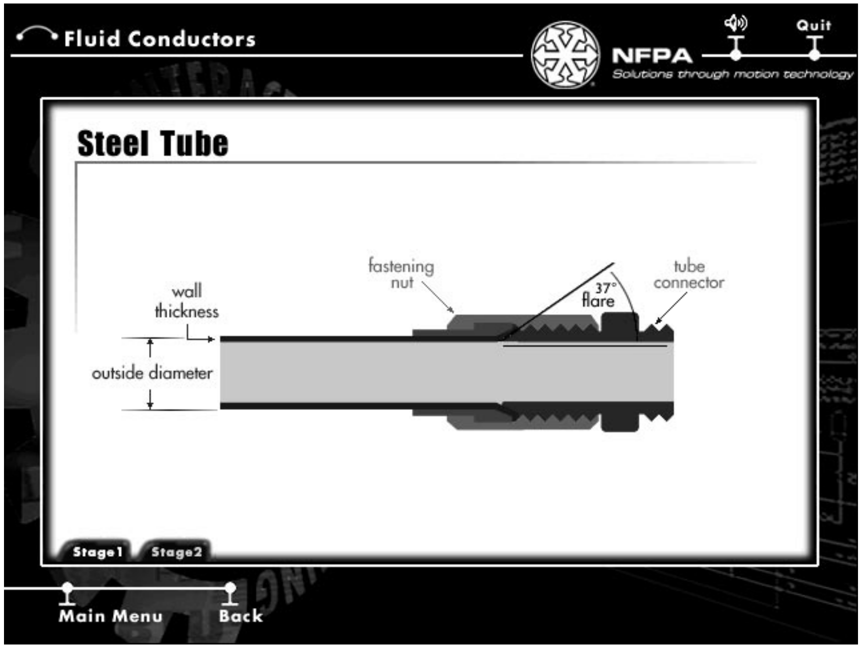
(figure 39)

Steel Tubing

Stage 1: Tubing is used as a conductor when rigid lines are required. It is often easier to assemble and form and requires no welding to achieve leak-free connections. As with all types of conductors, certain requirements must be met. The line must be large enough to carry the required flow and strong enough to withstand internal pressures.

NOTES

Flow velocity *(ft/s) = flow rate x .3208 ÷ area* (in^2)



(figure 40)

Stage 2: Tubing is measured and specified by its wall thickness and outside diameter. Pressure ratings are based on tubing grade and wall thickness. One piece of tubing is joined to another tube connector, or component, with a tube connector and fastening nut. Often the tube is pre-flared to 37 degrees to accept a 37 degree flare connector (figure 40).

Sizing

In this learning lab you will learn proper size selection for desired flow rate or velocity. To determine the pipe size needed, enter the flow in gallons per minute and the velocity in feet per second in the windows labeled “gpm” and “fps”. You can also use your mouse to slide the red markers on either scale.

NOTES

Quiz

1. As flow increases, fluid velocity through a conductor increases.
   a) True
   b) False

2. Tubing is measured and specified by its wall thickness and its O.D.
   a) True
   b) False

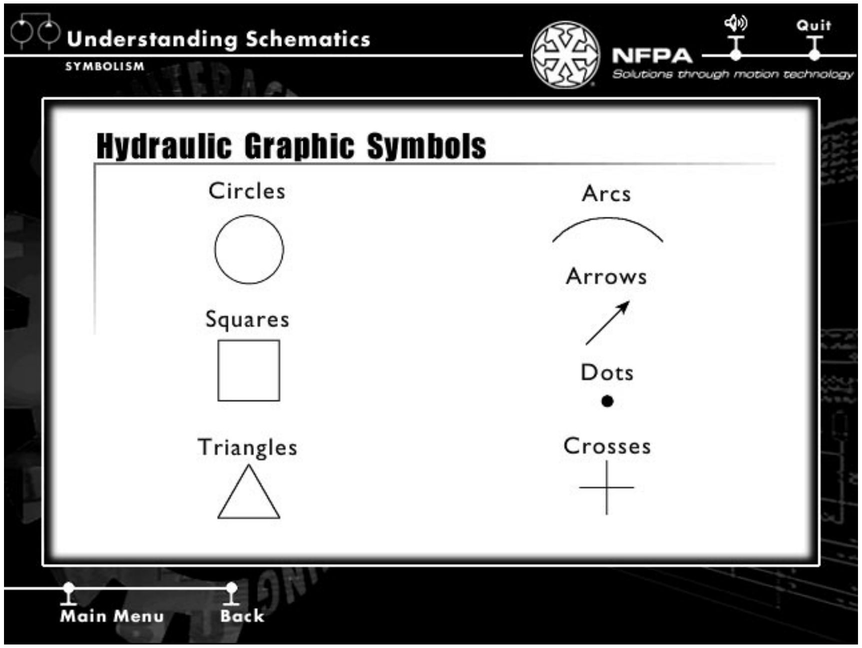
NOTES

Introduction

When hydraulic systems are designed, whether on paper or computer, the layout of the system is expressed in what is called a schematic. A schematic is a line drawing made up of a series of symbols and connections that represent the actual components in a hydraulic system. Although there are dozens of different symbols used in a complex schematic drawing, it is important to be able to recognize several basic symbols. In this section, you will learn to identify these basic symbols as well as where they are placed in the schematic of a basic hydraulic system. The learning labs in this section are fun and should be used until you can identify and use these symbols easily.

Symbolism

Symbols are critical for technical communication. They are not dependent on any specific language, being international in scope and character. Hydraulic graphic symbols emphasize the function and methods of operation of components. These symbols can be rather simple to draw, if we understand their logic and the elementary forms used in symbol design. The elementary forms of symbols are circles, squares, triangles, arcs, arrows, dots, and crosses (figure 41). Click on each of the following categories to see how these common hydraulic graphic symbols are logically constructed, giving symbolic representation of its component.



(figure 41)

Lines

Understanding graphic line symbols is critical to proper interpretation of schematics. Continuous lines indicate a working line, pilot supply, return, or electrical line. A dashed line indicates a pilot, drain, purge, or bleed line. Flexible line indicates a hose usually connected to a moving part. Lines crossing may use loops at crossovers or be straight across. Lines joining may use a dot at the junction or at right angles.

NOTES

Using your hydraulic symbols template properly draw the following symbols:

Pressure compensated pump

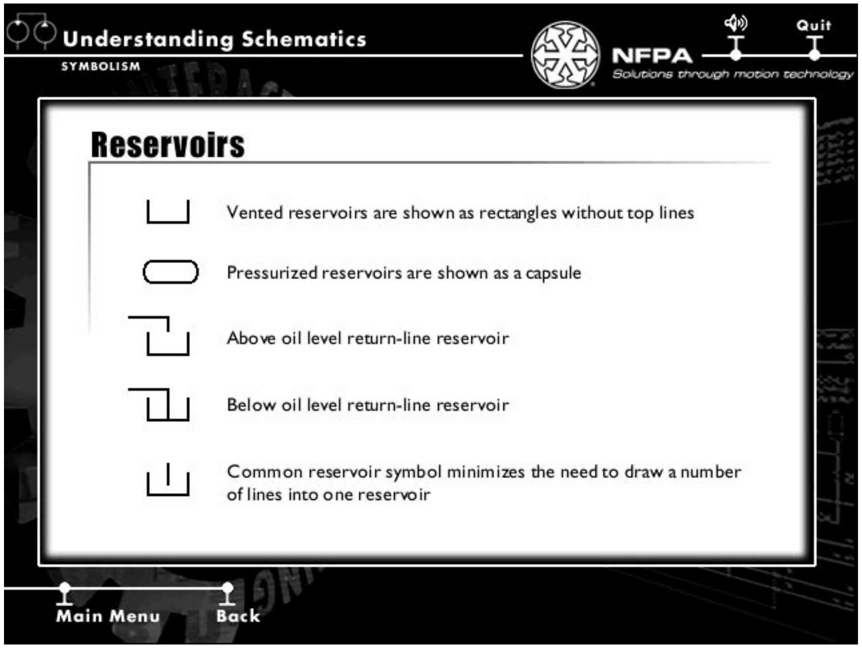
Gear pump

Flow control with reverse flow check (adjustable)

Pressure compensated flow control (adjustable)

Reservoirs

Reservoirs that are vented are shown as a rectangle with the top line omitted. Pressurized reservoirs are shown as capsules. Reservoirs may have fluid oil lines terminating above or below the fluid level. The above oil level return line terminates at or slightly below the upright legs of the tank symbol. The below level return line touches the bottom of the tank symbol. A simplified symbol to represent the reservoir minimizes the need to draw a number of lines returning to the reservoir. A number of these in the same circuit will represent a common reservoir. These symbols have the same function as the ground symbol in electric circuits (figure 42).



(figure 42)

Pumps

Rotary devices are shown as circles. Pump symbols have energy triangles pointing to the outside perimeter, indicating the energy is leaving the component. A sloping arrow through the circle indicates that the pump is variable, or the output flow can be regulated without changing shaft speed. A control symbol with an energy triangle that is connected to an adjustable spring indicates that the pump is pressure compensated. Some types of pumps have internal leakage that is returned to the tank by a case drain. This is indicated with a drain line drawn leaving the circle. Pumps that are bi-directional are shown with two energy flow triangles.

Flow Control

The symbol for a flow control valve begins with an upper and lower arc. This would symbolize a fixed orifice. An arrow drawn sloping through the arcs indicate that the orifice is adjustable. This would be the graphic symbol for a needle valve. When we add an arrow to the flow line inside a control box, we have indicated that the valve is pressure compensated or has true flow control. A flow control valve with a check valve indicates reverse flow around the valve.

NOTES

Using your hydraulic symbols template properly draw the following symbols:

Three position, four way, tandem center, spring centered solenoid operated, directional control valve

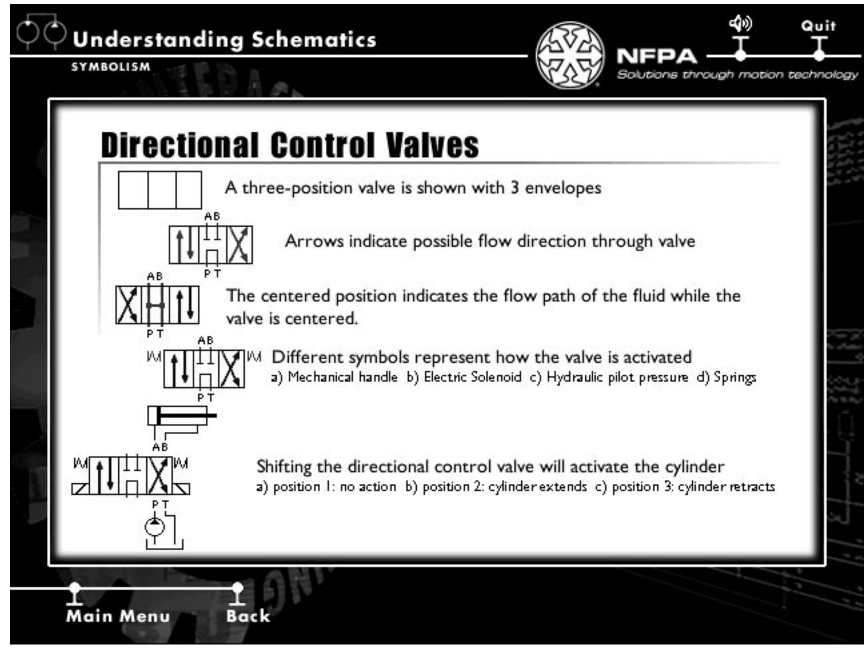
Pressure relief valve

Pressure sequence valve

Pressure reducing valve

Directional Control Valves

The symbol for directional control valve has multiple envelopes showing the number of positions the valve may have. A three-position directional control valve is shown with three envelopes. Arrows in each envelope indicate the possible direction and flow while the valve is in that position. The center position in a three- position directional control valve is designed according to the type of circuit or application. This centered position indicates the flow path of the fluid while the valve is centered. While there are many types of center configurations, the four most common are tandem, closed, float, and open. To shift the valve or activate it, we can use a mechanical handle or lever, an electric solenoid, or hydraulic pilot pressure. The spring on both sides of the symbol indicate that the valve is centered when not activated. In position one, or centered, fluid flows from the pump, through the valve, to the tank. This is a tandem center. When we shift the valve to position two, fluid now flows from P to A, extending the cylinder, shifting to position three, which shows flow now from P to B and from A to T, the cylinder retracts (figure 43).



(figure 43)

Pressure Valves

The symbol for a pressure valve begins with a single envelope. The arrow in the envelope depicts the direction of flow through the valve. The ports are indicated as 1 and 2, or primary and secondary. Flow through the valve is from the primary to the secondary port. Notice that in the normal position, the arrow is not aligned with the port. This indicates that the valve is normally closed. All pressure valves are normally closed with the exception of a pressure reducing valve, which is normally open. The spring located perpendicular to the arrow indicates that the spring force holds the valve closed. An arrow diagonally through the spring indicates that the spring force is adjustable. Pilot pressure opposes spring force. This is indicated by the dotted line running from the primary port perpendicular to the arrow opposite the spring. When the hydraulic pressure piloted from the primary port exceeds the force of the spring, the valve moves to the open position, aligning the primary and secondary ports.

NOTES

Using your hydraulic symbols template, properly draw the following symbols:

Hydraulic motor (bi-directional)

Pilot operated check valve (pilot to open)

Double acting cylinder

Hydraulic filter with a bypass check valve

Hydraulic oil cooler

Check Valves

Check valve symbols are drawn with a small circle inside an open triangle. Free flow is opposite the direction the triangle is pointed. As the circle moves into the triangle, this represents that the flow is blocked or checked. Check valves may be piloted to open or closed. Pilot to open is indicated with a pilot line directed to the triangle shown to push the circle away from the seal. Pilot to closed is indicated by directing the pilot line to the back of the circle or into the seat.

Motors

Hydraulic motor graphic symbols are opposite of hydraulic pumps', the difference being the energy triangle points into the circle, indicating fluid energy entering. Two energy triangles pointing in indicate a bi-directional or reversible motor. As with pumps, many hydraulic motor designs have internal leakage. A dotted line leaving the circle indicates a drain line to the tank.

Cylinders

Fluid power cylinders with no unusual relationship between the bore and rod size are shown: single acting, double acting, and double rod. An internal rectangle adjacent to the symbol for the piston indicates a cushion device at the end of the stroke. If the diameter of the rod is larger than usual for the bore size, the symbol must reflect this.

Filters

The graphic symbol for a hydraulic fluid conditioning device is shown with a square standing on end. A dotted line across opposite corners indicates that it is a filter or a strainer. Adding a check valve across and parallel to the ports indicates that the filter has a bypass.

Heat Exchanger

Hydraulic heat exchangers may be considered coolers or heaters. Their graphic symbols are often confused. As with a filter, the base symbol is shown as a square on end. Arrows pointing in indicate the introduction of heat or a heater. Arrows pointing out indicate heat dissipating or a cooler. Arrows pointing in and out would indicate a temperature controller or temperature that is maintained between two predetermined limits.

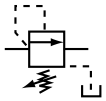
NOTES

Learning Lab (Symbols)

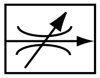
In this learning lab you will learn the proper names for schematic symbols. Roll the mouse over the symbols on the right side of your screen to reveal the proper names. Match the names with the symbols in the module to the left. When you feel like you have mastered these symbols, click on the "test yourself" button on the previous screen.

Quiz

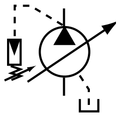
1. Identify the following symbol:
    a) Relief
    b) Counterbalance
    c) Sequence



2. Identify the following symbol:
    a) Needle valve
    b) Throttling valve
    c) Pressure compensated flow control valve



3. Identify the following symbol:
    a) Gear pump
    b) Piston pump
    c) Pressure compensated pump



NOTES

Using your hydraulic symbols template properly draw a simple "closed center circuit." For review, see "animation" under directional control/ "open vs. closed center." (NOTE: If you choose to draw a motor circuit, insure that the proper directional control center configuration is selected.)

Reading Schematics

Circuit #1

Stage 1: A schematic is a compilation of graphic symbols, interconnected, showing a sequence of operational flow. In short, they explain how a circuit functions. Correct schematic reading is the most important element of hydraulic troubleshooting. Although initially most circuits may appear complicated, recognizing standard symbols and systematic flow tracings simplifies the process.

This circuit uses two sequence valves. They are normally closed valves that open at a predetermined setting. By tracing the flow in this circuit, we should be able to determine how this circuit is designed to operate. This process is called reading a schematic. Let's begin at the pump.

Follow the flow past the relief valve to the directional control valve which is shifted to the upper position, as shown. The directional control valve directs flow to the lines in the upper circuit. Here, flow can go three places. The upper check valve blocks one passage. The closed sequence valve blocks another, but flow to the A port of the actuator is open. As the cylinder rod retracts, flow from the B port is blocked at the check valve, so it exits to the tank through the directional control valve.

Stage 2: When the cylinder is fully retracted, pressure will build in the pilot passage of the sequence valve. It opens and sends pilot pressure to the directional control valve. In the schematic pilot pressure on the upper side of the directional control valve will shift the valve downward. Pump flow is now directed to the lower circuit and the flow here goes to three places. It is blocked at the check valve and blocked at the closed sequence valve, but flow to the B port of the actuator is open. Flow in the port will apply pressure to the piston and extend the cylinder. Flow out of the A port is blocked by the upper check valve, so it flows through the directional control valve to the tank.

Stage 3: When the cylinder is fully extended, pressure continues to build. Pilot pressure opens the sequence valve on the bottom. This sends pilot pressure to the lower side of the directional control valve shifting it back into the upper position. Now, pump flow is once again directed to the rod side of the actuator to retract the cylinder, and the cycle begins once again.

Stage 4: Tracing the flow in this circuit reveals that it is designed to keep retracting and extending automatically. Now that we understand the circuit we may conclude that the proper function of the system will depend on the proper setting and function of the sequence valves and the proper function of the hydraulically piloted directional control valve.

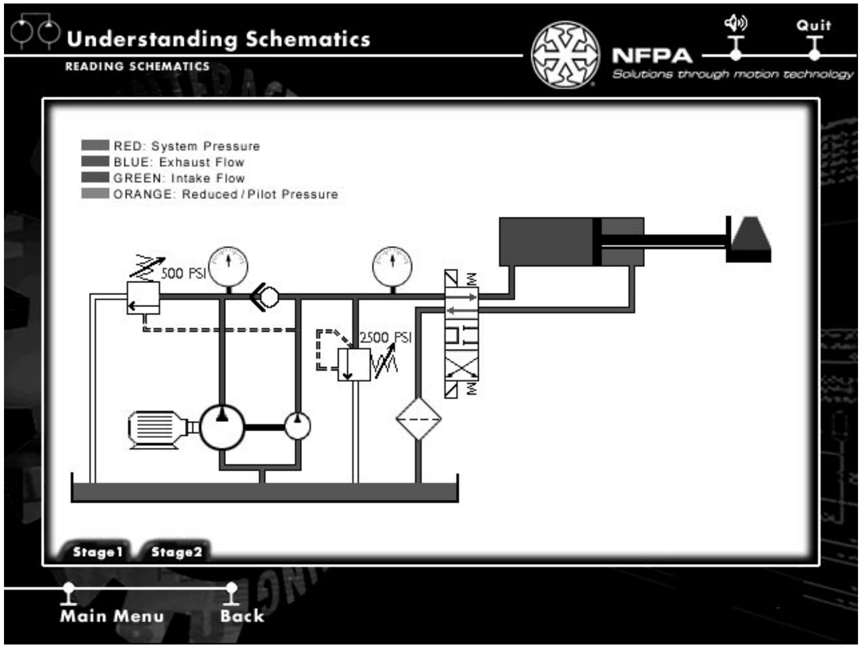
NOTES

Using your hydraulic symbols template properly draw a simple "High-Low circuit." (Use Circuit #2 from understanding schematics section as a guide).

Circuit # 2

Stage 1: This is a High-Low circuit. Such a circuit would be used to achieve high speed or rapid advance at low pressure, followed by slow speed and high force. A good example of a High-Low system would be a press where the ram would rapidly advance up to the work piece. At that time, the pressure starts to build. The flow from the high volume pump is diverted to the tank. The low volume pump would produce the little flow needed to continue moving the ram into the work piece. The pressure will continue to rise until it reaches the relief valve setting. When the directional control valve is reversed, the pressure drops and the unloading valve closes. The cylinder would retract at a rapid speed.

Stage 2: Now let's examine more closely the components that make up this system. First, the unloading valve. This valve has been set at 500 psi. When the system pressure reaches 500 psi, this valve will open and allow the flow from the high volume pump to go back to the tank at minimal pressure (figure 44).



(figure 44)

Next, we will look at the function of the check valve. When the system pressure is less than the unloading valve setting, flow from the high volume pump flows through the check valve to combine with the flow from the low volume pump. After the unloading valve opens, this check valve closes, so that the flow from the low volume pump won't flow to the unloading valve.

Now, let's take a look at the High-Low pump group. This is a double pump. These pumps have a common inlet and separate outlets. During low pressure rapid advance, both pump flows are combined. When the unloading valve opens, the large pump's flow returns to the tank and the small pump's flow is used to do the work.

Finally, we will look at the system's pressure relief valve. This valve limits the maximum system pressure. Notice the schematic shows the pressure at which the valve should be set. Now, watch as these components work.

NOTES

IMPORTANT:

Counterbalance valves may not require a pilot operated check valve in the circuit if they are specified as zero leakage. *(see notes page 36).*

Using your hydraulic symbols template, properly draw a hydraulic circuit with a counterbalance valve (Use Circuit #3 from the understanding schematics section, as a guide).

Circuit #3

Stage 1: In our circuit, the cylinder has a weight that would cause it to freefall or drop at an uncontrolled rate. A counterbalance valve is placed in the rod end port of the cylinder to apply back pressure. The back pressure is the result of the load trying to force the fluid out of the cylinder and through the counterbalance valve, which is closed. The counterbalance valve has to be set slightly above the load-induced pressure. When shifted, the directional control valve applies pressure on the cylinder piston. This in turn increases the back pressure, causing the counter balance valve to open, allowing the cylinder to lower the load at a controlled rate.

Stage 2:
Now let's examine more closely the components that make up this system. First, we'll look at the off-line or kidney loop filter circuit. This circuit consists of a pump motor group, a filter, and an air-to-oil heat exchanger. The pump draws hydraulic fluid from the reservoir, passing the fluid through a filter and an air-to-oil heat exchanger. This circuit usually runs continually to keep the hydraulic fluid clean and cool. Next is the pressure compensated pump. The pressure compensated pump de-strokes when the directional control valve is centered. At this time, there is pressure being maintained between the pump and directional control valve, but no flow. When the directional control valve is shifted, the pump goes on stroke, providing flow for the circuit.

Next, we have the directional control valve. This is a three-position, four-way valve with a float center. This valve, when centered, will block flow from the pump so that pressure will build and de-stroke the pump. Both work ports are routed back to the tank, so there is no pressure in the work port lines, except between the rod end of the cylinder and the counterbalance valve.

Now, we look at the counterbalance valve. The counterbalance valve maintains back pressure on the rod side of the cylinder so that the cylinder brings the load down at a controlled rate of speed. The check valve is used to lock and hold the load on the cylinder when the directional control valve is centered. Now, let's watch the system work again and see how each component operates.

NOTES

Introduction

Before you begin this section, you should already be comfortable with the previous section, Understanding Schematics. This basic system design section builds on your knowledge of the symbols and schematics by teaching you to identify actual system components as they are displayed on the screen. You will notice that whenever a component is displayed that its associated symbol is also shown. The second part of this section will teach you how to build a hydraulic system using realistic drawings of components rather than using symbols. These exercises will give you a feel for how actual systems look and operate.

Power Unit

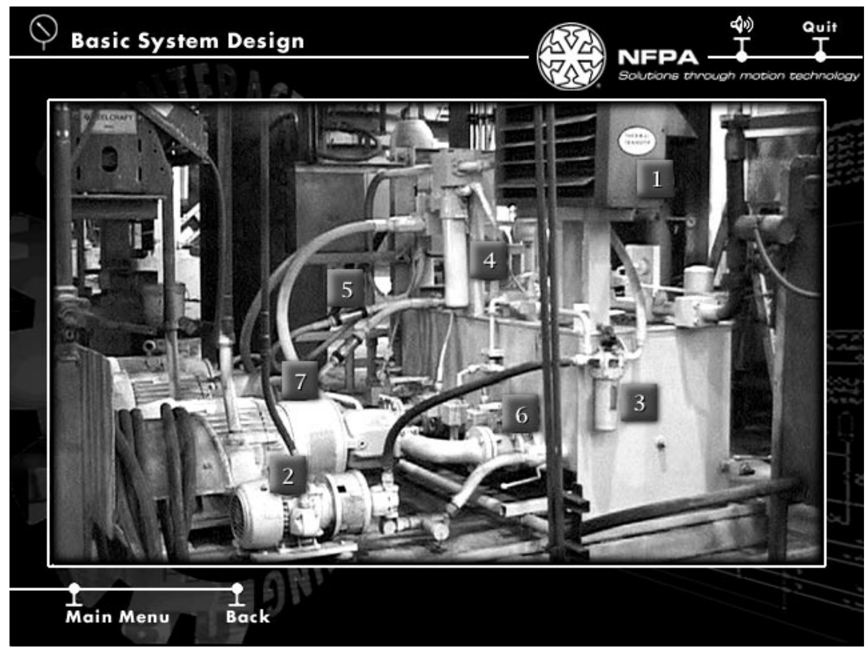
In previous sections we discussed hydraulic components individually, showing their function and application. In this section we will show an actual working system, highlighting some of the components previously studied. Click on view 1, view 2, view 3, or view 4.

View #1 (figure 45)
Choose an area of interest and click on the appropriate number.

1. **Fan cooled heat exchanger**
   Connected in series to the off-line re-circulation loop
   Provides cooling for main hydraulic reservoir
   System temperature not to exceed 160 degrees Fahrenheit

2. **Off-line re-circulation pump and motor**
   Three horsepower electric motor
   15 gpm gear type hydraulic pump
   Provides flow for the re-circulation loop

3. **Off-line re-circulation filter**
   Connected in series to the off-line re-circulation loop
   10 µm pressure filter
   Spin-off housing
   Off-line filtration



(figure 45)

NOTES

4. **System pressure line filter**
   Connected in line and downstream from main hydraulic pumps
   10 µm filter
   Provides filtration protection for proportional control valve on the motor drive manifold

5. **Flow meter**
   Installed in the main pump case drain lines
   0-10 gpm monitoring
   Provides case drain flow monitoring to determine internal wear
   Case flow should not exceed 5 gpm

6. **Shut-off valve and pump suction line**
   Installed between reservoir and suction port of pump
   Swing valve design with locking handle
   Closes reservoir flow during pump change out

7. **Main pump**
   45 gpm at 1750 rpm
   Axial piston pressure compensated
   Provides system flow
   Compensator set at 1500 psi

View # 2

Choose an area of interest and click on the appropriate number.

1. **System accumulators**
   5 gallon accumulator pre-charged to 450 psi
   10 gallon accumulator pre-charged to 450 psi
   Provides stored energy in the event of input power loss

NOTES

2. **Accumulator bleed off and isolation valves**
   Ball valve design, normally closed
   Used to bleed down and isolate accumulators for maintenance or repair

View # 3

Choose an area of interest and click on the appropriate number.

1. **System reservoir**
   150 gallon reservoir
   Provides oil storage for main system power unit

2. **Reservoir breather**
   5 µm
   Spin-on element
   Provides filtration protection for vented system reservoir

3. **System pressure gauge**
   0-3000 psi
   Glycerin filled
   Used to measure the main system pressure relief and pump compensators

4. **System return line filter**
   10 µm element
   Bolted cover for element removal
   Provides main source of contamination control for hydraulic system

5. **Reservoir clean out cover**
   Provides access to clean out the reservoir
   Bolted with Buna seal

6. **Level indicator**
   Sight glass designed with thermometer
   Provides visual indication of fluid level
   Do not fill reservoir past top glass

NOTES

View #4

Choose an area of interest and click on the appropriate number.

1. **Manifold assembly**
   Ductile iron
   6000 psi rated
   Multi-valve 4 station

2. **Valve stack**
   1. **Pilot Valve**
      Size 6 directional control valve
      Float center
      Shifts size 25 directional control valve

   2. **Flow control valve**
      Size six sandwiched configured
      Controls shift speed of size 25 directional control valve

   3. **Directional control valve**
      Size 25
      Starts, stops, and changes direction of flow to hydraulic cylinder

   4. **Check valve**
      Pilot operated
      Locks cylinder in position

   5. **Pilot valve**
      Size 6 directional control
      Pilot opens check valve

   6. **Pressure reducing valve**
      Size 16, three-way reducing valve
      Reduces pressure to piston side of hydraulic cylinder

NOTES

7. **Pilot valve**
   Size 6 pressure reducing valve
   Pilot control for size 16 pressure reducing valve

Build a System

System 1

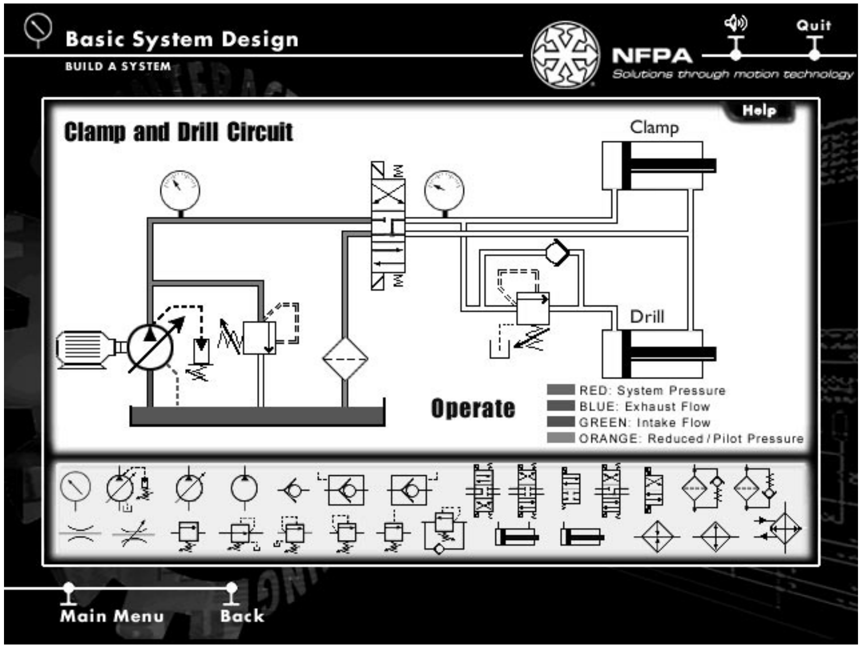
In this learning lab, you will properly build the given circuit by dragging the appropriate components from the selection of components at the bottom of the screen and placing them into the given circuit. When you have correctly built the circuit, push the "operate" button to see the circuit operate (figure 46).

System 2

In this learning lab, you will properly build the given circuit by dragging the appropriate components from the selection of components at the bottom of the screen and placing them into the given circuit. When you have correctly built the circuit, push the "operate" button to see the circuit operate.

System 3

In this learning lab, you will properly build the given circuit by dragging the appropriate components from the selection of components at the bottom of the screen and placing them into the given circuit. When you have correctly built the circuit, push the "operate" button to see the circuit operate.



(figure 46)

NOTES